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Engineering and Operations in the Bell System

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Preface

This book presents a broad picture of engineering and operations in the Bell System with emphasis on those matters of particular interest to Bell Telephone Laboratories. Its purposes are to provide:

- An understanding of the interrelated disciplines.
- An insight into the planning and development of equipment and systems, with attention to constraints and alternatives that must be weighed.
- An understanding of Bell System operations and an awareness of the environment within which systems must function.
- A useful amount of background information in a framework that will serve as a guide to more detailed sources.

The material has been prepared for a course given within Bell Laboratories primarily for those with little background in the telephone business. Its scope, balance, precision, and insight are intended to make it useful as a reference to those with more experience. None of the material is intended for use as design requirements for communications products.

The book is presented in five parts. Part One, *Introduction and Overview,* describes the telephone business from an engineer's viewpoint. Part Two, *Networks,* deals with the technical aspects of communications networks. Part Three, *Economic Evaluation,* is a brief introduction to the role of economic evaluations in engineering. Part Four, *Systems—The Network Elements,* describes the systems that are used to build networks. Part Five, *Operations,* addresses operating company activities and related Bell Laboratories work.

The reader should be aware that the Bell System and its engineering and operating functions are changing continuously in response to many factors including market for new services, economic outlook, regulatory actions, new technologies, and new systems. The material presented represents the status at the time of final preparation, 1975-1976. Trends are noted wherever they are clearly evident. The validity of some of the material, however, will diminish with time.

The material has been prepared and reviewed by a large number of people in the American Telephone and Telegraph Company, Bell Telephone Laboratories, and Western Electric Company. Editorial support has been provided by the Technical Publication Department of Bell Laboratories. Thus, the book represents the cooperative efforts of many people too numerous to acknowledge. Special mention is appropriate for J. R. Harris, who drew up the initial plans for the book and made many recommendations during preparation, and P. V. Dimock, who coordinated assembly of the material as technical editor.

Irwin Dorros
Executive Director
Network Planning Division
Bell Telephone Laboratories

Contents

Part One Introduction and Overview

The first four chapters of this book are intended to provide a broad understanding of the Bell System and its business. Chapter 1 addresses the nature of the Bell System; it touches briefly on the communications services the Bell System provides and then describes its organization and the functions of its constituent companies.

The events that take place in a typical telephone call are reviewed in Chapter 2. This introduces many of the concepts that are expanded in later chapters, develops a rudimentary understanding of the telephone network, and builds familiarity with the terminology.

In Chapter 3, network concepts are explored. A single communications network concept is not adequate; two overlapping network concepts must be considered—one embodying a facilities or hardware network, and the other a plurality of traffic networks, each handling a particular body of traffic. The total Bell System investment is analyzed in terms of broad classes of facilities in the facilities network, and the Bell System revenue is broken down by classes of traffic networks.

Chapter 4 discusses services and tariffs. The variety of services now offered is described in more detail than in Chapter 1. Tariffs may be thought of as descriptions of, and prices for, specific services; they reflect the fact that the telephone business is a regulated public utility.

1 The Bell System

The Bell System can be described conveniently in terms of the variety of services that it provides and in terms of its organization. The services are mentioned briefly here and are treated in more detail in Chapter 4.

1.1 SERVICES

The Bell System provides a variety of communications services to the general public, to businesses, and to certain government organizations. It should be emphasized that it has been the policy of the Bell System, from its inception to the present, to market services rather than equipment. The principal communications services now offered include public telephone service and various private services. Public telephone service, as used in this book, is synonymous with message telephone service; "public" is used rather than "message" to indicate widespread use, to contrast with private services, and to avoid possible confusion with "message switching". Public telephone service should not be confused with "coin telephone service".

Public telephone service (PTS) is the most common form of service and accounts for about 90 percent of Bell System revenue. Public telephone service provides voice communication between any pair of customers at residential, business, or coin telephone locations. The service makes use of individual customer lines or party lines and includes both local and long distance service. Many options and variations are available, such as:

(1) TOUCH-TONE® dialing.

(2) Extension telephones.

(3) Keyset, private branch exchange, and centrex service to provide business customers with internal as well as external communications.

(4) Various charging plans such as wide area telecommunications service (WATS) and measured-rate service.

Little more needs to be said in this chapter concerning the ubiquitous PTS. There are about 150,000,000 telephones in the United States, approximately one-fifth of them in independent non-Bell territory. Therefore, nearly every-one in the U.S.A. has a working familiarity with PTS in its basic form. Because it is so important, many aspects of PTS will be discussed in the chapters that follow.

Private services provided by the Bell System include private-line services and private switched networks. Private-line services cover a wide range of applications. Their common characteristic is that the customer leases a circuit connecting two or more fixed points. The 2-point circuit is the most common, but multipoint circuits are used also. Terminal devices (teletypewriters, for example) may or may not be included in the lease. Private lines are used for the transmission of voice, television and audio signals for broadcasting networks, and data at a variety of speeds and with a range of channel bandwidths.

Many businesses and a number of government organizations are served by private voiceband networks that provide a switched connection capability similar to that of PTS, but with access restricted to the company or organization buying the service. There are many private networks in operation. They range in size from nationwide networks that serve hundreds of locations down to quite small metropolitan networks that serve fewer than ten locations. Private networks provide a number of conveniences at a lower price than PTS for organizations with a large volume of traffic among a limited number of locations.

1.2 ORGANIZATION OF THE BELL SYSTEM

The organization of companies that make up the Bell System has evolved into a complex integrated structure. Fig. 1-1 gives an overall view of the main components of the Bell System. These are the American Telephone and Telegraph (AT&T) Company, which is the parent company; the Western Electric Company, which is the manufacturing and supply branch of the Bell System and which is wholly owned by AT&T; Bell Telephone Laboratories, which does research and development and which is owned half by AT&T and half by Western Electric; and 24 telephone companies, commonly referred to as *operating companies,* which provide services to customers. There are also a number of subsidiary companies owned by AT&T and Western Electric, such as Nassau Recycle Corporation and Teletype Corporation. These subsidiary companies perform vital roles in the Bell System, but they are not necessary to the understanding of engineering and operations and are therefore not shown in Fig. 1-1.

The widespread geographical area served by the Bell System and the need for close coordination among its parts make a single coordinating organization essential. AT&T has evolved into that organization by acquiring controlling ownership in the various operating telephone companies. AT&T owns a majority of the stock in 21 of the operating companies and a minority in Southern New England Telephone Company and Cincinnati Bell. AT&T holds no stock in Bell Telephone Company of Nevada, which is wholly owned by

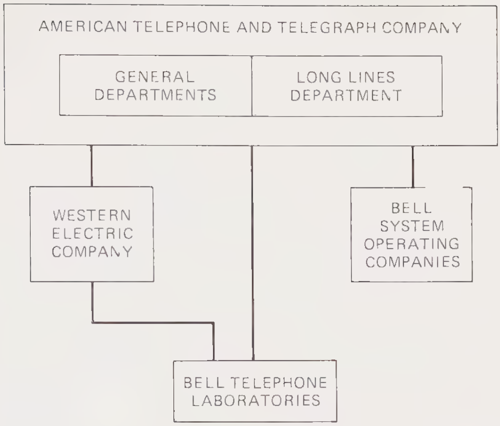

Fig. 1-1. Organization of the Bell System

Pacific Telephone and Telegraph Company. AT&T's principal functions are performed by the General Departments and the Long Lines Department. The General Departments provide the operating companies with advice and assistance in the following areas:

Accounting
Finance
Legal matters
Engineering
Marketing
Operations
Construction plans
Human resources development
Regulatory matters
Federal government relations
Public relations
Labor relations

These services are provided under a license contract between AT&T and the operating companies. Each operating company pays AT&T in return for the services. The actual cost of the services rendered is billed each year to the operating companies. A substantial portion of the license contract fees goes to the support of research and fundamental development at Bell Laboratories. The AT&T General Departments exercise leadership and coordination, but not rigid control of the operating companies. Because of the wide variety of local conditions and changes in local needs, these needs are best assessed by the individual operating companies. The Long Lines Department owns and operates long distance transmission facilities and certain switching systems to provide connections between the operating companies and with foreign countries. Long Lines, being an operating organization, is the largest part of AT&T, with about 90 percent of all AT&T personnel.

The Western Electric Company is the manufacturing and supply unit of the Bell System. Its principal function is to manufacture to uniform standards of design and quality a great variety of apparatus and equipment, cable and wire that go into the Bell System. Western Electric differs from other manufacturing companies in its technical integration and multiplicity of interactions with the other components of the Bell System as discussed in Sections 1.6 and 1.7. There are 21 major manufacturing locations, as shown in Fig. 1-2. Western Electric produces some 100,000 different telecommunications products including telephones, wire and cable, switching systems, transmission equipments, and many types of apparatus. Another important aspect of Western Electric's operations is its role as storekeeper and distributor. It maintains over 30 service centers, geographically dispersed to provide a rapid response time, as shown in Fig. 1-3. The service centers include shop facilities to repair and modify communications equipment as well as warehouses in which to stock the materials and supplies needed by the telephone companies for their day-to-day operations. There are also a number of distribution centers that provide only warehouse services and a number of material management centers that supply the other centers.

Fig. 1-2. Western Electric Manufacturing Locations

Western Electric has a standard supply contract with each operating company. The supply contracts obligate Western Electric to supply the operating companies with telephone equipment when they need it. These contracts state that Western Electric will manufacture or purchase materials that the telephone companies may reasonably require for their business and will perform certain services including delivery, preparation of equipment specifications, in-

Fig. 1-3. Western Electric Service Centers

stallation, and repairs. The telephone companies, however, are not obligated to purchase equipment and materials from Western Electric. In fact, substantial amounts of equipment are purchased from a multitude of independent manufacturers. Western Electric must retain the operating companies' business by being competitive with other suppliers in type of products, quality of products, services, and prices.

Bell Laboratories operates at five major locations: Murray Hill, Holmdel, Piscataway, and Whippany in New Jersey, and Naperville in Illinois. There are seven branch laboratories collocated with Western Electric manufacturing locations at Allentown, Atlanta, Columbus, Denver, Indianapolis, Merrimack Valley, and Reading. There also are several other locations in New Jersey. Bell Laboratories is funded by AT&T and Western Electric and is operated as a nonprofit corporation. AT&T supports research and fundamental development; Western Electric supports development and design of apparatus and equipment and, as contractor to government agencies, also supports military research, engineering, and development. Bell Laboratories is organized into the following Vice-Presidential areas:

1—Research and Patents
2—Electronics Technology
3—Network Planning and Customer Services
4—Transmission Systems
5—Switching Systems
6—Military Systems
7—Personnel, Finance, and General Services
8—Computer Technology, Design Engineering, and Information Systems
9—Business Information Systems Programs

Bell Laboratories output consists principally of (1) design information in the form of detailed specifications for Western Electric to manufacture or buy systems, equipment, and apparatus, (2) technical information relating to planning, engineering, and operating telephone systems for AT&T to disseminate to the operating companies as appropriate, and (3) software systems for use by the operating companies, AT&T, and Western Electric. Feedback on problems encountered with existing equipment is provided from the operating companies through field representatives of the Bell Laboratories Quality Assurance Center. These representatives are assigned as residents to various operating companies. Another form of feedback to Bell Laboratories is obtained from surveys of performance parameters and collections of data on certain network aspects. These surveys and data collections may be done by Bell Laboratories, by the operating companies, or as a cooperative venture. Other interactions between the operating companies and Bell Laboratories include joint participation in field trials and scheduled visits of Bell Laboratories teams to the operating companies. Advisory panels with members from AT&T, Bell Laboratories, and the operating companies have been established to help guide Bell Laboratories programs.

The Bell System operating companies and the territories they serve are shown in Fig. 1-4. Each of these companies operates its business to meet local needs. Expansion programs are planned and engineered to be worthwhile to local customers. Rates must be established to produce enough revenue to meet the costs of doing business in a particular state. The operating companies, as public utilities, have the responsibility to provide service reliably, economically, and without undue or unjust discrimination. The Federal Communications Commission (FCC) regulates the rates and conditions of interstate services. The various state commissions perform the same functions for intrastate services. AT&T files interstate rates with the FCC, and the operating companies deal directly with local regulatory bodies.

There are many independent telephone companies in the United States that are not part of the Bell System. In 1975, there were over 1600 independent telephone companies. Although Bell System companies do not provide service in the areas served by the independents, there is a high degree of cooperation and coordination between the Bell System operating companies (and Long Lines) and the independent companies, so that a unified nationwide telephone service is available to the public. Coordination with independent telephone companies is handled largely by the operating companies, with overall technical coordination by AT&T. The United States Independent Telephone Association (USITA) is an important point of contact for the Bell System in its relations with the independents. Coordination between the Bell System and foreign telephone companies is handled by AT&T, with Bell Laboratories participation. Technical planning for coordination on an international basis is accomplished through participation in the activities of the International Telegraph and Telephone Consultative Committee (CCITT), an international organization operating under the auspices of the United Nations.

Fig. 1-4. Operating Companies of the Bell System

1.3 OPERATING COMPANY ORGANIZATION

The major activities within operating companies are introduced in the following section, and some are discussed in more detail in Part Five of this text. As background, it is appropriate to examine the organizational structure of operating companies. It should be understood that there is not one rigid organizational structure to which all companies conform; there are differences in size, geographical distribution, personnel, and other factors that dictate variations in structure. The intent is to describe basic aspects of organization that are similar for most companies and to point out some of the variations.

At the officer level, there is considerable similarity among the operating companies. Fig. 1-5 shows the basic structure. The Board of Directors manages the affairs of the company on behalf of the shareowners. Among other things it authorizes security issues and capital expenditures and declares dividends upon recommendations of the President. As mentioned previously, AT&T owns a majority of the stock in most operating companies. The Board usually elects an Executive Committee and the officers of the company. The Executive Committee functions for the Board of Directors between meetings of the Board.

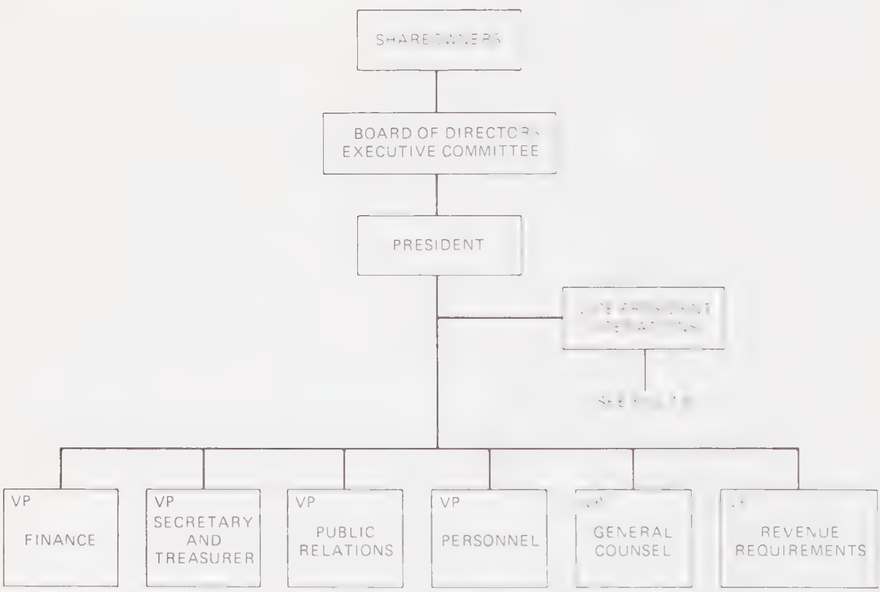

Fig. 1-5. Organization of a Telephone Company

The President has direct charge of the administration of company business. A number of Vice Presidents report to the President. The number and functions of the Vice Presidents vary somewhat from company to company. The Vice Presidents shown in Fig. 1-5 are found in most companies; their responsibilities are briefly summarized as follows.

VP—Operations—Manages the companies' operations including the engineering, construction, and maintenance of physical property, the furnishing of telephone service to the public, and the conduct of business relations with customers. Acts in place of the President when the President is not available.

VP—Finance and/or Comptroller—Handles all financial transactions of the company, and maintains corporate accounts.

VP—Secretary and Treasurer—Records actions at meetings of shareowners, Board of Directors, and Executive Committee. Has custody of corporate records, contracts, and other documents. Is responsible for tax matters.

VP—Public Relations and/or Public Affairs—Carries out specific public relations functions in the areas of advertising, press relations, opinion research, public and employee information, and relations with shareowners, educators, and other special groups. Acts as company spokesperson on legislative proposals and governmental matters affecting employees, shareowners, and customers.

VP—Personnel—Develops and coordinates administration of all personnel policy matters. Surveys salaries and working conditions. Negotiates with unions. Develops and maintains a health program. Maintains the company Affirmative Action Program.

VP—General Counsel—Provides legal services for the company.

VP—Revenue Requirements and/or Regulatory Matters—Determines revenue requirements, and plans activities relating to changes in rates for services. Serves as company contact with regulatory bodies.

From the viewpoints of engineering and operations, the organization reporting to the VP—Operations is of particular interest. This organization usually constitutes between 85 and 90 percent of an operating company. As indicated in Fig. 1-6, which is typical of a large company, this organization has both functional and geographical aspects. The functions are grouped into departments. Departments, depending on the size and configuration of the company, may be replicated in states and/or geographical areas.

The territory served by an operating company is typically divided into several areas. In large companies, the major areas, which may correspond with states, may be further partitioned into smaller areas. The areas are divided into divisions and the divisions into districts. In general, the district is the fundamental building block in the operating company and has the actual responsibility for supplying service to customers.

The operating company organizations are currently in a state of evolutionary change. The traditional form of organization shown in Fig. 1-7 was in general use from 1920 into the 1960s. Area organizations had plant, traffic, commercial, and engineering departments; sales departments were introduced in 1960. The departments grouped people of similar skills. Plant, traffic, and commercial departments extended down into divisions and districts. The

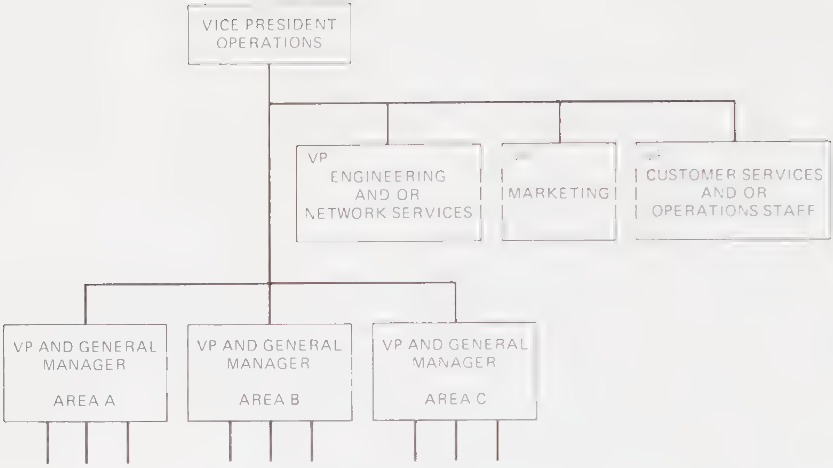

Fig. 1-6. Organization of Vice President—Operations

merging of all functions and responsibilities usually occurred at the area level under a Vice President and General Manager.

In the 1960s, pressures of growth, changes in technology, and competition began to be felt by some of the companies, causing them to modify the traditional organization. By the early 1970s, organizational experimentation by the individual companies had reached a point where it began to erode the desirable organizational unity of the Bell System. AT&T conducted a study that resulted in the recommendation to adopt a new structure, shown in Fig. 1-8, in which facility services, customer services, assistance services, and engineering and network services departments replace plant, traffic, commercial, and engineering departments. Note that departments are task-oriented rather than skill-oriented as in the traditional form of organization. At this point, most companies have adopted parts or most of this structure, and the other companies have taken steps to start evolving in this new organizational pattern. The reader should be aware of both the traditional and the recommended organizational structures. Vestiges of the traditional structure probably will remain for some time, and the recommended structure indicates the most probable direction of evolution.

Determination of the organizational level at which departments of the recommended structure should be joined under common supervision has been left to the individual operating companies. This can range from the division to the VP—Operations level. One of the most important considerations is the expertise required of a manager to effectively coordinate several dissimilar activities. This expertise derives mainly from the breadth and depth of experience and the managerial capabilities of the person in question.

Returning to the VP—Operations organization shown in Fig. 1-6, several special functional groups are indicated. These are engineering, marketing, and staff, but other functions such as computer systems may be appropriate.

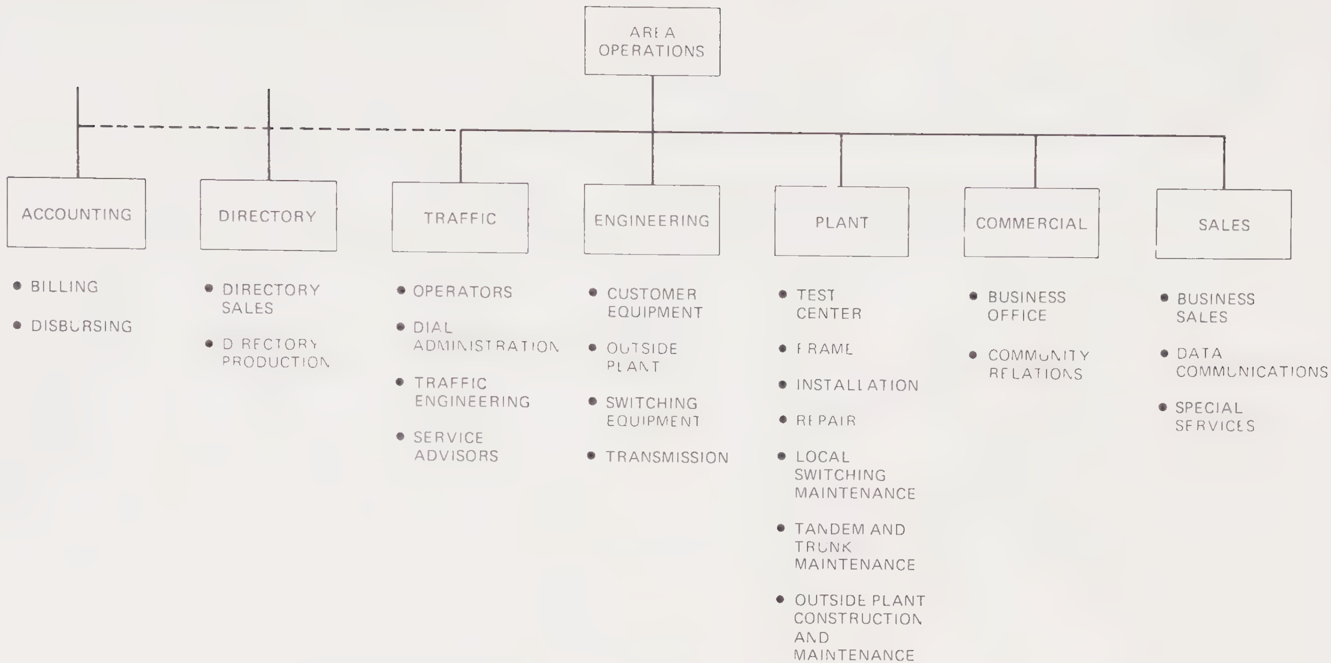

Fig. 1-7. Traditional Operating Company Structure

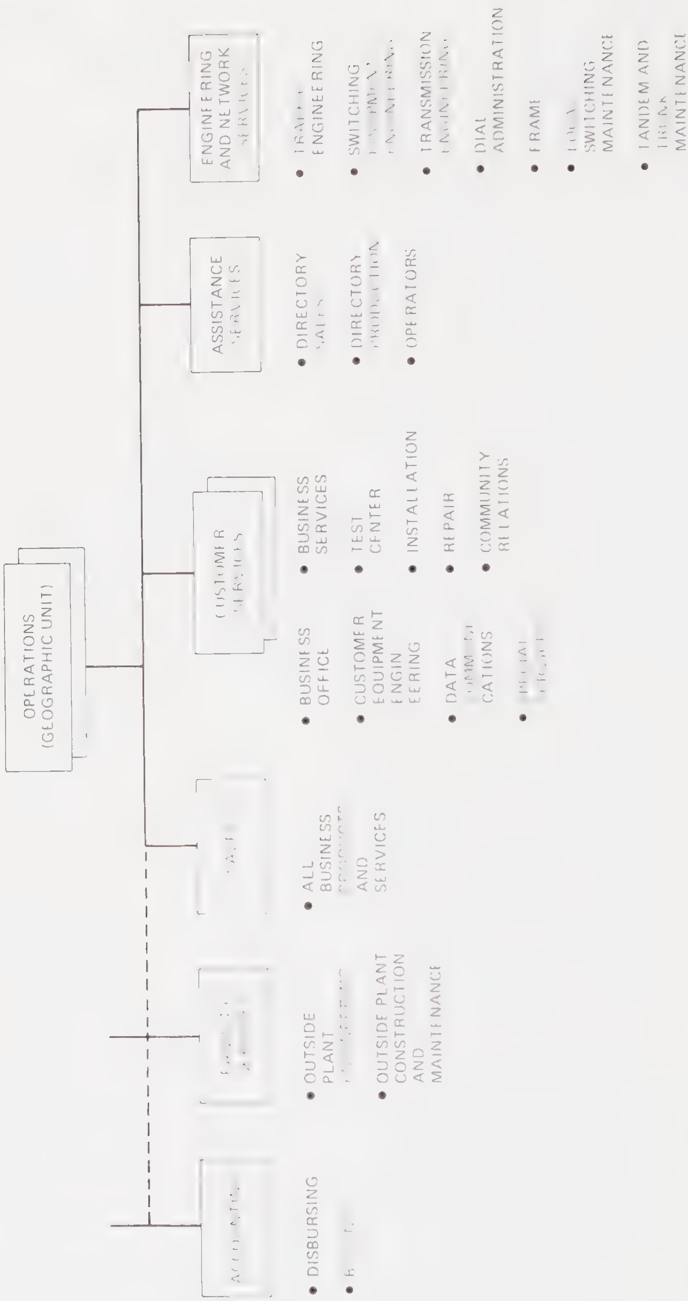

Fig. 1-8. Recommended Operating Company Structures

These functions have certain characteristics that warrant separate consideration. The body of expertise required is usually more specialized than that needed in daily operations, and frequently some unique education is required; relatively few people are needed to execute these activities; and, perhaps most importantly, these activities are somewhat detached from the process flow of daily operations. Each specialty can be consolidated in a central location or dispersed and fully integrated into line organizations; these are the two extremes, but there are intermediate degrees of centralization. Neither option is clearly superior. The degree of consolidation or integration of specialized functions often depends on factors within a particular company. Some companies have a history of highly developed central control; others have tended to delegate many of these functions to the states or areas. The particular style or management philosophy of a company President can have great bearing on whether the company centralizes or disperses its expertise.

1.4 MAJOR ACTIVITIES IN OPERATING COMPANIES

Several major classes of activity are carried out in the operating companies. This section summarizes these activities, and Section 1.5 indicates the relative levels of personnel involved in each activity.

1.4.1 ENGINEERING ACTIVITIES

Engineering activities are quite varied and fall into several categories.

Forecasting—A logical starting point is the forecasting of future demands for traffic capacity. The forecasts are based partly on projections of traffic growth as measured over a period of several years and partly on predictions of population growth, business activity, and changes in telephone usage habits. Such forecasting, of course, is a fundamental step in planning. Underestimates lead to an inability to meet new service demands promptly; overestimates can lead to excessive investment commitment with no compensating revenue.

Facilities and Equipment Planning—Based on forecasts of increase in demand, transmission facilities such as cables or microwave systems to be added to the network may be planned. Additional terminal equipment may be planned for existing systems to increase their capacity. Similarly, planning may include additional switching systems in either existing or new locations and additions to existing systems to provide increased capacity. Typically, planning is done both for short-term growth (one to two years) and for longer-term growth (five years or more). The long-term planning helps to ensure a smooth rate of growth throughout the network and to avoid mistakes that might be made if only short-term growth were considered. Frequently, the planning of new facilities will result in installations that have more potential capacity than can be used initially, with the capability of augmenting the capacity in succeeding years by adding equipment.

Preparation of Construction Budget—A construction program, based on the facility and equipment additions, is first examined in detail two years in advance. The construction budget is subject to careful review and is updated even during the year in question. The construction budgets of all Bell System companies are reviewed and coordinated by AT&T.

Equipment and Building Engineering—This activity may be looked upon as an extension of facilities and equipment planning. Equipment engineering leads to orders for equipment and installation service, primarily to Western Electric. A large part of the equipment engineering is, in fact, done for the operating companies by Western Electric. Building engineering leads to specifications for building modifications, building additions, and new buildings.

Traffic and Transmission Engineering—Traffic engineering includes analysis of traffic data to produce forecasts and determination of equipment requirements to handle projected traffic loads. Transmission engineering includes planning for transmission improvements, determining trade-offs where two or more types of transmission systems can be considered, and planning specific applications. Both of these activities are involved in forecasting, in facilities and equipment planning, and in equipment engineering. The techniques, procedures, and objectives are developed by Bell Laboratories and AT&T, but their application is largely an operating company matter.

1.4.2 CONSTRUCTION

The principal construction activities of operating company personnel are the construction of outside plant structures such as pole lines, buried cable, and cable in conduit. The major functions involved in outside plant construction include placing poles, placing cable conduit, stringing cable on poles, pulling cable in conduit, burying cable, and splicing at cable junctions. Because outside plant facilities are susceptible to damage, service restoration is an important but unscheduled activity. Construction of buildings usually is done by contractors. Major conduit and buried cable jobs also are done by contractors in certain cases.

1.4.3 INSTALLATION OF EQUIPMENT

The principal installation activity of the operating companies is installation of station equipment on customer premises. This includes the installation of telephone sets, wiring within the customer's building, and the connection to outside plant. Major installations such as switching systems and carrier system terminals are installed by Western Electric. Repeater installations for cable and radio carrier systems and PBX installations on customer premises are done either by Western Electric or operating company personnel or by a combination of both.

1.4.4 TESTING AND MAINTENANCE

Testing and maintenance are necessary on all types of transmission, switching, and customer premises facilities. As will be discussed in Chapter 16, they are prime candidates for application of automation techniques.

Training is a necessary support activity as it is also for installation and construction. Since most of the required skills are specific to the telephone industry, in-hours training is a necessity. An operating company typically has an instruction force that teaches a curriculum of from 100 to 200 courses. In the course of his or her career, an average craftsperson spends about 100 days in class.

1.4.5 OPERATOR SERVICES

Operator services represent the largest class of activity within an operating company and require about 25 percent of the company's personnel. Operator services are discussed in more detail in Chapters 4 and 7. Briefly, the functions performed by operators include:

(1) Completing or helping customers to complete toll or assistance calls.

(2) Preparing billing inputs for those calls.

(3) Providing directory assistance.

(4) Intercepting and helping customers with calls to nonworking or changed numbers.

(5) Providing special services such as PICTUREPHONE®, mobile telephone, or conference calls.

(6) Giving on-the-job consultation to business customers.

Unlike most other activities, operator services must be provided continuously, 24 hours a day and 7 days a week. Training of operators is an important subactivity; it is not considered as a separate activity because a large portion of the training is done on the job. About 10 percent of all operator service personnel have training as a major responsibility.

1.4.6 OTHER SERVICE-RELATED ACTIVITIES

In addition to the services provided by operators, there are other service-related functions performed within a telephone company. These include the following:

Service Order Operations[1]—A customer service order is originated when a customer requests the customer services department of an operating company to establish, change, or terminate his telephone service. The service order, after being carefully reviewed for accuracy and completeness, is forwarded to the assignment organization which assigns specific circuits. A copy of the order then goes to the engineering and network services department for installation of the necessary equipment and whatever connections are necessary at the central office. The order also goes to the accounting department and, if appropriate, to the organization responsible for directory listings. Orders also are originated within a telephone company for the provision of certain types of channels that must be requested internally rather than by a customer. Requests for such channels for PTS usually originate in the traffic engineering organization, while requests for channels for private-line services generally come from marketing.

Billing and Collecting—Bills are prepared, usually at monthly intervals, and mailed to customers. Payments are received, and revenue accounting records prepared. The degree of detail in billing, the number of service options that must be handled, and the large number of customers make this a unique business operation. Revenues must be divided with Long Lines, other Bell System operating companies, and independent telephone companies.

Directory Production—Directories of PTS customers are continuously revised and are distributed at regular intervals. Directory advertising and the sale of directories are additional sources of revenue.

Tariff Preparation and Filing—Tariffs are descriptions of services that are offered and rates that will be charged (see Chapter 4).

Market Assessment—Customer needs or desires for new or modified services are assessed. Type of service, magnitude of demand, and price are evaluated.

Other Customer Services—The customer services department of an operating company serves as the point of contact with the public on a variety of matters, such as questions about telephone service, claims of damage to property, special requests of a public relations nature, and complaints about billing errors.

1.4.7 SUPPORT ACTIVITIES

In addition to the activities just described, in which Bell Laboratories has a direct interest, there are a number of important supporting activities that are essential to the effective operation of a telephone company. These include:

(1) Administrative functions including personnel, legal matters, and public relations.

1. Service orders are discussed in more detail in Chapter 15.

(2) Regulatory matters and revenue requirements.

(3) Comptroller functions, including maintenance of corporate accounts and handling of all financial transactions of the company.

(4) Building maintenance.

1.5 RELATIVE PERSONNEL LEVELS IN OPERATING COMPANY ACTIVITIES

Estimates of the proportions of operating company personnel engaged in the various classes of activity described in the preceding section are shown in Fig. 1-9, which gives a graphic indication of the areas of principal activity. Note that operator services (25 percent) and other service-related activities (15 percent) account for 40 percent of all operating company personnel. Engineering (5 percent), construction (10 percent), installation (15 percent), and testing and maintenance (15 percent) account for 45 percent; the remaining 15 percent are engaged in various types of supporting activities.

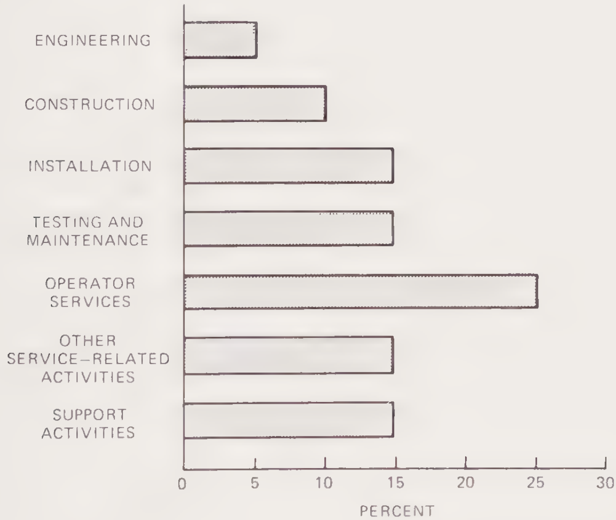

Fig. 1-9. Percent of Operating Company Personnel in Various Activities

1.6 PRINCIPAL AT&T, WESTERN ELECTRIC, AND BELL LABORATORIES ACTIVITIES

Now that the principal activities within the operating companies have been described, some of the functions performed by AT&T, Western Electric, and Bell Laboratories will be examined, those done jointly as well as those done individually.

1.6.1 DEVELOPMENT

The development of new types of devices and systems is carried out largely by Bell Laboratories. Proposals for various development activities are prepared by Bell Laboratories. Specific development programs are chosen after tricompany (AT&T, Western Electric, and Bell Laboratories) review of technical opportunities and Bell System needs. The cases are subject to final approval by Western Electric, since the funds come from sales to the operating companies. Progress on the various development cases is monitored jointly by Bell Laboratories, Western Electric, and AT&T. An example of a project is the development of a new switching system.

In addition to hardware development, software development has become a substantial part of the activities both in the development of integrated hardware/software systems and software-only systems. Apart from software developments that result in Western Electric products, Business Information Systems (see Section 15.4.2) are developed by Bell Laboratories. This work is funded directly by the operating companies and produces systems that are used by the operating companies to mechanize many of the repetitive clerical and engineering operations required to provide service.

1.6.2 PREPARATION OF PLANS

Technical plans for transmission, switching, and numbering for the PTS network are prepared by Bell Laboratories in consultation with AT&T. These plans will be discussed in Chapters 5 and 6. Similar plans are prepared for private switched voiceband networks. Plans and procedures are developed for many different aspects of network operations where Bell System-wide uniformity is advantageous and where operating companies need assistance with special problems. These plans and procedures include:

(1) Plans for new services to be offered.

(2) Plans for the introduction of new types of equipment or systems into the network.

(3) Maintenance methods.

(4) Traffic data collection and analysis methods.

(5) Operator procedures.

AT&T Engineering and Network Services must approve the annual cases for these planning projects before the funding (by AT&T) is made available. Bell Laboratories holds periodic progress reviews with the AT&T case managers.

1.6.3 MANUFACTURING

The manufacturing activities of Western Electric, which makes the bulk of the telephone equipment used in the Bell System, are carried out at a number of product-oriented plants. For example, electronic switching equipment is made at the Oklahoma City Works in Oklahoma and carrier transmission equipment is made at the Merrimack Valley Works in Massachusetts. Equipments, apparatus, and devices are manufactured to specifications prepared by Bell Laboratories. A Product Engineering Control Center (PECC) organization for each major product line generates detailed engineering information, such as drawings and test procedures, and coordinates all phases of engineering for that product line, including manufacturing, system standards, installation, and repair engineering. The various PECC organizations work concurrently with Bell Laboratories during the design and development stages to ensure a reproducible product of consistent high quality. This close association makes possible the timely availability of information and associated facilities for engineering, installation, and repair functions to meet customer requirements. PECC organizations are concerned with the entire life of a product from design through repair and are coordinating centers for evaluating the effectiveness of individual items.

Associated with the various manufacturing organizations are Western Electric Quality Assurance organizations that perform quality audits designed to measure product quality based on inspections of samples. Quality audits on products are made after manufacture, after installation, and after repair. Section 13.3 contains discussion of this and other aspects of quality assurance.

1.6.4 ADDITIONAL WESTERN ELECTRIC ACTIVITIES

Western Electric provides the operating companies with engineering, installation, and repair services. As an interface between the operating companies and the factories, Western Electric has Systems Equipment Engineering groups at each of the seven regional centers (see Fig. 1-3). These groups analyze the operating companies' equipment orders and custom tailor facilities to achieve the specific service requirements of the individual operating companies. Western Electric maintains a large mobile force of installers (25,000 to 35,000) at some 30 area offices. They install switching systems and other equipment in central offices, radio relay facilities, and major items such as private branch exchanges on customer premises. Because equipment generally is standardized throughout the Bell System and installers use common tools and methods, Western Electric has a great deal of flexibility to respond promptly and effectively to the continually changing and sometimes critically urgent needs of particular operating companies.

In addition to the purchase of raw materials, components, and other supplies used in its manufacturing operations, Western Electric acts as a central purchasing agency for the operating companies. From other suppliers, it purchases telecommunications equipment and other materials that the operating companies may need in their business. Such purchases are in the order of $1 billion a year.

Research and development of manufacturing processes is carried out at the Western Electric Engineering Research Center in Princeton, N. J. This center has produced innovations in the manufacture of many communications products. It has provided new techniques for the mass production of semiconductor devices, such as transistors and integrated circuits. It has pioneered in the use of ultrahigh pressures for forming metals and in commercial uses of lasers. The new manufacturing techniques developed at the Engineering Research Center have provided substantial improvements in quality and major reductions in cost.

In addition to its Bell System-oriented activities, Western Electric, supported by Bell Laboratories, also undertakes special tasks under contract to various agencies of the federal government. These tasks are beyond the scope of this book.

1.6.5 ADDITIONAL AT&T ACTIVITIES

As mentioned previously, AT&T provides advice and assistance to the operating companies. AT&T offers this direction and guidance to every one of the operating company organizational groups described in the preceding section. This includes the preparation and distribution of Bell System standard methods and procedures, compilation and publication of performance data for all parts of the Bell System, acting as an information clearing house for the Bell System, and analysis of areas that may require special assistance.

The General Departments also perform some "stand-alone" functions, such as coordination of Bell-Independent relations, placing of Bell System advertising, maintenance of corporate financial records, marketing on a systemwide basis, coordination of FCC-related activities, and the provision of various shareowner services. The Bell System Purchased Products Division serves as the Bell System's interface with general trade manufacturers of telecommunications products and evaluates their applicability to Bell System needs.

1.6.6 LONG LINES ACTIVITIES

The Long Lines Department of AT&T provides long distance transmission facilities and certain switching facilities necessary for connections between operating companies and with foreign countries; it is also responsible for local facilities and station equipment on customer premises associated with interstate private-line services. Long Lines activities closely parallel many operating company activities and include the following:

Forecasting
Facilities and equipment planning
Preparation of construction budget
Equipment and building engineering
Financing
Construction

Installation of equipment
Testing and maintenance
Service restoration
Marketing

Long Lines also accepts service orders and bills customers for private-line services that are primarily interstate in nature.

1.6.7 ADDITIONAL BELL LABORATORIES ACTIVITIES

In addition to the device and system development already discussed and technical assistance provided to AT&T and Western Electric, Bell Laboratories engineers and scientists look for new knowledge in many different fields including physics, chemistry, mathematics, electronics, metallurgy, and mechanics. They also work to uncover additional basic knowledge by building and testing experimental communications systems.

1.6.8 INTERACTIONS

A broad spectrum of interactions among AT&T, Western Electric, and Bell Laboratories organizations ensures the continuing efficient support of the Bell System operating companies. Only the most significant interactions will be noted here.

The principal technological guidance of the Bell System is formulated and set into motion by a group of tricompany management councils. The principal tricompany councils are the Transmission Council, the Switching Council, the Customer Products[2] Advisory Council, and the Data Products Advisory Council. Each council consists of the top executive officials of the the three companies responsible for the design, manufacture, operation, and marketing of the related products. At regular meetings throughout the year, these councils review the needs of the operating companies and examine proposals for meeting these needs.

As development proceeds in Bell Laboratories, interactions between a Western Electric Product Engineering Control Center and the developers ensure that the design reflects manufacturing considerations. The interactions between design and manufacture are particularly critical during the development stages. Accordingly, most Bell Laboratories specific design organizations have a branch laboratory located at or near a major Western Electric manufacturing location. There are eight branch laboratories ranging in size from a few hundred to over a thousand employees. They develop the following types of products:

Cable and wire
Electronic components

---

2. Customer products include telephone sets and other products generally used on customer premises.

Electronic switching
Electromechanical switching
Customer switching
Trunk transmission
Loop transmission
Station apparatus

It is in these branch laboratories that the final design of most products is completed. The purpose of locating the function at or near a Western Electric manufacturing location is to permit and assure the closest possible interaction between the designers of a product and the Western Electric engineers who must develop and determine the processes that will be used for its manufacture. Western Electric also has concentrated its engineering talent for introducing new products into manufacture at these same locations.

The Quality Assurance (QA) organizations of Bell Laboratories and Western Electric constitute another area of interactions. The QA organizations of the two companies supplement each other as explained in Section 13.3. Bell Laboratories sets quality requirements against which Western Electric's performance is monitored. As a result, the operating companies do not need the extensive incoming product inspection staff and quality assurance procedures otherwise required.

1.7 THE INTEGRATED BELL SYSTEM

The functioning of the components of the Bell System as an integrated system can be illustrated by reviewing the steps involved in putting a new product into service. Because of the size of the Bell System, the variety of equipment embedded in it, and the need for new equipment to work with the old, the introduction of a new product requires tight coupling and interplay between people and organizations if it is to occur rapidly and effectively. This interaction starts with the conception of a new service or product, continues throughout development and manufacture, and usually extends until the product has been applied for a number of years.

When new ideas are conceived, the first questions that must be asked are: do service needs or operating problems exist where the idea could be used, and can the idea be applied economically? Answers to these questions require knowledge of operating company needs and public desires as well as the economics of manufacturing, supplying, and maintaining the equipment that will embody the idea. The combination of fundamental research, systems engineering, and development within the Bell Laboratories organization encourages the generation of new ideas and aids in answering these questions.

If the initial considerations appear promising, exploratory development will be started. Models are made, and the operational characteristics and economic factors are better defined and, in many cases, field tested. Operating company interactions help validate the technical and economic feasibility of new concepts. Rough price estimates are made by working informally with manufacturing people. The desirability of new services is explored with AT&T marketing and engineering people, and the compatibility with existing equipment and operating practices is investigated. Often, in the course of these studies, ideas are abandoned or modified substantially to make them more useful.

If exploratory development results are promising, specific development is considered. The marketing, operating, and manufacturing experts become more deeply involved. Sales projections and operating and manufacturing costs are formally developed. Operating company guidance on project priorities is sought. The decision to proceed into specific development usually implies the commitment of much larger resources than research and exploratory development. Consequently, thorough study is required.

If the study results are favorable, specific development is started. Frequently, tricompany teams of Bell Laboratories, AT&T, and Western Electric personnel are established to follow development progress and operating and manufacturing cost forecasts. Operating company people also may be members of the teams to provide their unique views of the operating environment and customer needs. Review teams, involving Bell Laboratories systems engineering and development personnel and Western Electric engineering, manufacturing, and pricing personnel, continually examine design-cost relations as new designs and their technologies develop.

The specific development process usually is not an easy or smooth one. As the original concept is reduced to hardware models, unanticipated problems invariably arise. Sometimes they may be so severe that the project is abandoned or returned to the exploratory phase. More frequently, substantial changes are required. In every case, the systems engineer, the developer, the manufacturer, and the potential user work closely to assure that service, compatibility, and cost objectives are met.

Frequently, especially for products based on new technology, a market or field trial is required. In these cases, an advanced model of equipment or apparatus is placed in actual operation to test customer reaction, compatibility, and other operational factors. Despite the most careful prior work, significant changes usually must be made to improve service, convenience, operating margins, and other aspects of design. These changes then are incorporated into the first production models.

However, even the most carefully planned field trials cannot examine all the environments that a new product will experience. This is especially true in the Bell System where, over time, a wide variety of equipment configurations has evolved. Experience has shown that only by extensive use of new equipment throughout the operating companies can all the potential incompatibilities be discovered. The development, marketing, manufacturing, and operating interactions often reach their peak after manufacturing has begun. Only after manufacturing and use continues for a number of years do design and manufacturing changes diminish to the point where the product can be considered relatively stable.

Continuous growth and change in the Bell System must be accomplished while maintaining compatibility with a variety of equipment configurations and utilizing cost-reducing technological advances. Therefore, integration of the planning, development, manufacturing, and operating functions is crucial to providing optimum service. The ability of AT&T, Bell Laboratories, Western Electric, and the operating companies to work together without proprietary barriers has been the key to the success of introducing new services and products in the Bell System in a timely manner.

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2. *Independent Telephone Statistics 1975*, U.S. Independent Telephone Association.
3. A. W. Page, *Bell Telephone System.*

2 A Typical Telephone Call

This chapter looks at a typical telephone call in terms of the equipment used and the sequence of steps involved in establishing the connection. This exercise will afford a basic understanding of how public telephone service works and will define some of the telephone terminology used in subsequent chapters. It also will provide an opportunity to introduce a number of engineering and operations aspects that will be expanded later.

2.1 SETTING THE STAGE

The scenario chosen for the call has been selected to make several points. It is quite simple and typical of calls that are made millions of times every day. Mrs. Smith originates the call from her home. Mrs. Smith's telephone is served by central office A, identified by the number sequence 747 (called an office code). The central office contains the switching system and related equipment that provides telephone service for customers in the immediate geographical area, within a radius of approximately 5 miles for example. The communication path between the telephone and the central office is called a line or loop. Mrs. Smith's call is to the residence of a friend, Mrs. Jones, in a nearby town. Mrs. Jones' telephone is served by central office B, identified by the central office code 432, and her telephone number is 432-5656. Since central offices A and B are relatively close, there are many calls to each from customers served by the other. Therefore, a number of trunks (a *trunk* is a communication path connecting two switching systems) are provided between the two central offices. However, at the time Mrs. Smith originates her call, all of the trunks between the two central offices are busy with other calls. The call, therefore, takes an alternate route from central office A to a third switching office, and from there to central office B. The call then reaches Mrs. Jones' telephone, she answers, and converses with Mrs. Smith.

Fig. 2-1 is a schematic representation of the facilities (telephone sets, transmission paths, and switching systems) involved in this call. A brief description of these facilities is appropriate at this point; more details will be found in Chapters 9 through 12.

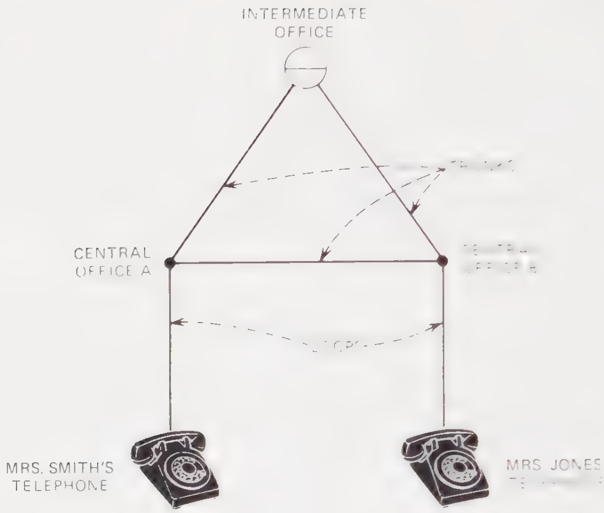

Fig. 2-1. Facilities Used in the Call From Mrs. Smith to Mrs. Jones

Telephone Sets

The functional components of the telephone set that are important to this discussion are the handset, containing a transmitter (microphone) and a receiver; the dial and associated mechanism; the ringer or bell; and the switchhook contacts. The switchhook contacts are open when the telephone is not in use, but are closed when the handset is picked up. When the switchhook contacts are closed, a dc path to the central office is completed. The rotary dial mechanism interrupts this dc path a number of times corresponding to each digit that is dialed. The transmitter converts acoustic energy from the talker to electrical energy for transmission, and the receiver performs the opposite conversion. The bell, of course, is used to alert the customer to an incoming call. These devices have been carefully selected and refined over the years to perform their functions effectively for minimum cost.

Because of the large number of telephone sets in service, a saving of a few cents in a single component can be very important. Of particular interest is the carbon button transmitter. Alexander Graham Bell's first transmitters were of the electromagnetic type and were similar in principle to the present receivers. However, Bell soon recognized that more electrical energy than was generated by this type of transmitter would be needed to transmit speech successfully. Experiments by a number of people, including Thomas Edison, showed that a microphone that used variations in the resistance of carbon particles to convert speech into variations in the electrical current would be effective. The carbon transmitter was adopted at an early date in telephony and has since been refined and improved. In telephony, it is still the most effective and economical device for converting speech into electrical energy.

Loops (or Lines)

The connection between the customer's telephone set and the central office is usually (but not always) a pair of wires. For most of the distance, the wires may be in a multipair cable, either on poles or in the ground. The length of the loop can range from nearly zero to several miles, depending on the proximity of the customer to the central office. Approximately 90 percent of all loops are less than 20,000 feet in length. Note that the loop is a 2-wire circuit for ordinary residential or business telephones; the same two wires are used both for transmitting and receiving.

Switching Systems

Although there are a variety of switching systems in use today, assume that the two central offices and the third switching office in the example are of the same type, No. 5 Crossbar. This type of switching system is one of the most common in existence today. The name is derived from the name of the electromechanical device, the crossbar switch, that performs the connecting function for the voice path in the system. The No. 5 Crossbar System makes use of a limited number of specialized equipment units to control the operations. A unit of control equipment performs its function on one call and then becomes available to perform the same function on another call. Much of the control function that directs the path the call takes through the system is concentrated in a small number of pieces of equipment, and these are used repeatedly. This mode of operation is called *common control.* The principal pieces of common-control equipment in the No. 5 Crossbar System are:

Dial tone marker
Originating register
Completing marker
Sender
Translator

Their functions will be described in the sequence of steps involved in establishing the call. Another important part of the central office is a dc voltage supply that is continuously applied to all loops. Of course, little current flows in any of the loops until the switchhook contacts of a telephone set are closed. The dc voltage permits the telephone set to signal the central office by merely closing or opening contacts with the switchhook or rotary dial. It also supplies direct current for the carbon transmitter in the telephone set.

Trunks

Offices A and B in the example are only a few miles apart; a trunk in this case would use a pair of wires in a multipair cable. As the distance between offices increases, it becomes economical to use a carrier system that combines a number of voice channels on two pairs of wires, one pair for each direction of transmission. The economy of a carrier system is due to a reduction in cost of wire or cable per voice channel. However, additional terminal equipment required at each end to multiplex (combine) the voice channels represents an additional cost. There is a breakeven distance below which the carrier system will be more expensive than simple wire transmission because of the additional cost of terminals and above which the carrier system will be less expensive because of the more efficient use of cable.

For the call in the example, it will be assumed that a T1 short-haul carrier system is used for the trunk group from office A to the intermediate office and another T1 system for the trunk group from the intermediate office to office B. The T1 system combines up to twenty-four 2-way voice channels on two pairs of wires, one pair for each direction of transmission. The voice channels are multiplexed (combined) by a time-sharing process involving pulse code modulation. The amplitude of each signal to be transmitted is sampled 8000 times a second. Each sample is transformed, or coded, into seven binary (having two values) pulses called *bits* (*bi*nary dig*its*). An additional pulse for signaling is added, and then the eight pulses are transmitted in a time slot slightly less than 1/(24 x 8000) of a second in length. The actual transmission rate is 1,544,000 bits per second. At the receiving terminal, the individual samples are decoded, distributed on the output channels, and then filtered to reconstitute the voice signals. The sampling rate and the 7-bit code used for this application permit the voice signal to be reconstructed at the receiving terminal with a satisfactory degree of accuracy.

Note that the individual channels provided by the T1 Carrier System can be used for different purposes. In the T1 system from office A to the intermediate office, some of the channels might be used to provide the trunk group mentioned, and others would be used for other purposes, for example, for private-line services or as elements of other trunk groups requiring channels on this geographical route.

It is important to note that in the loop and in the switching systems both directions of transmission are superimposed on two conductors (2-wire transmission). However, the two directions of transmission are separate when a carrier system is used in the trunk. One direction of transmission is put on one pair of wires and the opposite direction on another pair of wires. This is called 4-wire transmission. Four physical wires per voice channel are, of course, not needed, because a number of voice channels share the wires. It is necessary to provide a suitable interface between the 2-wire and 4-wire portions of a connection. This is accomplished by a hybrid circuit, one version of which is shown in Fig. 2-2. When the impedance of the matching network is exactly equal to the impedance of the 2-wire circuit, none of the energy entering the hybrid from one branch of the 4-wire circuit will be transferred to the opposite-direction branch of the 4-wire circuit. However, if these impedances do not match exactly, some portion of the energy will be transferred from one branch of the 4-wire circuit to the other. As shown in Fig. 2-3, this reflected energy will appear as an echo at the other end of the 4-wire circuit.

An echo can have a disturbing effect on long circuits of several hundred miles or more unless adequately controlled. This is discussed in Section 6.3.

The circuits in the example are assumed to be short enough that the echo delay is short, and echo thus presents no problem.

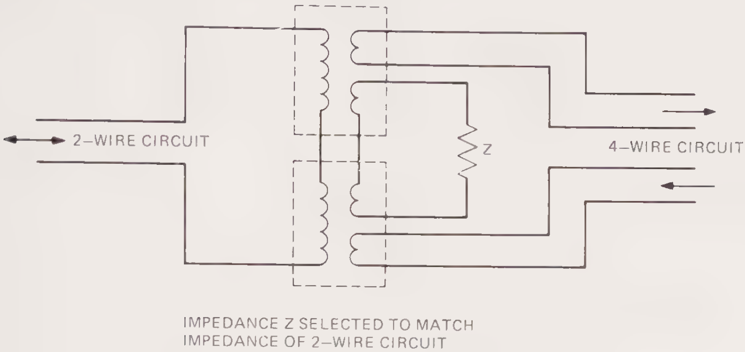

Fig. 2-2. Hybrid Circuit Using Two Transformers

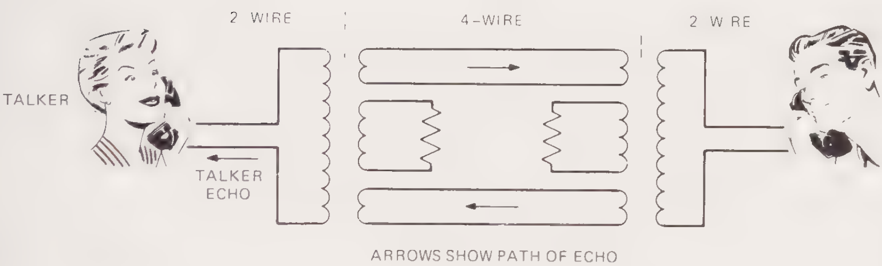

Fig. 2-3. Echo Path in a Telephone Connection

2.2 THE TELEPHONE CALL SEQUENCE

The stage is now set for Mrs. Smith's telephone call, which will be followed through all of its steps from start to finish. As Mrs. Smith picks up her handset, the switchhook contacts in the telephone set close; the weight of the handset holds the contacts open when the telephone is not in use and the handset is on the cradle. The switchhook contacts close a dc circuit through the loop to the voltage supply in central office A. The resulting current operates a relay that is permanently associated with that loop in the central office, thus indicating to the office that service is desired. A dial tone marker responds by finding the line requesting service. This marker selects an idle originating register and connects it to the line requesting service. Dial tone is then returned to the caller, indicating that the register is ready to receive the dialed number. These steps are indicated in Fig. 2-4.

Upon hearing the dial tone, Mrs. Smith dials the telephone address, or number, for Mrs. Jones: 432-5656. As the dial returns after Mrs. Smith dials each of the seven digits, the dial mechanism momentarily opens a pair of contacts a number of times equal to the dialed digit, e.g., four times for the digit 4. These contacts open and close the dc circuit through the loop to the central office. The dial tone is removed when the register receives the first digit. After Mrs. Smith has finished dialing, all seven digits are stored in the originating register.

The next series of steps occurs internally in central office A, as shown in Fig. 2-5. The register performs one of its functions by recognizing the first three digits as indicating another central office in the immediate area and therefore expects that only seven digits will be dialed. After the seventh digit is received, the register connects to an available completing marker and passes to it the 7-digit called number and the identification of the calling line. At this point, control of the call has shifted to the completing marker, and the register is disconnected. The marker then consults a unit called a route translator to find the identification of trunks on which this call to central office B should be routed. The translator indicates that the direct trunk group to B is the first choice. The marker tests all trunks in this trunk group and finds them busy. It again consults the route translator, which indicates that an alternate route to the intermediate switching office can be used and identifies the trunks. The marker tests the trunks in this second group and finds one that is not busy. Then, several actions take place almost simultaneously:

(1) The available trunk is seized.

(2) An idle sender is connected to the outgoing trunk, and the marker transfers the called number to the sender.

(3) The marker sets up a connection between the line on which the call was placed and the appropriate outgoing trunk.

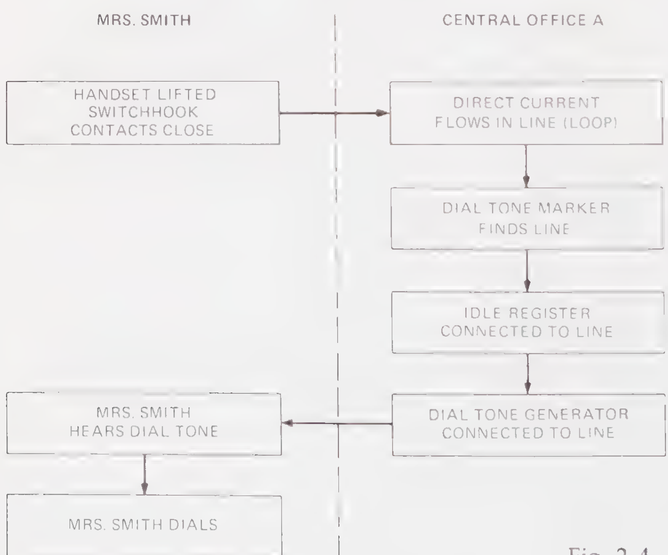

Fig. 2-4. Initiating the Call

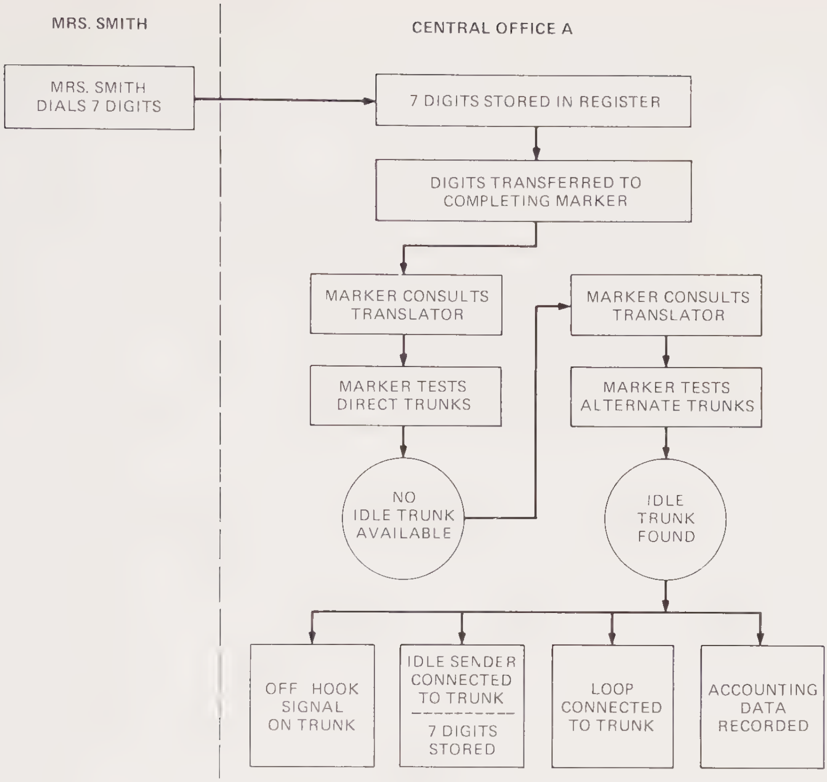

Fig. 2-5. Dialing and Subsequent Operations in Central Office A

(4) If the route translator has indicated that a toll charge should be made (this call is assumed to be a toll call), appropriate data for accounting use is recorded.

The marker is released at this point, leaving Mrs. Smith and the outgoing sender connected to the selected outgoing trunk.

Consider what is meant by "seizing" a trunk and how this is accomplished. Many trunks, including the alternate-route trunks in this example, are made up, at least in part, of carrier transmission facilities and therefore cannot accommodate dc signals over the transmission path. A common arrangement for signaling over trunks therefore makes use of tones. When a trunk is idle, a 2600-Hz tone is transmitted continuously in each direction; this is called an *on-hook signal,* a term derived from the idle condition of a telephone set when the handset is on-hook. When an idle trunk is seized at one end, the 2600-Hz signal is removed in the outgoing direction; this condition is called an *off-hook signal.* After the switching system at the far end of the trunk detects the absence of the 2600-Hz tone on the incoming side, it takes appropriate action which may lead to the removal of the 2600-Hz tone in the opposite direction of transmission. The 2600-Hz on-hook signal can, of

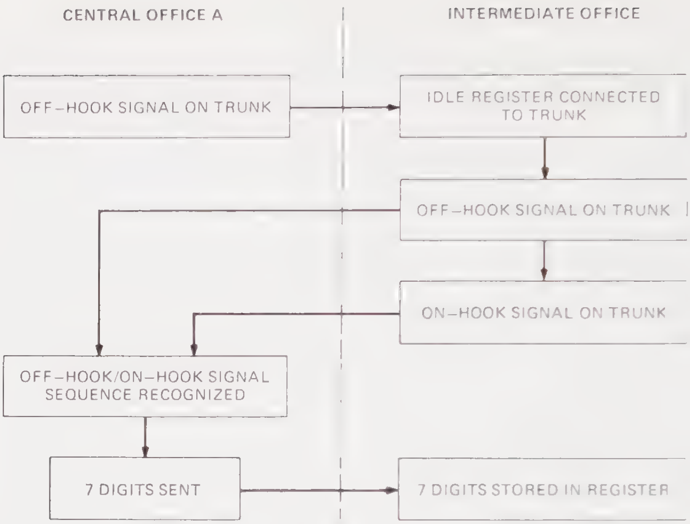

Fig. 2-6. Address Sent to Intermediate Office

course, be used on trunks that have T1 carrier facilities. However, on T1 trunks a more common arrangement is to make use of the built-in digital signaling capability of the T1 system. As mentioned previously, a signaling bit is associated with each sample so that every eighth bit associated with a particular channel is a signaling bit. The value 1 for this signaling bit is used as an on-hook signal, and the value 0 as an off-hook signal.

Now return to Mrs. Smith's call. Central office A has just seized a trunk to the intermediate office. The seizure is recognized at the intermediate office, and an idle register is connected to the trunk that has the incoming call. An off-hook signal is sent back to central office A and, after a short interval, an on-hook signal is again transmitted by the intermediate office to central office A. Central office A recognizes the removal and replacement of the on-hook signal as an indication that a register has been connected at the far end of the trunk and proceeds to send address information to the intermediate office. These steps are summarized in Fig. 2-6.

Consider address signaling over trunks. As mentioned, the trunks in this example cannot accommodate dc signals over the transmission path; accordingly, the dc pulsing technique employed on loops cannot be used to send the address from office A to the intermediate office. However, an on-hook/off-hook can be sent, employing either the 2600-Hz tone or the eighth bit. The address could therefore be sent by means of trains of on-hook pulses from office A to the intermediate office. However, much faster techniques for signaling have been developed. In one technique, each digit is represented by a pair of tones. By using 6 tones (frequencies), up to 15 signals, each represented by a pair of tones, can be coded and a single pulse of 2 tones can transmit any of the digits. Thus, seven 2-tone pulses can transmit a 7-digit telephone number. This multifrequency (MF) pulsing technique can be applied to the trunks in the example that use T1 Carrier Transmission Systems. The tones fall in the voiceband and so will be adequately encoded and decoded by the T1 techniques.

After the called number has been received in the register at the intermediate office, the completing marker consults the route translator in that office to identify the trunk group on which the call should be routed, in this case the trunk group to central office B. As before, an idle trunk is seized, a sender is connected to the outgoing trunk, and a connection between the two trunks is established as shown in Fig. 2-7. Note that if there had been no idle trunks to central office B, it would have been impossible to complete the call. In that case, a channel-busy (or reorder) tone would have been returned to the originator. However, it has been assumed that a trunk is available, and the call will progress.

Now the trunk seizure is recognized at central office B. A register is connected and the called number is transferred from the intermediate office. Note that only the last four digits of Mrs. Jones' telephone number need be transferred because all calls on this trunk group will terminate at office B. The completing marker recognizes this as a terminating call. It tests the called line to determine if it is busy, and, finding it idle, it sets up a connection

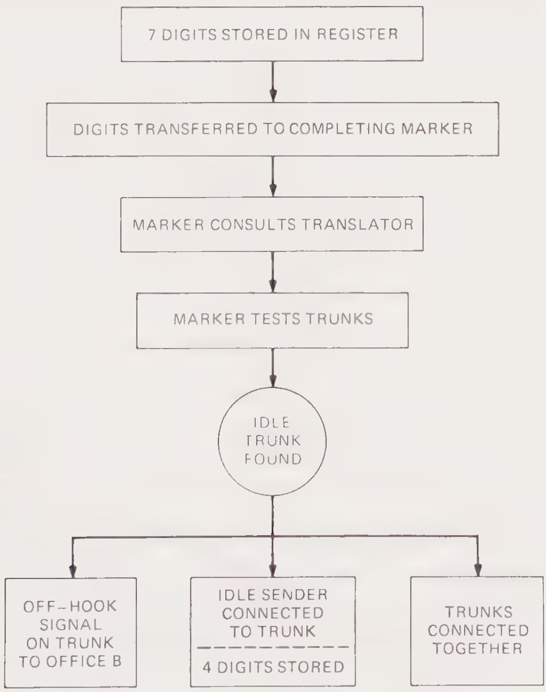

Fig. 2-7. Operations in the Intermediate Office To Connect Trunks

between the incoming trunk and the line and applies a ringing signal. The ringing signal rings the bell on Mrs. Jones' telephone, and a separate audible ringing signal is transmitted back over the connecting trunks and is heard by Mrs. Smith in her receiver. These steps are shown in Fig. 2-8.

The ringing signal consists of an ac voltage at about 20 Hz superimposed on a dc voltage. When Mrs. Jones lifts her handset to answer the call, the switchhook contacts in her set close, permitting a direct current to flow in the loop. This operates a relay in central office B that disconnects ("trips") the ringing voltage supply, thus permitting voice communication over the telephone connection. Also, an off-hook signal is placed on the trunk to the intermediate office and then on the trunk to the originating office. Detection of the off-hook signal at central office A indicates that the called party has answered, and a record is made for accounting. These steps are shown in Fig. 2-9. The telephone connection is now complete. Mrs. Smith and Mrs. Jones can carry on their conversation for as long as they desire. The elapsed time since Mrs. Smith picked up her handset is about 15 to 20 seconds, most of which is required by Mrs. Smith to dial the 7-digit number and for Mrs. Jones to answer her telephone after it starts to ring. The time required for signaling and for the switching systems to respond is small by comparison.

In the example, the process of switching in the No. 5 Crossbar System involved perhaps half a dozen functional units other than the crossbar switches. What is the rationale for the kinds of functional units into which a switching system is divided? It is based in part on the length of time for which the equipment is required in completing the call. There are generally three time scales involved. The longest is the holding time of the call. Much shorter is the time required for the customer to dial a number. The shortest time scale is that which is limited by the speed of devices used (relays or transistors) and in some cases by the speed of signaling between switching systems. It will be seen in Chapters 5 and 9 that the system architecture of a switching system is chosen to time-share a functional unit among calls to the greatest degree permitted by considerations of device speeds, reliability, traffic considerations, and economics.

At this point, consider the mechanisms of speech transmission in the established telephone connection. As Mrs. Smith talks into her handset, the minute variations in air pressure caused by her voice result in resistance fluctuations in the carbon transmitter. This, in turn, causes a corresponding variation in the direct current through the transmitter. The ac component of the transmitter current, which is an electrical analog of the speech, is propagated on the wire loop to the serving central office and is attenuated somewhat in the process. After passing through the switching system at central office A, this electrical analog of the voice signal is converted into a digital signal and is combined with several other similar voice-channel signals at the T1 carrier terminal.

At the intermediate office, the digital signals for the voice channel of interest are separated out, and an electrical analog of the voice signal then is

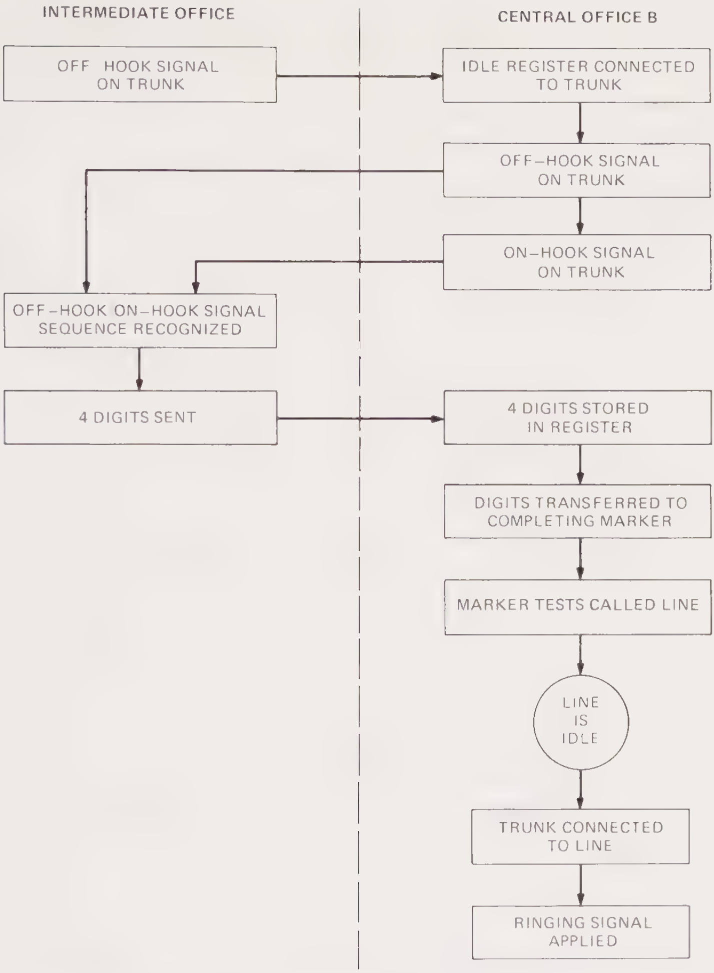

Fig. 2-8. The Call Advances to Central Office B and the Called Telephone Is Rung

passed to the outgoing trunk. There the signal is converted again to digital format and combined with several other voice-channel signals for transmission on the T1 Carrier System.

At the terminating office, the digital signals for the specific voice channel again are separated out and reconverted to an electrical analog of the voice signal, which is passed to the loop that goes to Mrs. Jones' telephone. This electrical voice signal is propagated along the wire loop, again being further attenuated, until it reaches Mrs. Jones' telephone. The receiver in the handset, which contains a diaphragm moved by an electromagnet, converts the electrical signal back to air pressure fluctuations that correspond closely to the air pressure fluctuations of Mrs. Smith's speech. The acoustic energy has been re-

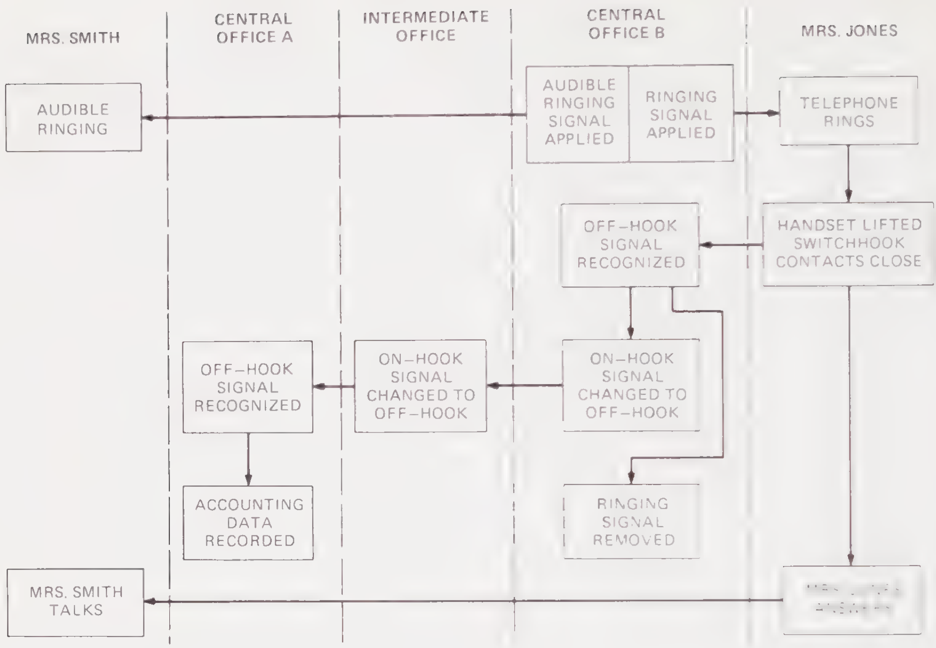

Fig. 2-9. The Call Is Established

duced somewhat because the electrical signal has been attenuated at various places along the transmission path, and some noise has been added. These impairments normally are minor, resulting in a highly satisfactory quality of transmission.

At the conclusion of the telephone call, both parties hang up their handsets. This opens the dc paths to both central offices, which in turn causes the trunks involved in the call to be restored to an idle condition and the connections within the switching systems to be released. Completion of the call is recorded for accounting purposes at central office A.

The accounting records are made on either punched paper tape or magnetic tape, depending on the type of equipment installed. These records are made at the originating office, that is, the office serving Mrs. Smith, who originated the call. The records include Mrs. Smith's number, the number called, the time Mrs. Jones answered, and the time the call ended. Thus, all information needed to compute the toll charge for the call is available. Periodically, all such records are processed by computer to calculate toll-call charges. Mrs. Smith's next monthly telephone bill will contain a charge for this call.

After looking in some detail at the things that happen in a rather simple telephone call, it is apparent that the processes are quite complicated and that many factors must be considered in planning a reliable, economical, easy-to-use network that will provide good transmission.

In the following sections, several broad observations based on the call sequence just described will be made.

2.3 SIGNALING

It is clear that signaling is an important function. Careful coordination of switching and signaling is necessary to provide foolproof operation. Three basic signaling functions were performed in the example call:

Supervision—Basically, indicating the status of a component, such as trunk idle or busy, telephone on-hook or off-hook.

Addressing—Specifying to a switching system the destination of a call.

Alerting—Signaling the called telephone that a call is being made. (This may be considered a special case of supervision.)

Several different signaling techniques were mentioned in the example:

Direct Current—Used on loops to indicate the desire to originate a call or to indicate answer at the called telephone.

Pulsed Direct Current—Used to send the address from the originating telephone to the associated central office.

Multifrequency—Used to send the address between switching machines.

AC Ringing—Used to ring the bell at the called telephone set.

Audible Ringing—A signal used to inform the caller that the called telephone is being rung.

Dial Tone—A signal used to inform the caller to start dialing.

2600-Hz Tone—Used on trunks to indicate status. Sometimes used instead of multifrequency to send address. (*Note:* This tone is not audible at the telephone set because it is removed at the end of each trunk by a filter switched in when the tone is present.)

Channel-Busy Tone—Although this did not occur in the example, it is used to inform the caller that for some reason the call could not be completed.

Busy Tone—Although this did not occur in the example, it is used to inform the caller that the call could not be completed because the called telephone was in use.

There are, of course, a number of signaling techniques that were not involved in the example. Two that are rapidly growing in use are digital signaling (used with digital carrier systems and mentioned briefly) and TOUCH-TONE signaling for addressing at the originating telephone set. Signaling equipment must be coordinated with the switching and transmission systems with which it functions. More will be found concerning signaling in Chapters 7 and 11.

2.4 TRANSMISSION PLANS

The telephone call example illustrates that a number of circuits are connected in tandem to form a complete telephone-to-telephone connection. In the example, a loop, two interoffice trunks, and another loop were connected together. Naturally, larger numbers of trunks are needed in some long distance calls, and a local call within a central office area does not involve trunks of any appreciable length. The value of loss associated with each trunk is an important parameter in a transmission plan. Some loss in addition to the loop losses is desirable, as will be discussed in Section 6.3. It is intuitively evident that the loss for a multitrunk connection should not be too great or the received volume will be too low. Thus, a plan for allocating loss to individual trunks is a necessity.

Note that the completed connection in the example call contained two trunks; however, if the direct trunk group between the two central offices had not been busy, the connection would have contained only one trunk. The overall loss for different connection configurations such as these should not be significantly different. Under the present transmission plans, the loss objective associated with the direct trunk would be about 6 dB, and the loss objective associated with each of the other trunks would be about 3 dB. Thus, the connection losses for the two connection configurations would be about equal.

Another aspect of transmission plans, mentioned previously but not illustrated by the example call, has to do with echos. When a significant end-to-end delay is introduced by transmission facilities in long distance calls, the talker may be disturbed by an echo returning from the far end of the connection. This effect may be controlled by ensuring that there is enough loss in long connections to reduce the amplitude of the echo to an acceptable value. Alternatively, a device called an *echo suppressor* can be inserted in the connection. Control of echo will be discussed in Section 6.3.

2.5 BALANCE BETWEEN TRANSMISSION AND SWITCHING

The example provides an opportunity to see the interesting balancing process that regulates the relative amounts of transmission and switching in the public telephone network. Consider the configuration of the three switching offices and the interconnecting trunks shown in Fig. 2-1. First, suppose that there are many telephone calls between the two central offices, enough to load a large number of trunks efficiently, 30 for example. Additional trunks may be inexpensive to provide because the distance is not great and because additional cable pairs may be available. Further, suppose that the intermediate switching office is so heavily loaded that for it to handle any additional traffic would require rather expensive augmentation of its equipment. Under this set of assumptions, it probably will be more attractive to add to the trunk group between the two central offices to accommodate any growth of traffic. It may even be attractive to route all traffic between the two central offices on the trunk group between them without provision for alternate routing; this trunk group would then be called a *full group.*

Now consider a different set of assumptions. Suppose that there are very few calls between the two central offices, perhaps 10 a day. Suppose also that large trunk groups exist between each of the central offices and the intermediate office to accommodate traffic destined to other locations and that there is sufficient available capacity in the intermediate switching office. Under this second set of assumptions, it probably will be economically attractive to route all traffic between the two central offices through the intermediate office and not to provide a trunk group directly connecting the two central offices at all. These two extreme assumptions show that there is a degree of interchangeability between switching and transmission. In one case, augmentation of a direct trunk group avoided the use of a third switching office; in the other case, use of the third switching office for all traffic avoided the need for a trunk group between the two central offices. These balances are continually being made as traffic grows and as the public telephone network expands.

2.6 HIERARCHY OF SWITCHING OFFICES

Two of the switching offices in the example provided switching service to customers' telephone sets, whereas the third switching office provided switching service to other switching offices. This constitutes an elementary hierarchical structure consisting of two offices on the lower level and one on the higher level, as shown in Fig. 2-10. If several similar elementary hierarchical structures are now imagined, it may be desirable to introduce a third level in the hierarchy, as shown in Fig. 2-11. Actually, the public telephone network has five levels in its hierarchy of switching offices. This is shown in Fig. 2-12.

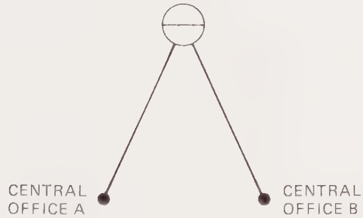

Fig. 2-10. A 2-Level Hierarchy

A characteristic of the hierarchical structure is that each switching office is connected to an office of higher level except, of course, at the highest level; these top-level offices are completely interconnected. This tree-like structure of a hierarchy ensures that there is a path from each switching office in the network to any other switching office in the network.

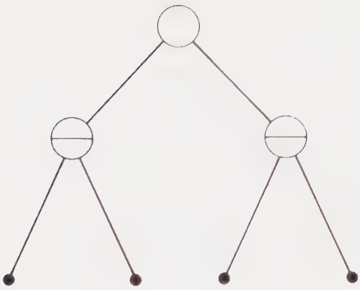

Fig. 2-11. A 3-Level Hierarchy

The network structure for the U.S.A. and Canada is divided into 12 regions; each region has one switching office of the highest level. The trunk group that connects a switching office to the next higher level switching office within a region is called a *final group.* Note that additional trunk groups supplementing the tree-like structure are permissible; in fact, they are desirable where sufficient traffic exists between switching offices not directly connected by the tree structure. Examples are shown in Fig. 2-13.

These trunk groups, which are not part of the tree structure, are called *high-usage groups.* The trunk group between offices A and B in the example is a high-usage group. Because this group was busy when Mrs. Smith originated her call, the call was routed on the two final groups.

The hierarchy that has been described is not the only way to organize the structure of a large network. For example, a large private network serving the Department of Defense, known as AUTOVON (Automatic Voice Network), has a fundamentally different structure which has been engineered to have essentially the same efficiency and economy as a hierarchical structure. Network structures and the related topic of traffic engineering are discussed in Chapters 5 and 14.

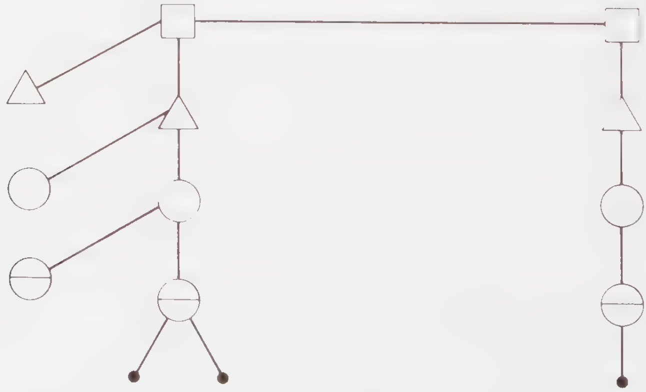

Fig. 2-12. Five-Level Public Telephone Network Hierarchy

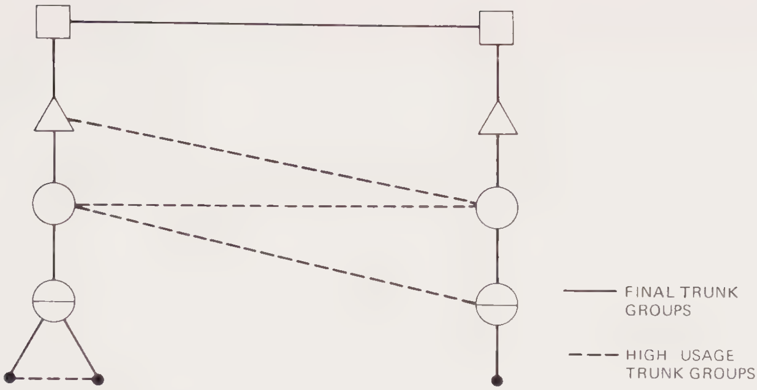

Fig. 2-13. High-Usage Trunk Groups Superposed on the Hierarchical Structure

2.7 EVOLUTION

An observation may be made here regarding the evolutionary process that has produced the techniques and equipment described in the example. Performance and economy have been the two paramount criteria in guiding the development and installation of new devices and equipment. Some of the choices made early in the history of telephony have proved to be remarkably durable. For example, the carbon transmitter, electromagnetic receiver, and ringer have been improved in various ways, but are still based on the original principles. Other components of the telephone network have undergone basic changes; for example, manual switching systems have been replaced by automatic switching systems which, among other things, do automatic alternate routing. Digital carrier systems such as T1 have been added to the network because these systems have proved to be less expensive than other transmission systems. This evolutionary process has resulted in a network that provides good performance in an economical manner.

3 Network Fundamentals

A network can be defined as a system of interconnected elements. This chapter discusses two general kinds of networks. In the first, the emphasis is on the ability to interconnect stations for the exchange of traffic. In the second, the emphasis is on the transmission and switching systems that make up the network. These two kinds of networks are defined as traffic networks and facilities networks, respectively.

3.1 TRAFFIC NETWORK DEFINITION

To introduce the concept of traffic networks, consider a simple form of network in which a number of stations are always connected together. This may be thought of as a "party line" by means of which any station can communicate with any other or perhaps with all of the others. An example of such a telephone network is shown in Fig. 3-1. Note that it would be necessary to monitor continuously at all stations or to provide a signaling arrangement to alert appropriate stations. This type of network is rare; certain intercom arrangements and some private-line voice networks are similar in principle but may not provide complete flexibility as to stations alerting other stations.

The more common conception of a traffic network includes switching. All of the stations in a traffic network do not have to be simultaneously interconnected, but the capability must exist to establish a connection between any planned combination on demand. For example, a traffic network can be designed to connect any pair of stations on demand; Fig. 3-2 is an example of such a network. More complex arrangements can be designed to interconnect any specified number of stations.

The stations on a traffic network intended for voice communications are, of course, telephone sets. Stations on other types of traffic networks may be other devices such as teletypewriters or PICTUREPHONE sets. All of the stations on a traffic network must handle the same type of traffic. Stations of the same type may be on the same or on different traffic networks; thus groups of stations of the same type, having no reason to communicate between groups, can be on separate traffic networks.

The aspects of traffic networks discussed above are summarized by the following definition: a traffic network carries any of a variety of types of traffic (voice, data, picture, etc.) between a number (possibly a large number) of sta-

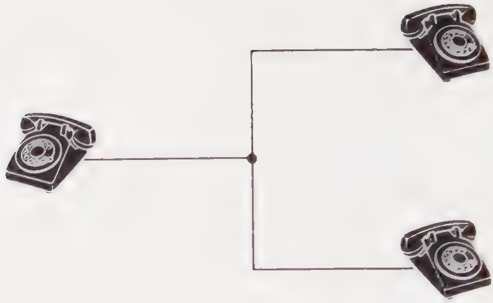

Fig. 3-1. Telephone Network With Permanent Connections

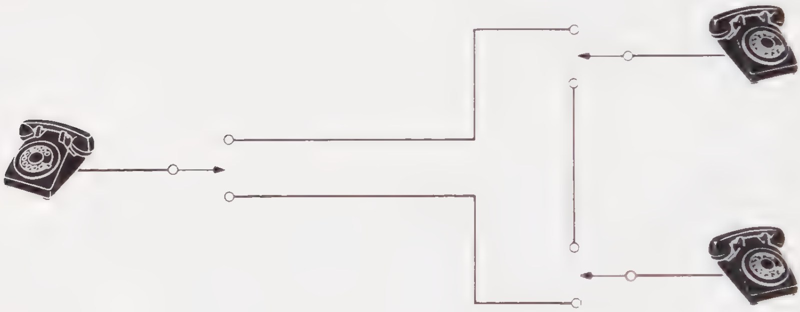

Fig. 3-2. Telephone Network With Switched Connections

tions that can be connected on demand or, in some cases, are permanently connected. The number and location of the stations, transmission channels, and switching arrangements are directly related to the magnitude and characteristics of the traffic the network is designed to carry. There is a very large number of traffic networks. The network that provides public telephone service (which is called the *public telephone network*) is the most widely known traffic network and is also by far the largest. Other examples of traffic networks are private-line voice networks, private-line data networks, and the networks that carry television programs from studios to broadcast stations.

3.2 FACILITIES NETWORK DEFINITION

Now consider the second network concept. Instead of viewing a network as a group of station terminal devices interconnected to accommodate a particular body of traffic, think of a network as being made up of facilities. These facilities include station equipment, transmission systems, and switching systems. Station equipment includes telephone sets, PICTUREPHONE sets, teletypewriters, and other types of terminals. With suitable switching arrangements, a terminal can be connected to two or more traffic networks. For example, an arrangement common in businesses permits a telephone set to be used either on the public telephone network or on a private telephone network. Some transmission systems can provide many voice channels; voiceband channels can be used for other types of signals such as data, and some system capacity may be used for wideband channels that can handle television signals. A transmission facility may carry channels for several different traffic networks. The T1 Carrier System mentioned in Chapter 2 is an example of a transmission facility. The channels it provides may be elements of several traffic networks. Similarly, a switching system may handle traffic for several different traffic networks.

Station, transmission, and switching facilities, taken together, form a facilities network. The pattern of association can be appreciated by thinking of a map showing all of these facilities and by realizing that these facilities can be connected together so that each element handles its share of a large and diverse body of communications. It is convenient to refer to the aggregate of all telephone company facilities as "*the* facilities network". However, in principle, there can be isolated facilities networks with no connection whatever to the main facilities network.

The facilities network is a vehicle for a large number of traffic networks. For example, the public telephone network, a number of private telephone networks, several television networks, and numerous other traffic networks are carried on the facilities network. Obviously, the capacity of the transmission and switching facilities must be large enough to accommodate the aggregate of traffic for all the traffic networks served. Additional capacity may be designed into the facilities network in anticipation of growth in traffic and the addition of new traffic networks.

The two network concepts, traffic and facilities, are complementary; one emphasizes traffic flow and interconnections in response to short-term traffic demands, and the other emphasizes facility systems which are rearranged and augmented on a much longer time scale. Neither concept by itself forms a sufficient framework for dealing with all aspects of telephone engineering and operations. The two overlapping concepts will be used as appropriate in the following chapters. In the remainder of this chapter, traffic networks and the facilities network will be discussed in more detail.

3.3 TRAFFIC NETWORK EXAMPLES

There are many traffic networks providing a variety of services. Several important types, which will be described, are:

Public Telephone Network
Private-Line Networks
Audio Program Networks
Video Program Networks
Private-Line Data Networks
PICTUREPHONE Networks

3.3.1 PUBLIC TELEPHONE NETWORK

This is the network that provides public telephone service. It is by far the largest traffic network in terms of traffic volume and revenue. It served over 150 million telephones in the United States (120 million Bell System telephones) at the end of 1975. The main function of this network is to carry business and residential telephone traffic. It also carries DATAPHONE® traffic, for which a connection between two data terminals is dialed, just as for an ordinary voice call. Data transmission then can take place over this connection at a number of speeds, the present maximum being 4800 bits per second. Teletypewriter service also can be provided via DATAPHONE terminals; however, further growth of this service was prohibited for a 5-year period as one of the terms of the sale of the teletypewriter exchange (TWX) network to Western Union in 1971.

3.3.2 PRIVATE-LINE VOICE NETWORKS

Many private-line voice circuits connect only two stations; others interconnect a number of stations and may have signaling arrangements to alert appropriate stations when communication is desired. In addition to these nonswitched networks, there are several thousand private switched voiceband (PSV) networks. Their customers are government organizations and large companies. For example, AUTOVON is a large network serving the Department of Defense; it spans the United States and extends to overseas and Canadian locations. The federal telecommunications service (FTS) network is another large network, serving civil organizations of the Federal Government. The remaining PSV networks range in size from large nationwide networks that serve hundreds of locations to small networks in metropolitan areas that serve fewer than ten locations. They are used by several state governments and by many large multilocation companies. Some large PSV networks use switching systems of the types that serve the public telephone network. Other private networks use PBXs for switching.

3.3.3 PROGRAM NETWORKS

Radio and television broadcasters make extensive use of networks to distribute program material to their affiliated stations. Both audio and video program networks exist; they are each characterized by distributing the same program simultaneously to a number of stations. Program networks are not switched in the same sense as PSV networks; however, some switching functions related to program distribution are performed.

3.3.4 PRIVATE-LINE DATA NETWORKS

Customers can lease point-to-point private-line data circuits on analog transmission facilities in three speed ranges:

TRANSMISSION CHANNELS	HIGHEST SPEED[1] (BITS PER SECOND)
Telegraph	150
Voiceband	9600
Broadband	250,000

A data service in which data signals are transmitted on digital facilities, called the Digital Data System (DDS), was started in 1974. Available speeds are 2.4, 4.8, 9.6, 56, and 1544 kilobits per second. Private-line data circuits are leased to customers.

Telegraph channels provide circuits employing a fraction of a voiceband. Telegraph channels are used for teletypewriter, remote metering, burglar alarms, and other such services. There are on the order of 8000 interstate private teletypewriter networks. About half of these are simple 2-point networks; the rest are multipoint networks. There are, of course, many more shorter teletypewriter networks.

Many private-line data circuits at speeds greater than telegraph are in use. Although most applications do not involve switching, customers can form their own switched data networks by leasing private lines and interconnecting them by data processors. Examples of extensive networks are those operated by the National Aeronautics and Space Administration (NASA) and the Advanced Research Projects Agency (ARPA).

3.3.5 *PICTUREPHONE* NETWORKS

PICTUREPHONE service is similar to telephone service, with the addition of a television-like picture of a person, object, or graphics transmitted in each direction. Limited network services are available in Chicago, Pittsburgh, San Francisco, and Washington, D.C. as exploratory market trials. No intercity network exists as yet. If this service's popularity warrants, these trial networks can be expanded to provide a service similar in scope to that of the public telephone network or private switched voiceband networks.

3.4 REVENUES FROM TRAFFIC NETWORKS

In 1974, the total revenue of the Bell System amounted to approximately $26 billion[2]. An idea of the relative importance of the different traffic networks described in the previous section can be gained by examining their relative contributions to the total revenue, as indicated in the Bell System operating revenues report. Fig. 3-3 shows the percentages of revenue contributed by the various traffic networks.

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1. Lower speeds are available at lower prices with different data sets.

2. From the 1974 AT&T Annual Report. The total revenue was $29 billion and $33 billion in 1975 and 1976, respectively.

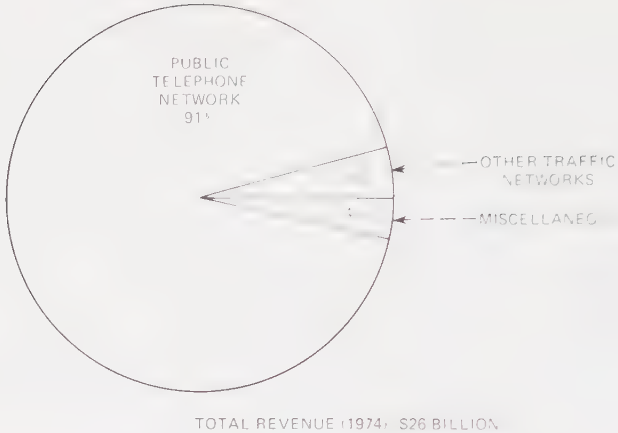

Fig. 3-3. Sources of Bell System Revenue

3.4.1 PUBLIC TELEPHONE NETWORK

Service provided by the public telephone network, including both local and toll service, is the principal source of revenue. In 1974, it produced 91 percent of the total revenue, approximately $24 billion. This emphasizes the importance of public telephone service in the Bell System's business and justifies the considerable emphasis placed on the public telephone network in the following chapters. In addition to charges for simple, ordinary telephone service, public telephone network revenues include charges for a variety of other services which are described in Chapter 4. These include toll charges under special rate plans such as WATS and charges for PBX service for internal as well as external communications over the public network. Revenues for DATA-PHONE service also are included.

3.4.2 OTHER TRAFFIC NETWORKS

Various private-line traffic networks provide 5 percent of the total Bell System revenue. The portions of revenue derived from several types of these networks can be readily identified:

(1) Teletypewriter networks provide 0.4 percent.

(2) Audio program networks provide 0.1 percent.

(3) Video program networks provide 0.3 percent.

Other private-line services account for 4.2 percent of the revenue. It is estimated that about half, 2.1 percent, comes from private-line voice services, a substantial portion of this being associated with private switched voiceband networks. Other private-line services (largely data services) account for the remaining 2.1 percent. An additional amount of revenue from DATAPHONE service is included in the public telephone network revenue.

3.4.3 MISCELLANEOUS REVENUES

A significant part of Bell System revenue comes from sources other than traffic networks. These sources account for about 4 percent of the total or approximately $1 billion. The principal sources of this miscellaneous revenue are directory advertising and the sale of Bell System directories for use in independent telephone company territories.

3.5 MAJOR ELEMENTS IN THE FACILITIES NETWORK

The elements of the facilities network that provide service are:

- Station equipment
- Transmission facilities
  - Loop systems
  - Exchange area systems
  - Long-haul systems
- Switching facilities
  - Local systems
  - Toll systems

3.5.1 STATION EQUIPMENT

The most numerous examples of station equipment are, of course, ordinary telephone sets. Key telephone sets are also quite common. These are similar to ordinary telephone sets, but have additional switching and signaling arrangements that permit the user to originate or receive calls on any one of several lines and provide several other functions; they are used extensively at business locations. PBXs are switching systems, usually installed on customers' premises, to permit a number of local telephones (called extensions) to communicate with each other or, alternatively, to be connected to a central office. PBXs are widely used by businesses and range in size from small systems serving about 20 extensions to very large systems with more than 10,000 extensions. Other types of station equipment include data terminals and PICTUREPHONE sets. See Chapter 12, "Customer Services Systems", for a more complete discussion.

3.5.2 TRANSMISSION FACILITIES

Loop Systems—Loops are the transmission paths between station equipment and the serving central office. A loop is usually a pair of wires which, for most of its length, is in a multipair cable suspended from poles, buried in the ground, or placed in cable ducts. Loop systems are described in Section 10.1.

Exchange Area Systems—These are the types of systems ordinarily used to provide relatively short trunks. Many exchange area systems are only a few miles in length. Voice-frequency transmission on multipair wire cables is used extensively. Analog and digital carrier systems are used on multipair cables. There are also some high-capacity systems using coaxial cable or radio. High-capacity systems differ from long-haul systems in that they achieve economies by designing to less stringent performance objectives and by optimizing the design for shorter length. These systems are discussed in Section 10.2.

Long-Haul Systems—These systems can be used to provide long circuits, as their design allows good performance for distances of several thousand miles. They are high-capacity carrier systems using coaxial cable, submarine cable, microwave radio relay, satellite radio, and (perhaps ultimately) waveguide. Long-haul systems are described in Section 10.3.

3.5.3 SWITCHING FACILITIES

Switching facilities may be divided into two basic categories: local and toll. Local switching facilities are the central office switching systems to which station equipment is directly connected by loops. These switching systems connect loops to loops and loops to trunks. Toll switching systems connect trunks to trunks. These are found in the upper levels of the hierarchical structure mentioned in Chapter 2. Some local switching systems also connect trunks to trunks, thus performing some toll switching functions in addition to local switching. A special class of trunk-to-trunk switching system called a "tandem" is used in large metropolitan areas to interconnect central offices. Tandems are classed as toll switching systems, although a large portion of the connections they establish may be within the exchange area. Arrangements for providing operator services, such as directory assistance, special charging on toll calls, and intercept of calls to nonworking numbers, also are considered to be switching facilities.

3.6 INVESTMENT IN THE FACILITIES NETWORK

An appreciation of the size of the Bell System facilities network and the relative proportion of the various types of facilities it contains can be gained from an examination of the Bell System plant accounts. Note that the numbers quoted represent the total investment in facilities regardless of how the facilities are used in traffic networks; except for unused capacity in facilities, the numbers also represent the total investment in traffic networks. The investment in the facilities network can be broken down according to the major elements of the network: station equipment, transmission facilities, and switching facilities. However, the investment cannot easily be segregated by individual traffic networks because facilities are shared by a number of traffic networks; for example, a long-haul transmission system provides circuits for many separate traffic networks in addition to the public telephone network.

3.6.1 TOTAL INVESTMENT

The 1974 AT&T Annual Report shows a total investment of approximately $78 billion in land, buildings, and equipment.[3] Examination of the telephone plant accounts reveals how this investment is apportioned among the classes of facilities defined in Section 3.5. Fig. 3-4 shows the relative percentages invested in station equipment, transmission facilities, and switching facilities. Only about 12 percent of the total investment is for land, buildings, and general equipment such as furniture, office equipment, motor vehicles, computers, tools, and work equipment. The remainder of the investment, approximately $68 billion, is for the facilities network.

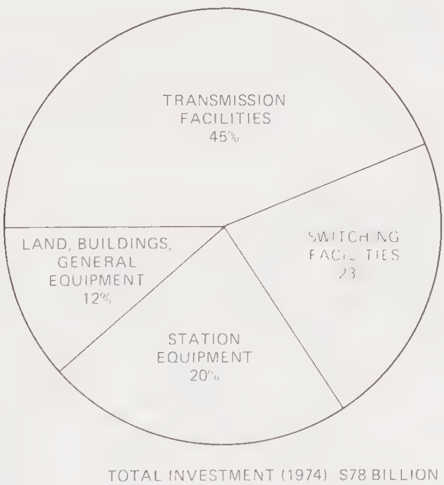

Fig. 3-4. Breakdown of Bell System Investment

3.6.2 INVESTMENT IN STATION EQUIPMENT

The investment in station equipment is approximately $15 billion or 20 percent of the total investment. This includes investment in telephone sets, key equipment, PBXs, teletypewriters, mobile radio equipment, and data sets. Three-quarters of the $15 billion is invested in telephones and is divided about equally between the station sets themselves and the materials and labor associated with their installation.

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3. The total investment was $85 billion and $91 billion in 1975 and 1976, respectively.

3.6.3 INVESTMENT IN TRANSMISSION FACILITIES

The investment in transmission facilities is approximately $35 billion, representing 45 percent of the total investment. These facilities include aerial wire, aerial cable, underground cable in conduit, buried cable, radio equipment, repeaters, multiplex equipment, etc. About one-third of this investment is in long-haul systems, and the other two-thirds in loop systems and exchange area systems.

3.6.4 INVESTMENT IN SWITCHING FACILITIES

The investment in switching facilities is approximately $18 billion or 23 percent of the total. It is interesting to note that this is roughly equal to the investment in station equipment and to about half the investment in transmission facilities. It is estimated that toll switching systems account for about one-quarter of the switching facilities investment, while local switching systems account for about three-quarters.

4 Services and Tariffs

From the point of view of both the customer and the regulator, the Bell System exists to provide quality service at a reasonable price. All equipment must be considered in the light of how it will contribute to providing this service. Ideas for change must be evaluated from the standpoint of providing new, better, or lower-priced service to customers. The first section of this chapter reviews services that are now offered. The second section deals with tariffs, their purposes and structures. The treatment in this chapter gives a broad introduction to services and tariffs; it is not intended to be comprehensive. The reader also should recognize that services and tariffs are not static; changes occur frequently.

4.1 SERVICES

To most of the Bell System's residence customers, the most frequently used service is local exchange service. Local exchange service is defined as telecommunications within designated areas, termed local service areas, for which no toll charge is levied. Local service areas vary in both geographical size and number of telephones included. The local service area is often configured to include an area that matches the community of interest of the customers within it, preferably not excluding any obvious civic, religious, or social entities with which the local residents frequently communicate.

Calls to points outside the local service areas ordinarily incur additional charges. Such traffic is referred to as toll traffic, and customers ordinarily are charged for each individual call.

Local exchange services are provided in two broad categories: those used by residence customers and those used by business customers, although some services such as coin telephone and operator services are used by both classifications.

Business services also can be used by residence customers. For example, if a private branch exchange is desired in a private home, one may be installed. Wide area telecommunications service, foreign exchange, or private-line service also may be obtained, but this is rare indeed. These business services are described in Section 4.1.2.

An idea of the relative size of the business and residence service categories can be gained from Fig. 4-1, which shows the percentages of telephones and revenues (for local and toll service) associated with business, residential, and coin services.

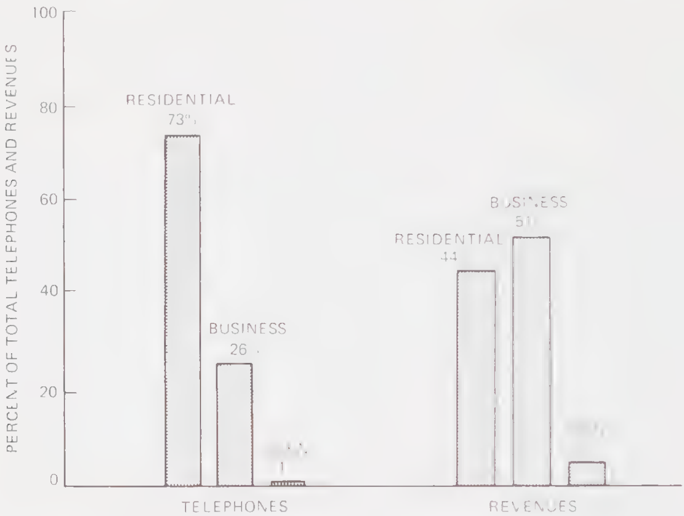

Fig. 4-1. Comparison of Residential, Business, and Coin Telephones and Revenues

4.1.1 RESIDENTIAL SERVICES

The basic building block of residential service is a telephone set on the customer's premises and access to the public telephone network. The telephone set is connected to a central office by a loop (or line), so that local service and toll service can be provided to the customer. Residential service may be individual line or party line. In party-line service, two or more customers share the same line to the central office or, alternatively, the lines are bridged at the central office and share the central office equipment associated with a line. Party lines have been decreasing in recent years because of the reduction in the rate differential between party and individual service and because of changing customer attitudes. Party lines still remain, mainly in rural areas where loop facilities may be expensive.

4.1.1.1 Telephone Instruments and Vertical Services

The telephone instrument is the interface between the customer and the network. An effort has been made to make the station set, once as drab and standardized as the Model T, an attractive, pleasant-to-use instrument. A variety of styles and colors of station sets is now available. In addition to the standard telephone set (which can be either a desk or wall-mounted instrument), PRINCESS® sets, TRIMLINE® sets, and panel-mounted sets are available. These sets provide additional features over the standard set, such as an illuminated dial. The DESIGN LINE[1] series of telephone sets has been introduced by operating companies. The distinctive decorator housing of these sets is sold to the customer for a one-time charge; the internal mechanism remains the property of the Bell System. DESIGN LINE housings are available in several styles, including a replica of an antique cradle phone and a wooden-boxed executive-style phone. Some of the DESIGN LINE series of telephone sets are shown in Fig. 4-2.

Fig. 4-2. DESIGN LINE Telephone Sets

In the modern home, extension phones are commonplace, and the use of two or more lines is expanding. Extension phones add utility to telephone service by making a phone available in each major living area of the home.

Extensions and premium station sets are examples of *vertical services* for which there is an additional charge; they are not necessary for basic communications, but are useful adjuncts that make communicating more pleasant or more convenient. Another example of a vertical service is TOUCH-TONE dialing. In areas served by TOUCH-TONE equipped central offices, this service offers advantages both to the Bell System and to the customer. Among other conveniences of TOUCH-TONE dialing, it is faster than rotary dialing. The Bell System can take advantage of the faster dialing rate in the engineering of switching equipment. For example, a register that is occupied only dur-

1. Trademark of AT&T.

ing the dialing period is available sooner for use on other calls if the dialing time is reduced, and so fewer registers are needed. It is anticipated that at some future time the Bell System will be predominantly TOUCH-TONE equipped.

4.1.1.2 Custom Calling Services

In areas served by Electronic Switching Systems, custom calling services are available to residence and business customers. The majority of current users are residence customers. Custom calling services generally include features that take advantage of the stored program control of Electronic Switching Systems. Examples of features offered are:

Three-Way Calling—A customer can add a third party to an existing conversation. When the third party answers, a private 2-way conversation with that party can be held before bridging the connection for a 3-way conference.

Speed Calling—A customer can reach certain frequently called numbers, including long distance numbers, by dialing an access code plus the speed calling code. Repertories of 8 and 30 stored numbers are available.

Call Forwarding—A customer can forward incoming calls automatically to any telephone that can be dialed directly.

Call Waiting—A call to a busy station line equipped with this feature can be held while an audible burst of tone is provided to the busy station to indicate that a call is waiting. The notification tone is heard only by the called customer; the incoming caller hears regular audible ringing.

4.1.2 BUSINESS SERVICES

The needs of the business customer are in some respects basically different from those of the residence customer. The size of the business organization, the need for internal as well as external communications, and the nature of the business traffic dictate which of several business communications services is appropriate. If there is a large volume of toll traffic, the bulk rates associated with wide area telecommunications service (WATS) may be attractive. Private lines, which are transmission paths furnished to a customer for his exclusive use, and private networks have advantages for many business customers. A variety of data communications services also is available.

4.1.2.1 Business Customer Services

Business Customer Services include business line, key telephone, private branch exchange (PBX), automatic call distribution, and telephone answering services. Business Customer Services do not include private-line services or WATS, which will be described separately.

Business Line Service

Very small businesses, for example a corner butcher shop, usually will need only a single business line. This service is essentially the same as residence service except a higher rate, based on the expected traffic and the value of the service, is charged. The butcher shop, because of its business class of service, receives a business listing, indicating the name of the shop rather than the name of the subscriber in the White Pages of the local directory, and also a Yellow Pages listing.

There are shortcomings that may make this simple service inadequate. For example, a customer trying to contact the business when the line is already busy might go elsewhere to buy. To eliminate this problem, one alternative would be simply to have several business lines, each terminated on a different station set. These lines could each have a different listed telephone number, or the central office could be arranged to hunt for an idle line in the group when a single listed number is dialed.

Key Telephone Service

For better service, in small business environments where several lines and perhaps an intercom within the business are desired, key telephone service often is used. This service is also widely used in conjunction with a PBX.

Key telephone systems provide station sets that have a number of depressible keys or buttons, with associated equipment located at a convenient place on the customer's premises in a cabinet or closet or, in recent models, in the set itself (see Section 12.3.2). The service the equipment provides can be arranged so that several stations have access to a particular incoming line, and several different lines can appear on each station. The station user selects the line by depressing the appropriate key. Thus a user can "pick up" a call on any line terminated on his instrument. A hold feature allows a station user to hold one line off-hook and talk on another line. When a line is put on hold, the distant party on that line hears nothing (or music or a recorded message in some systems) and can be retrieved by simply redepressing the corresponding line key. The hold feature is thus useful for isolating the distant party from the noise of the office, as well as to allow the user to handle other calls without releasing the original connection.

The lines that commonly appear on a key telephone set are PBX lines or lines to the local central office. Other lines that may appear are private lines and intercom lines.

If one key telephone user wants to talk to another user in the same office, the user can dial the desired party's number just like anyone not part of the key telephone system. Alternatively, if there is a need for frequent internal communications among a small group of instruments, intercom service can be provided. Internal communications then can take place without tying up PBX or central office lines and making them inaccessible to other users. Intercom service provides abbreviated dialing plans or nondial signaling by buzzer. Boss-secretary communication is a situation in which nondial intercom service is used commonly.

In summary, key telephone service provides a convenient means for a small group of people to communicate both internally and externally, allows one user to answer calls directed to others, and, via the hold feature, allows the handling of several calls simultaneously. The service ordinarily is limited to a few, or at most a few dozen, lines for a group of phones.

Private Branch Exchange Service

PBX service satisfies the communication needs of business customers who generally are larger in size than key telephone-only customers. Manual PBX service is still used extensively, but there is a strong trend to dial service.

Basic dial PBX service includes the following capabilities:

(1) A user can dial other stations on the PBX.

(2) A user can dial outside calls directly.

(3) An attendant answers all incoming calls and connects them to the desired station.

There is a large variety of additional features available depending on the PBX system (see Section 12.3.3) and on options selected by the customer.

Direct Inward Dialing (DID) service, over and above basic dial PBX service, provides for incoming calls to be routed directly to the desired station without attendant aid. The attendant still can route incoming calls when the main PBX number has been dialed and supervise usage of special facilities such as WATS or private lines. The billing for outgoing toll calls can include identification of the calling station, whereas in basic PBX service billing is done for the customer as a whole. DID service usually requires fewer attendants because attendants need not handle all incoming calls. It should be recognized, however, that this service might not be appropriate in a business environment where the customer wishes to control the flow of incoming calls to employees. When provided by a central office switching system, this service is called *centrex*.

Both PBX and key telephone service are useful to business customers who need both internal and external communications. Within the community of the PBX there often are smaller communities of interest served by key telephone systems. For example, key telephone systems could serve the intercom function and secretarial pickup function for a department within a business served by a PBX. In fact, about half the stations served by PBXs also are part of key telephone systems, typically three or four stations in a group.

Automatic Call Distribution Service

Automatic call distribution service provides a means for directing large volumes of incoming calls to a number of staffed answering positions when the nature of the calls is such that they can be handled by any of the answering positions. The incoming calls are distributed automatically to the answering positions. If all answering positions are busy, incoming calls are held and serviced in an approximate order-of-arrival fashion. Automatic call distributors are described in Section 12.3.4.

Telephone Answering Service

Telephone answering service (TAS) is provided by firms who specialize in answering the telephones of their clients (at central locations called bureaus). These firms sell the answering service to their clients. The Bell System does not offer TAS directly, but only provides the equipment to the answering bureau. The TAS bureau arranges with their clients under what conditions the bureau will answer their calls. In typical arrangements, after several rings the bureau will answer and take a message; later, the TAS client is contacted by the answering bureau (or vice versa) and the messages are repeated to the client. Telephone answering systems are described in Section 12.3.5.

4.1.2.2 Wide Area Telecommunications Service

WATS permits customers to make or receive long distance voice or data calls and have them billed on a bulk rather than individual call basis.

For an interstate WATS customer, the entire United States is divided into a number of service areas or bands extending outward from (but not including) the customer's home state. A customer may subscribe to some or all of these service bands, and each service band added includes the area or areas closer to the home state. If a customer attempts to dial outside of the subscribed WATS band, the customer is notified either by an intercept operator or by a recorded announcement. Intrastate WATS also is available in most states.

WATS is available for a monthly charge that depends on the amount of usage and the number of subscribed service bands. Because of its cumulative nature (that is, purchase of a distant service area includes all areas back to the home state boundaries), WATS is suited to calling patterns that tend to be geographically diffused, as opposed to highly defined point-to-point traffic which is often better suited to private-line service.

4.1.2.3 Private-Line Services and Private Networks

Many private-line services could be approximated using services available on the public telephone network. Point-to-point private lines and private networks, however, offer the following advantages to users:

(1) Where traffic is heavy enough and the geographical pattern lends itself to the use of private lines, private lines may be the most economical alternative.

(2) There is a specified charge for a private line that is independent of the amount of usage; this may be attractive to a customer.

(3) In some cases the simple signaling or abbreviated dialing in a private-line network may be attractive.

(4) The connection time or alerting time can be shorter with a private line than with the public telephone network.

Private-Line Types

Private lines are tariffed on a Series basis. Different Series lines have different uses and electrical characteristics. The primary Series designations and some uses are shown in Table 4-1.

TABLE 4-1
PRIVATE-LINE OFFERINGS

SERIES	EXAMPLES OF SERVICE
1000	Private-line telegraph, teletypewriter, teletypesetter, and remote metering
2000	Voice
3000	Data
4000	Telephoto
5000*	Voice and/or data (including telegraph) transmission at bulk discounted rates
6000	Audio (bandwidths to 15 kHz available)
7000	Television
8000	Wideband data

* Referred to as "telpak" service.

Private Networks

One type of private network is the Selective Signaling (SS) system, a voiceband network that enables a customer to select and signal distant stations by dialing numeric codes. The SS-1 system uses 2-digit signaling with rotary instruments; the SS-3 system uses 3-digit signaling with TOUCH-TONE instruments. Operation and features of the two systems are similar. All stations on a network are connected together in party-line fashion, and station-to-station calling is done simply by dialing the code of the desired station. A series of codes dialed in sequence will establish a conference call among the dialed stations.

A tandem tie-trunk network is a type of private network that allows communication between stations at two or more locations served by PBXs or having centrex service. Connections are initiated by a station user dialing a code or series of codes. As these codes are dialed, connections are established through two or more PBXs until the desired destination is reached. A simple connection uses one tie trunk to interconnect two switching systems; more complex connections involve three or more switching systems and two or more tie trunks in tandem, hence the name tandem tie-trunk network.

Another type of private network, the switched service network with common-control switching arrangements (CCSA), is intended for customers having extensive service requirements. Whereas the trunks and access lines in a CCSA network are private lines, the switching systems generally are the same types as those used for the public telephone network. Depending on the customer's requirements and the size of the network, automatic alternate routing to increase network efficiency may be incorporated. Western Electric's CORNET (*cor*porate *net*work) is an example of a CCSA network.

The Bell System has aided in the design and implementation of several special private networks for the federal government for which no conventional network arrangement would suffice. Two of these are AUTOVON and JCSAN/COPAN.

AUTOVON (*auto*matic *vo*ice *n*etwork) is a military worldwide switched network for private telephone and data transmission. The network permits calls between military bases that may be miles, nations, or oceans apart. The network serves a broad spectrum of traffic, ranging from critical command and control communications to everyday administrative calls, and carries data as well as voice. One unique feature of AUTOVON is precedence preemption. This allows a call of higher precedence to preempt a trunk or line carrying a call of lower precedence. Another special feature is the availability of 4-wire transmission all the way to the customer's station.

Military operations today require rapid, direct, and reliable voice communications between the Joint Chiefs of Staff at the Pentagon and various overseas and domestic command locations. In an emergency, these command locations must be quickly connected to the Pentagon for conferences. A global command post alerting network (COPAN), designed by Bell Laboratories, performs these functions. This network generally is referred to as the Joint Chiefs of Staff alerting network (JCSAN). By means of simple pushbutton operations in the Pentagon, the JCSAN system can establish an automatic worldwide conference network alert in less than 5 seconds, including the return acknowledgment signals that indicate the required locations are connected to the network.

Foreign Exchange Service

Foreign exchange (FX) service enables a customer in one exchange to communicate with customers in a distant exchange like a customer served by the distant exchange. This service is implemented by a private line that connects the customer's equipment to a central office in the foreign exchange. The customer's equipment may be a station or a PBX. The customer is given a directory listing in the foreign directory. The customer receives two bills for the FX service: one is a bill for the private line that connects the customer to the foreign exchange, and the other is a bill at normal rate for the telephone service that the customer uses through the foreign exchange. FX service is generally suited to a situation in which there is a removed, but somewhat localized, community of interest. For example, a firm in New Jersey might use FX lines to New York City if much of its business were there.

4.1.2.4 Data Services

As computers and other sophisticated business machines become more commonplace, data transmission becomes an increasingly larger part of business communications.

DATAPHONE service permits customers to use the public telephone network (including WATS and FX lines) for data communications. A DATAPHONE set on the customer's premises performs modulation, demodulation, and control functions. A telephone set ordinarily is used for setting up the channel or for voice communications alternately with data transmission, but the calling and answering can be entirely automatic.

DATAPHONE service also is provided on voiceband and wideband private lines. A DATAPHONE set is used on the customer's premises, and, on voiceband lines, the channel can be used alternately for voice communications if this is desired. Multipoint arrangements are used widely.

DATAPHONE digital service (see Section 12.4.3) is provided on digital transmission facilities. Point-to-point and multipoint private-line circuits are leased to customers. It is expected that a switched service also will be offered.

In addition to providing transmission and control capability, the Bell System provides some terminal equipment for use with data sets on Series 1000 channels (see Table 4-1), on DATAPHONE digital service, and on the public telephone network. Teletypewriter (TTY) service provides for the receiving and transmitting of hard copies of information by encoding characters into binary form for transmission and decoding the binary signals back into characters at the receiving end. These characters then are printed by the receiving teletypewriter. Teletypewriters can operate on the public telephone network or on private lines. The user can operate in an on-line mode by manually typing the desired message, which is simultaneously transmitted. The teletypewriter also can operate in an off-line mode through the use of a paper tape punch and tape reader. An off-line paper tape containing the message is prepared and can then be transmitted at higher-than-manual speed by the teletypewriter's tape reader.

DATASPEED® data service is provided by a family of high-speed data communications terminal devices. DATASPEED equipment includes paper tape senders and punches, magnetic tape terminals, and, most recently, cathode ray tube (CRT) terminals. DATASPEED equipment can be used on the public telephone network or on private lines.

4.1.3 OTHER SERVICES

The services described so far have been grouped into residence and business classes. Services that do not fall neatly into either category will now be described.

4.1.3.1 Coin Services

In 1975, there were over 1.3 million public and semipublic coin telephones in the Bell System. These telephones provide service on the public telephone network to individuals away from their residence or place of business. The public type of coin telephone is installed where a public need exists, such as in an airport lobby, at the option of the telephone company with the agreement of the owner of the premises or space. There is no directory listing. Compensation is paid to the owner of the installation site in recognition of the value of the space, for lights and power, and sometimes for cleaning. Semipublic coin telephones are installed where there is a combination of general public and individual customer need for the service, such as in a gasoline station. The customer receives a listing in the White and Yellow Pages of the directory, just as business line customers do.

A party who places a call from a coin phone elects either to pay for the call at the time it is made or to use a billing option such as credit card or collect calling.

Since the 1920s, when the Bell System began conversion to dial operation, coin-first service has been predominant. The customer receives a dial tone only after the appropriate coins have been deposited. An exception to this is postpay service, used in some outlying community dial offices. In this service, the customer receives dial tone without a deposit and deposits the required money after the called station answers. There is no provision for returning coin deposits with postpay service. Dial-tone-first coin service, currently being introduced into the Bell System, permits coin telephone customers to reach the operator and to dial certain service calls (such as directory assistance or 911) without depositing a coin. This allows the telephone to be used more easily in emergency situations, and the initial dial tone feature serves to give the customer some assurance the telephone is working before any money is deposited.

4.1.3.2 Mobile Telephone Services

Mobile telephone services are a class of services utilizing radio transmission. Development of these services has been hampered by limited radio frequency assignments and technological limitations. Mobile telephone services include:

- Land mobile telephone service
- BELLBOY® service
- Air/ground service
- VHF maritime service

Coastal harbor service
High-seas maritime radio-telephone service
High-speed train service

Land Mobile Telephone Service—Land mobile telephone service provides 2-way voice communications, through mobile-equipped central offices, between mobile units and land telephones or between two mobile units. Users have full access to the public telephone network either on a manual (i.e., operator-handled) or direct dial basis when in the mobile serving area. Land mobile telephone service and its future are discussed in Section 12.6.

BELLBOY Service—BELLBOY personal signaling service notifies a customer when someone desires to talk with him. Notification is by means of an audible tone emitted from a cigarette-pack-sized radio receiver carried on the customer's person. The audible tone is switched on when a party desiring the individual dials a special telephone number. This number causes the BELLBOY equipment in the central office to transmit a signal that activates the tone in the intended BELLBOY unit if it is within the coverage area, which generally is comparable to a metropolitan area. In some areas, BELLBOY service is on a manual basis whereby all signaling is done by an operator at a caller's request.

Air/Ground Service—Air/ground service provides 2-way telephone service between aircraft in flight and parties on the public telephone network. The service is provided by radio base stations connected to control terminals (which perform the interconnection into the public telephone network) and mobile service switchboards. All aircraft-mounted radio equipment is customer-owned and maintained. In 1976, approximately 2000 aircraft were so equipped, and 60,000 calls were placed during the year. Most of the customers for this service are the owners of private or corporation aircraft.

Marine Radio Telephone Services—VHF maritime service, coastal harbor service, and high-seas maritime radio-telephone service provide 2-way telephone service to ships at sea. The three services differ basically in the distance range over which they operate. VHF maritime service offers reliable communications in the very-high-frequency band up to 50 miles offshore. Coastal harbor service communications can range up to 1000 miles offshore, and high-seas service is intended for ships engaged in high-seas operations and transoceanic passages. The ship-mounted radio equipment for all three services is customer-owned and maintained.

High-Speed Train Service—High-speed train service provides telephone service between a train and the public telephone network. Train telephone service was inaugurated in 1947 on an operator-handled basis. By 1952, service was provided to 19 "name"[2] trains on 5 railroads. Most of these installations are now out of service, in most cases because of the demise of the equipped trains.

2. For example, B&O's Royal Line and Pennsylvania's Congressional Limited.

Train telephone service has been installed aboard the Metroliner trains operating between New York and Washington, D. C. The service provides the public with TOUCH-TONE, single-slot, dial-tone-first coin telephones. In all, about 30 Metroliner train cars had been equipped in 1972, and over 72,000 calls were handled. Approximately 45,000 calls were handled in 1976.

4.1.3.3 PICTUREPHONE Service

PICTUREPHONE service is a switched service that provides a visual image as well as standard audio transmission. Introduced commercially in the mid-1960s, the service is currently offered in several companies, although the majority of activity is in just one company. The service is offered on both an exchange and an intercom basis.

PICTUREPHONE booth service was introduced in 1964. Service is available between Chicago, New York, and Washington, D. C. on a point-to-point basis. In each of these cities there is a special phone booth (actually a small room) set up to provide PICTUREPHONE service. Customers also may have private video conference rooms on their premises.

4.1.3.4 Operator-Assisted Services

All customers on the public telephone network have available certain services that involve a telephone company operator. Such services can be classed into two categories: those that require special billing or other operator assistance, and those that the customer could dial but for some reason does not. Services in which the operator is necessarily involved are described in Table 4-2. Note that this table does not apply to attendants in PBX services.

4.1.3.5 Support Services

The telephone company provides a group of support services that increase the general utility of the company's offerings. The following paragraphs describe these services.

Business Office Services

The business office in the Customer Services Department is the area of the telephone company with which most customers first have contact. The functions of the business office include taking orders for new service or for changes in service, answering billing queries, and in general completing the link from the customer to the rest of the telephone company's working forces.

A service representative is an individual in the business office who deals with customers. Service representatives truly represent the company, and much care is taken to ensure that the job is performed courteously and efficiently. Typically, a group of customer accounts is assigned to a service representative, and that representative has available the appropriate customer records. Incoming calls to the business office are routed to the appropriate service representative, usually by the attendant of the telephone company's

TABLE 4-2
OPERATOR SERVICES—SPECIAL BILLING AND CONFERENCE ARRANGEMENTS

SERVICE	DESCRIPTION
Collect Calling	Allows charges to be billed, upon acceptance, to the called party.
Credit Card	Allows charges to be billed to an account identified by a credit card number.
Bill to Third Number	Allows charges to be billed to a telephone number different from the calling or called number.
Enterprise	Allows long distance incoming callers to bill the toll charges to a party receiving the call, usually identified by his having an "Enterprise" listing such as, "Ask operator for Enterprise 3124." (This service goes under different names in different areas, for example, Zenith or Commerce.)
Conference	A telephone operator, on request, can set up conference calls among specified parties. The charge for the service, unless arranged otherwise, is billed to the party initiating the conference.

PBX. The appropriate representative is identified based on the customer's telephone number, if service presently exists, or last name, if new service is desired and the customer has reached the correct business office.

Telephone Directory

Directories are divided into White Pages and Yellow Pages, and in large metropolitan areas, these may be separate volumes. The White Pages is an alphabetical listing giving each subscriber's name, address, and telephone number. For an additional fee, several types of special directory listings can be obtained, such as, "if no answer, call," "after 5 o'clock, call," or bold-face type. An additional directory service is withholding a customer's listing from the directory. This service offers some measure of privacy, but because of the resulting effect on directory assistance calling, an additional fee is charged for it. Two types are generally available: a semiprivate (or nonlisted) listing which does not appear in the directory but which will be given out upon request, and a private (or nonpublished) listing which will not be given out.

The Yellow Pages portion of the directory contains an alphabetical listing of business subscribers by category of business. Advertisements in the Yellow Pages of the local directory also can be purchased, and large business firms use the National Yellow Pages Service to place advertisements in directories for selected areas.

Directory Assistance

For those telephone numbers not included in the local directory or for those customers unable or unwilling to look, directory assistance service is available. Directory assistance for the local area code usually is reached by dialing 411. Directory assistance for foreign area codes can be reached by dialing the area code and 555-1212. The growth in directory assistance calls for telephone numbers listed in the local directory has led an increasing number of companies to charge for this service. Typically, introduction of a charge for directory assistance calls in excess of a specified number, such as three per month, has been accompanied by a 70 to 80 percent reduction in the number of such calls.

Intercept

In our modern society, people move frequently. Calls to parties no longer served by a particular number need to be intercepted and the callers notified of this fact. Callers also must be told if there is a new number by which the desired party can be reached. This function has been served by intercept operators at positions equipped with daily updated information on line changes. Calls requiring intercept treatment are routed automatically to these operators. The Automatic Intercept System (AIS) described in Section 9.6 has been put into service in some locations.

Community Services

Some telephone company services are of a civic nature; that is, they are provided mainly as a public service to the community. The program to make 911 the emergency reporting number is one example. Dialing 911 in some areas of the United States puts one in direct contact with the local police, first aid squad, or similar group.

A Bell System offering called the emergency reporting telephone system uses special phones and provides at a remote location (e.g., police or fire headquarters) a hard-copy indication of the location of a phone going off-hook. This allows police or fire officials to quickly locate the fire or other emergency being reported. Emergency reporting telephones typically are installed in public areas where they are readily available for use when needed.

4.1.4 ORDINARY AND SPECIAL SERVICES

Services have been described in terms of uses by customers. They also are classified from the telephone company viewpoint as ordinary or special services depending on whether they require special treatment in respect to transmission, signaling, switching, maintenance, or customer use. Ordinary services usually are understood to be residence service, coin service, and non-PBX business services. All other services are considered to be special services; they either may be separate from public telephone service or may contribute to certain aspects of public telephone service. Special services are used primarily by business customers. Special services include:

- Foreign exchange service
- Wide area telecommunications service
- Private branch exchange service
- Private-line services
- Private network services

4.2 TARIFFS

4.2.1 REGULATION AND OVERVIEW OF TARIFFS

The Bell System and regulation grew up hand-in-hand. In 1866, the Post Roads Act was passed to regulate the placement and usage of telegraph lines. The Interstate Commerce Commission, founded in 1888, was given regulatory authority over communications in 1910. The Federal Communications Commission (FCC) was created in 1934. The telephone was born into this environment in 1876, when Alexander Graham Bell's "Improvement in Telegraphy" was patented.

Historically, the tenor of regulation has been aimed at protecting the consumer and providing a fair rate of return to the public utility firm. The procedure generally followed by regulatory bodies has been to authorize rates as low as possible and to keep profits at a minimum level consistent with the long-term objectives of providing good service and of the serving firm remaining solvent. In practice, the most obvious function of regulation has been the control of the firm's rate of return on its investment. Tariffs are a major manifestation of regulation. Tariffs identify and quantify a firm's offerings in terms of the services available and rates charged and are intended to be consistent with meeting the allowed rate of return.

4.2.1.1 Tariffs—What They Do

Tariffs serve three basic purposes: (1) to define the services offered, (2) to establish the rate the customer will pay for the service, and (3) to state the general obligations of the common carrier and the customer in the provision and use of the service. The tariff states the nature of the service, the class of customers to which given rate schedules apply, the availability of the service (i.e., in what areas it is available or under what conditions), the measurement of service provided (e.g., initial and overtime minutes on long distance calls), and how charges to the customer are to be computed.

4.2.1.2 Regulatory Bodies, Procedures, and Tariff Content

A regulated public utility generally is defined as a firm that supplies a service under naturally monopolistic conditions, with governmental regulation of prices, profits, and service quality. Telephone companies are regulated public utilities. The particular regulatory body having jurisdiction depends on the extent of the service in question; intrastate services are regulated by the appropriate state Public Utility Commission (PUC), and interstate services by the FCC. In 1974, approximately 69 percent of the total Bell System operating revenue of $25 billion (excluding miscellaneous revenue) was generated from state offerings, the rest coming from interstate services.

Operating Company Intrastate Tariffs

PUCs exist in all states and the District of Columbia, and the laws defining their jurisdiction vary widely from state to state. Each telephone company must file with each regulatory body in its territory a set of tariffs covering all standard intrastate service offerings. This gives rise to well over 50 different sets of tariffs. Hence, service offerings and rates can vary from state to state. Telephone companies, including over 1600 independent companies, file local exchange service tariffs. The independent companies, however, typically concur with the Bell company of the state in which they operate on intrastate toll and private-line tariffs.

Although the format of state tariffs varies from company to company, the typical topics covered are:

(1) General regulations (basic regulations covering use and provision of services).

(2) Local exchange service.

(3) General exchange service (includes key telephone, PBX, and other vertical services).

(4) Long distance message telecommunications service (intrastate).

(5) Wide area telecommunications service (intrastate).

(6) Private-line service (intrastate).

Services and/or rates are introduced or modified either by petition or by filing new tariff schedules. Petitioning is general in nature and may entail a request for an overall rate increase. The second technique is far less general and states specific rates for specific services. Once rate schedules are filed by a telephone company, there are generally three alternatives open to the commission. It can allow the schedule to take effect, it can reject the schedule, or it can suspend the schedule (usually for a specified period of time—presently 5 months maximum for interstate tariffs) and initiate public hearings on the matter. At the end of the suspension period, if no finding has been made by the commission, the filed schedule can become effective. Under this condition, the commission may require the carrier to maintain strict accounting records for the purpose of making appropriate refunds (plus interest), should it be determined through the hearing process that a lower rate schedule be adopted. At the public hearings, the burden of proof rests with the utility to show just cause for granting the rate increase or decrease for an existing service or for granting the rate for a new service.

Bell System Interstate Tariffs

The FCC, in its regulatory role related to interstate communications, has jurisdiction concerning:

(1) Interstate wire and radio telecommunications services.

(2) Telecommunications service between the United States and ships at sea.

(3) Telecommunications services between the United States and foreign points. These are usually individually negotiated, subject to FCC approval, with the foreign carrier in question.

The filing procedures followed by the Bell System in dealing with the FCC are analogous to those used with the state PUCs; however, the Long Lines Department of AT&T is the filing organization. The FCC tariffs currently filed by Long Lines are listed in Table 4-3. Table 4-4 (at the end of this chapter) summarizes the regulatory responsibility for several types of services.

4.2.2 TARIFFS FOR LOCAL EXCHANGE AND TOLL SERVICES

4.2.2.1 Local Exchange Service

Historically, the cost of installing station equipment on customer premises has far exceeded the connection charge. This has helped to promote the expansion of telephone service. For a variety of reasons, there is now a trend toward higher connection charges.

Exchange rates are based on an examination of the residual revenue requirements of the state as a whole, taking into account revenues from services other than local exchange such as toll and vertical services. These residual revenue requirements are transformed into exchange rates so that the rate for local exchange service generally is related to the number of telephones contained in the local service area. The overall constraint is that statewide revenue requirements, computed to yield the allowed rate of return, be met. Predefined exchanges are sorted into varying numbers of groups for which rates are set. The rate for each group is applicable to all exchanges within the group. For example, the New Jersey Bell tariff defines the first rate group for exchanges whose local service area includes up to 28,000 customers. The second group is for local service areas including 28,001 to 38,000 customers; the third is for areas with from 38,001 to 68,000 customers, etc. Exchange rates related to exchange size can be viewed as an example of the value-of-service concept.

Basically, the value-of-service concept states that rates for providing a service to a specific customer should be related to the value or utility of the service to the customer. In the case of exchange rates, the value of service for customers in larger exchanges is greater because of the greater number of customers they can call on a local basis.

TABLE 4-3
LONG LINES TARIFFS

FCC TARIFF NUMBER	MAIN TOPICS
257	List of connecting carriers that do not cross state lines but do carry interstate-bound traffic.
258	Private-line services for experimental purposes (interstate).
259	WATS (interstate).
260	Private-line services (interstate and foreign). Includes tariffs for point-to-point private lines of telegraph, voiceband, and wideband grades, and private-line networks, such as CCSA (see Section 4.1.2.3).
261*	Short period telephone service; that is, long distance point-to-point service provided regularly but only for stated hours of the day. The connection is set up by an operator at a prescheduled time (interstate).
262	Special construction. Covers interstate facilities that are constructed at the customer's request.
263	Long distance message telecommunications service (interstate). Deals with toll traffic; land, aviation, and maritime mobile service; overseas services; DATAPHONE 50; and PICTUREPHONE services.
264	List of rate centers, mileage coordinates, and central offices for the United States, Mexico, and Canada.
265	Interstate entrance facilities furnished to domestic satellite common carriers.
266	Interstate facilities furnished to other common carriers.
267	DATAPHONE digital services for private-line interstate communications.
268	Interstate digital facilities furnished to other common carriers.
Joint No. 2	Overseas channels for television transmission via satellite, filed jointly with IT&T, RCA, and Western Union.

* This tariff, although still in force, is generally considered an archaic offering. The tariff dates from the days when switching was mostly manual, and it was aimed at increasing the use of the network.

Different classes of local exchange service are considered in the following paragraphs.

Business/Residence

Different categories of local exchange service have different rates and provisions in the tariffs. A major distinction is between business and residence service. Residence service, defined as home telephone service of a nonbusiness nature, generally has lower rates than equivalent business service. One justification for this is the higher traffic, and hence usage-dependent costs, typically associated with business lines. Secondly, one can reason that the value of the service is clearly higher to the business customer, as it serves as a direct link to his market and is capable of producing revenue for him. It is a Bell System objective to provide residence telephone service at the lowest possible cost to the customer so as to promote universal telephone service.

Individual/Party Line

A second distinction in local exchange service is that of individual and party lines. Individual-line service provides a customer with exclusive access to the serving central office, whereas party-line service may provide a single-access arrangement shared among two, four, eight, or more customers. Rates are highest for individual service, and they decrease for service with larger numbers of parties. Both cost and the value-of-service concept rationalize this rate progression.

Flat-Rate/Measured

Another major tariff distinction occurs between flat-rate and measured service. Flat-rate service provides local exchange service at a monthly rate independent of the customer's actual usage. There is a trend toward measured (or message-rate) service. Measured service usually provides a stipulated amount of outgoing local exchange usage (typically measured in message units) at a fixed rate. Any usage over this amount is charged for incrementally. The rate structure for this additional charging varies from locality to locality. It may be based on frequency, duration, or distance of calls or some combination of these measures; a time-of-day discount may be offered. For example, in Manhattan, regular message-rate service includes 50 message units without additional charge. Local calls to nearby areas are charged one message unit, regardless of the duration of the call. Local calls to more distant areas are charged two or more message units, with additional units charged for time in excess of an initial period. If the monthly sum of the message units exceeds the allowed 50, an additional charge is levied.

In some exchange areas, both flat-rate and measured services are tariffed, and the customer can choose between the two. However, in other areas, Manhattan for example, only measured service is available for business and residence customers.

One motivation for offering measured service is that the fixed charge component (i.e., the minimum payment) is usually less than the comparable flat-rate charge and hence acts as an inducement for low-usage customers to purchase telephone service, a socially desirable goal. The objective of providing exchange service on a measured basis, a form of usage-sensitive pricing, is to derive more revenue from those customers with higher usage who impose greater costs on the telephone network.

4.2.2.2 Toll Services

Traffic between two local exchange areas in the same state is called intrastate toll traffic and is under the regulatory jurisdiction of the state PUC. Traffic between areas in different states is called interstate toll and is under the regulatory jurisdiction of the FCC. Since the rate-making procedures for intrastate toll and interstate toll generally are similar, only the interstate case will be discussed in detail.

An important application of the value-of-service concept can be found in comparing the revenue/cost relationship between intrastate and interstate toll message service. Customers accept the principle that longer distance calls cost more than shorter distance calls. Under present tariffs, the revenue/cost relationship is better for long-haul messages than for short-haul messages. The basic reason for this is the per-circuit-mile cost advantage on long-haul, high-density routes as compared with short-haul routes. This arrangement, however, is troubled if for some reason the Bell System loses some long-haul message traffic, as in fact may occur. Although this problem will not be treated in depth, it should be noted that one area of competitive activity is long-haul point-to-point traffic, and the possibility exists of siphoning off some long-haul traffic from the Bell System public telephone network. The point is that there is a weakness in rate-averaging tariffing practices when viewed in the quasi-competitive light of specialized carriers selecting profitable routes and offering service at a lower price than the established carrier, who is using nationwide price-averaging.

The problem of determining individual message charges for interstate traffic, known as rating, can be appreciated by thinking of the output required. Any pricing technique used must be capable of simply and uniquely rating a toll message originating at any point in any one of the United States and terminating at any other point in any other state. The penalty for too complex a scheme can be appreciated by realizing that, in 1974, there were over 15,000 Bell System central office codes and over 10 billion long distance messages, each requiring a rating. To solve such a problem by considering each possible originating and terminating point separately would not be feasible. The rate-making technique in use first quantizes the problem and then removes particular location dependence. The quantizing takes place by assigning to each exchange area one (larger exchanges are further divided into zones) rate center. All toll traffic originating within the exchange is assumed to originate from the rate center, to which precise coordinates [called vertical and horizontal (V-H) coordinates] have been assigned. Similarly, terminating traffic is assumed to terminate at the distant rate center. A mathematical calculation on the coordinates of the two rate centers then is used to determine the airline mileage between the two points. All rating of individual calls then is accomplished by locating this mileage in a toll message rate table constructed with mileage intervals as one dimension.

This airline mileage method for rating toll messages, as compared with route-dependent rates, tends to increase the usage of the service by avoiding discrimination against those customers whose local switching equipment and toll routes would, on an individual rating basis, call for premium rates. A corollary to this rating plan is that toll message rates are bilateral; a call from Boston to Chicago costs the same as a similar call from Chicago to Boston, whereas the network facilities used might not be the same.

In addition to mileage, the parameters on which toll rates depend are type of call completion, time of day, day of week, day of year, and of course, duration of call. An example of a rate table, taken from FCC Tariff No. 263, is shown in Fig. 4-3. Rates generally are lower on weekends and during the evening and night hours of weekdays to motivate more uniform traffic loading in an effort to use the network more efficiently. Rates are lower for operator-handled station-to-station calls than for operator-handled person-to-person calls and lowest for direct-dialed calls, reflecting both cost and value-of-service considerations. Note that the Bell System has discouraged operator-handled calls with a "dial direct" advertising program. The motivation for this is to reduce the need for operator assistance and thereby help to avoid growth of the operator force as the volume of toll traffic increases.

4.2.2.3 Coin Telephone Services

The charging schedule for local calls placed from either public or semipublic coin telephones is the same. For long distance interstate messages, the rates (rounded to the nearest nickel) are the same as those for noncoin, operator-handled calls. For long distance intrastate calls placed from coin phones, some states have separate coin rate schedules. For local exchange calls from coin phones, a flat rate is charged except in a few locations that have measured service. The 10-cent rate has been prevalent since the early 1950s. The Bell System objective is to increase the rate for a local call from a coin telephone to 20 cents.

4.2.3 TARIFFS FOR VERTICAL AND COMPETITIVE SERVICES

When a decision, based on market studies, has been made to offer a new or revised service, a price for the service must be established. The Bell System approach to pricing vertical and competitive services differs from the approaches for local exchange service and toll service. It includes two important considerations: selecting the optimum price and testing for interservice subsidy.

The optimum price is one that will yield an optimum contribution to earnings and thus permit basic services to be offered at prices lower than would otherwise be necessary to meet overall earnings requirements. The optimum contribution is the largest contribution which is prudent or reasonably practicable, taking into account market conditions, prices of other services, and other factors.

AM. TEL. & TEL. CO. L. L. DEPT.
Adm. Rates and Tariffs
Bedminster, N.J. 07921
Issued: June 15, 1977

TARIFF F.C.C. NO. 263
14th Revised Page 26
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LONG DISTANCE MESSAGE TELECOMMUNICATIONS SERVICE

3. SERVICE CLASSIFICATIONS AND RATES [TWO-POINT] (Cont'd)

3.1 Intra-United States Mainland Service - Schedule I, United States Mainland - Alaska Service - Schedule IA, United States Mainland - Hawaii Service - Schedule IH and United States Mainland - Puerto Rico/Virgin Islands Service - Schedule IPV (Cont'd) (C)(x) (C)(x)

(C) Rate and Charge Application (Cont'd)

(7) Rate Table-Intra-United States Mainland Service - Schedule I

(a) Dial Station-to-Station, Operator Station-to-Station and Person-to-Person

	Initial Period			Additional Minutes	
	Day	All Days, All Hours		Day	
	Dial Station-to-Station	Operator Station-to-Station	Person-to-Person	All Classes of Service	
Rate Mileage	Initial 1 minute	Initial 3 minutes	Initial 3 minutes	Each Additional minute	
1-10	$ .19	$ .45	$ 1.45	$ .09	(I)(x)
11-16	.23	.60	1.60	.12	
17-22	.27	.80	1.80	.14	
23-30	.31	1.00	2.00	.18	
31-40	.35	1.10	2.10	.21	
41-55	.39	1.35	2.35	.25	
56-70	.41	1.60	2.60	.27	
71-124	.43	1.75	2.75	.29	
125-196	.44	1.85	2.85	.30	
197-292	.46	1.95	2.95	.32	
293-430	.48	2.00	3.05	.34	(I)(x)
431-925	.50	2.05	3.15	.34	
926-1910	.52	2.15	3.30	.36	
1911-3000	.54	2.25	3.55	.38	

(b) Rate Discounts and Application Periods #

	MON	TUES	WED	THUR	FRI	SAT	SUN
8:00 AM to *5:00 PM	Day Rate Period FULL RATE						
5:00 PM to *11:00 PM	Evening Rate Period 35% Discount						Eve 35%
11:00 PM to *8:00 AM	Night & Weekend Rate Period 60% Discount						

DISCOUNTS

Discounts apply to total charges for Dial Station-to-Station messages and to total additional minute charges only for Operator Station-to-Station and Person-to-Person with total fractional amounts rounded in accordance with (C)(3)(d) preceding.

* to but not including

(x) Filed under authority of Special Permission No. 8411 of the Federal Communications Commission.

Printed in U.S.A.

Fig. 4-3. Example of a Rate Table

In order to determine that a competitive service is free from cross-subsidy, it is necessary to assure that users of other services are not "burdened" by the provision of the competitive service.

The following paragraphs mention some aspects of the structure of tariffs for private lines and Business Customer Services.

4.2.3.1 Private Lines

Private lines may be either intra- or interstate. The interstate private-line tariff describes permitted uses and certain electrical characteristics and specifies rate structures for each of the private-line Series designations (see Table 4-1) and for DATAPHONE digital service.

Some intrastate rate structures are similar to interstate, but others differ in various respects. Private-line rates are typically independent of the amount of usage. The monthly prices generally have a component that is dependent on mileage and a terminal component.

Nationwide price averaging was long used so that services in low-density (high-cost) areas were priced the same as services in high-density (low-cost) areas. Competition for private-line services is primarily in the low-cost areas where a new company can offer service at prices substantially lower than prices based on nationwide averaging. This situation led to the Hi-Lo tariff filed by AT&T, Long Lines, in 1973, followed by the Multischedule tariff filed in 1976. These rate structures, applicable to Series 2000 and 3000 services for voice and voice-grade data, respectively, provided for lower prices on high-density routes than on low-density routes. High-density routes, usually connecting major cities, can take advantage of the large number of circuits to achieve a lower cost per circuit-mile. The intent of the Hi-Lo tariff and the Multischedule tariff was to reflect the difference in cost on high- and low-density routes.

4.2.3.2 Business Customer Services

Business Customer Services include several telephone services generally used in business environments as outlined in Section 4.1. The tariffing of only one of these services, PBX service, will be discussed.

PBX tariffs can be grouped historically into two categories: hardware and service. Hardware tariffs, which are older than service tariffs, refer to tariffing on the basis of the equipment used to provide the service. Although the customer purchases service, the rate actually depends on which pieces of equipment are used to provide the service. In this case, the rates for the additional service features that the PBX provides are based on the added equipment needed to provide the features. Traffic capacity depends upon the amount of equipment for which the customer pays.

Service tariffs, on the other hand, are written from a service point of view. They provide for stated lists of service features. The customer purchases the service comprising the number of lines and features required and is not directly involved in selecting the equipment.

PBX tariffs have come full circle from hardware tariffs to service tariffs and back to hardware tariffs. The return to hardware tariffs is motivated by customer attitudes. Customers are not restricted to the prepackaged groups of features, but instead are able to select features on an individual rather than a grouped basis.

The Two-Tier payment plan provides the business customer with an attractive alternative to conventional payment plans for terminal equipment products involving large capital investment and location lives of several years. Under the provisions of the plan, customers receive partial rate stability during an initial period, selected from among several options according to the customer's future expectations and financial circumstances. The rate paid during this period reflects the recovery of capital costs incurred and known at the time of installation in addition to the current operating expenses. After the expiration of the initial period, capital costs have been recovered and the rate is reduced to reflect only current operating expenses such as maintenance and property taxes. Since these factors are continually changing, the rate for the second period, or tier, is subject to normal adjustment through the regulatory process.

The principal advantages of the plan from the customer's viewpoint are the rate stability provided in the initial period and the rate reduction at the end of that period. The customer assumes an obligation to pay the full amount of fixed charges, and in the event that service is discontinued prior to the expiration of the initial period, is subject to a termination charge for the balance due less any credit granted on the basis of product reusability. Customers who do not desire Two-Tier payment have the option of conventional payment under a companion tariff.

4.2.4 TARIFFS FOR INTERCONNECTION

In its 1968 Carterfone decision, the FCC informed the Bell System that restrictions in tariffs that prohibited interconnection of private systems and equipments with the public telephone network were illegal and would no longer be permitted. This landmark case related to the acoustic interconnection of a private radio system with the public telephone network; however, its effects have been far-reaching. The FCC, in effect, ruled that interconnections would be permitted as long as there were no adverse effects on the telephone company's operations or on the utility of the telephone network to others.

4.2.4.1 Interconnection 1968-1975

FCC and state tariffs filed from 1968 to 1975 generally recognized three classes of customer-provided equipment: (1) equipment that had an electrical connection to the network through a protective connecting arrangement, (2) equipment that was acoustically or inductively coupled to the network, and (3) certain types of equipment for which a guarantee of technical integrity was made through "attestation" or "conformance".

Electrical Connection Through Protective Connecting Arrangements

Interconnected equipment with a direct electrical connection to the network generally was required to be connected through a device known as a protective connecting arrangement. The Bell System provided over 70 varieties of connecting arrangements. There were connecting arrangements for interconnecting voice and data equipment, station sets, and business customer equipment. Connecting arrangements provided protection of the network against voltages harmful to personnel, improperly balanced signals, excessive signal power, and interference with network signaling functions. Also stated in the tariffs were specifications (protective criteria) for the signal applied to the network. These specifications dealt with inband and out-of-band signal power.

Acoustic or Inductive Connection

Devices that were interconnected to the network by acoustic or inductive means were not required to use connecting arrangements. Specifications for inband and out-of-band signal power were stated in the tariffs.

Attestation

Certain relatively simple items of equipment, such as telephone headsets or nonpowered conferencing equipment, could be directly connected without a protective connecting arrangement through the attestation process. Prior to the connection of such equipment, the manufacturer had to submit a written request for an identification number to the telephone company attesting that the equipment complied with the standards and procedures set forth by the telephone company in its Technical References.

Conformance

Some customer-provided equipments that did not perform call-origination functions, such as call-answering equipments, could be connected directly to the telephone network without a protective connecting arrangement if the manufacturer met conformance requirements. Such equipment units had to include an authorized protective connecting module (APCM) manufactured according to Bell Laboratories specifications and were subject to quality inspection by the telephone company. The manufacturer had to submit a written request to the telephone company for a conformance number, attesting that the equipment, including the APCM, complied with the standards and procedures in the Technical References set forth by the telephone company.

4.2.4.2 The Registration Program

The FCC issued a series of orders in 1975 and 1976 to establish a registration program for all types of terminal equipment except coin telephones and terminal equipment for use on party lines. The objective was to permit direct connection of registered equipment to the public telephone network. Registration would certify that the registered equipment complies with technical specifications stated by the FCC. This program is in effect for data sets and for certain auxiliary terminal equipment such as answering sets and automatic dialers. However, a stay issued by the U.S. Court of Appeals in 1976 prevented the registration program from taking effect for other types of terminal equipment including telephones, keysets, and private branch exchanges. Resolution is in the hands of the courts, the FCC, and the state regulatory commissions. Bell System interstate tariffs have been revised to reflect the registration program.

4.2.5 RELATIONSHIPS OF TELEPHONE COMPANIES, LONG LINES, AND REGULATORY BODIES

Table 4-4 summarizes the regulatory responsibilities for several types of services. The ownership of facilities that are used to provide the services and the organization that deals directly with the customer also are indicated.

TABLE 4-4
EXAMPLES OF RELATIONSHIP OF SERVICE TO REGULATORY BODY, OPERATING TELEPHONE COMPANY, AND LONG LINES

SERVICE	REGULATORY ORGANIZATION	OWNERSHIP OF FACILITIES	ORGANIZATION DEALING WITH CUSTOMER
Local	State PUC	Telephone Co	Telephone Co
Intrastate Toll Call	State PUC	Telephone Co Long Lines	Telephone Co
Interstate Toll Call	FCC	Telephone Co Long Lines	Telephone Co
Intrastate Private Line	State PUC	Telephone Co Long Lines	Telephone Co
Interstate Private Line (Note 1)	FCC	Telephone Co Long Lines	Long Lines (Note 2)
Connecting Arrangement for Customer-Provided Equipment	FCC State PUC	Telephone Co	Telephone Co

Notes

1. If any part of a private-line traffic network is interstate, the whole network is considered interstate.
2. Long Lines bills the customer for certain station equipment, such as a data set or teletypewriter, but not for a PBX to which the private line connects.

REFERENCES

1. P. J. Garfield and W. F. Lovejoy, *Public Utility Economics,* Prentice Hall, 1964.
2. Tariffs filed by the Long Lines Department of AT&T with the Federal Communications Commission.
3. W. W. Betteridge, "A Realistic Approach to Pricing", *Telephony,* pp 48-54, July 14, 1975.

Part Two Networks

The objective of the following three chapters is to build a basic understanding of a range of subjects to bring out the way networks are structured, the functions involved in a network, and the fundamental plans that are necessary to make the parts work together as a whole.

Chapter 5 begins with a discussion of the reasons for switching, basic types of telephone switching systems, and switching functions. This leads to a discussion of the structure of traffic networks with emphasis on the public telephone network, the structure of the facility network, and the numbering plan for the public telephone network.

Chapter 6 presents some transmission fundamentals; signals, channels, media, modulation, and multiplexing are reviewed; and transmission plans are discussed.

Network functions other than switching and transmission are described in Chapter 7. Signaling functions and techniques are considered. The concept of interfaces and their functions in networks are discussed. Operator functions and force considerations are reviewed.

5 Network Organization

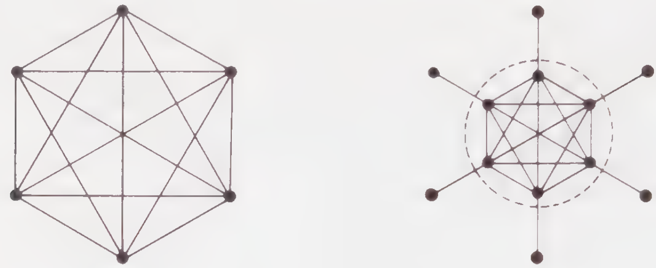
This chapter deals with several aspects of the organization and structure of networks. It starts with a brief introduction to switching, the basic types of switching systems, and their functions. The structure of local and toll portions of the public telephone network, the largest traffic network, is then described, and related traffic engineering considerations are introduced. The structure of the facilities network is described in terms of local, exchange area, and toll facilities. Examples are shown in each category. The chapter concludes with a description of the numbering plan for the public telephone network, which is another aspect of network organization and is closely related to the traffic network structure.

5.1 THE ROLE OF SWITCHING SYSTEMS

5.1.1 REASONS FOR SWITCHING

Consider a rudimentary telephone system serving six homes represented by the black circles in Fig. 5-1(a). This system would require 15 wire pairs (shown as solid lines) interconnecting the homes to provide full access to each phone by every other phone. In addition to the telephone instrument itself, each home would need a dc power source, a switching device to choose with which of the other five it connects, and some means of summoning an answer on the distant phone (such as by ringing a bell).

One disadvantage of such an arrangement is the large number of long wires needed; to fully interconnect N homes in this fashion, (1/2) N(N-1) wire pairs would be required. Fig. 5-1(b) shows a more economical scheme. Each home needs just one wire pair, which is shared by calls to or from the home. The 15 original lines in Fig. 5-1(a) have been shrunk to short connections in a centrally located telephone office, denoted by a dashed circle. Note that the switching devices (the smaller black circles) are no longer in the homes, but inside the central office. This adds a complication in that some way must now be provided for the customer at home to operate the switch remotely. On the other hand, the switching apparatus, being all in one place, may be combined and shared among the users, since all of them will not need it at one time. Similarly, dc power can now be provided from a central source, and bell-ringing apparatus can be shared.



(a) (b)

Fig. 5-1. Telephone System Configurations

The earliest remotely controlled switch was, of course, the manual switchboard operator, who received verbal instructions from the customer. To improve the economy and speed of telephone service, manual switchboards have been replaced by automatically controlled switching networks. These switching networks perform the basic connecting function in a switching system, using, for example, crosspoint arrays such as that shown in Fig. 5-2. Each black dot on the array represents a point at which a connection may be made between the horizontal and vertical wires that cross there. The 15 different crosspoints allow all possible combinations of connections between pairs of homes, corresponding to the 15 short lines in Fig. 5-1(b). Chapter 9 will examine the inner workings of switching systems in more detail.

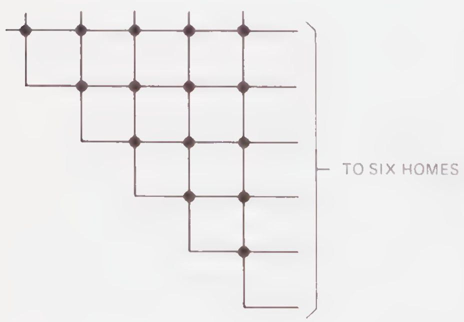


Fig. 5-2. A Crosspoint Array

It is clear that the first basic job of a switching system is to interconnect calls as economically as possible. This includes connections not only between customers' lines, but also between line and trunk or between trunk and trunk, as illustrated in Section 2.2 and described further in Section 5.2. Switching systems concentrate traffic from lines onto trunk groups and distribute traffic from trunk groups to lines. Traffic that comes in on trunks and goes out on trunks is similarly concentrated and distributed. Switching systems also perform alternate routing. These concentration, distribution, and alternate routing capabilities are needed to permit efficient use of trunk groups.

5.1.2 TYPES OF SWITCHING SYSTEMS

Relating to traffic networks, three types of offices are described in Section 5.2: local, tandem, and toll. The local or end office switches a number of customer lines, connecting them to other lines or to trunks. Since a typical line provides a small amount of traffic, the switching network may have a relatively large number of terminations to serve a great many lines for a given traffic capacity. Tandem and toll offices switch trunks, which are usually much busier than lines. Thus, for a given volume of traffic, there would be fewer trunks than lines, and the switching networks for tandem and toll offices would have relatively fewer terminations than a local switching office.

If the total traffic volume in an area does not justify separate tandem or toll systems, these functions may be performed in a portion of a local switching system. For instance, several small local offices may home on a larger local office. Part of the switching network in the large office is then equipped for trunk-to-trunk switching in a combined local-tandem-toll operation.

The Customer Switching System is a special kind of switching system dedicated to the use of a single customer who has a number of telephones. Typical examples are PBX and key telephone systems. These are described further in Section 12.3.

Two kinds of switching systems simply connect an input to any output that is idle. The first, a concentrator, might combine the traffic from 100 lines onto 20 transmission paths to make more efficient use of outside plant. The second kind, a call distributor, connects any call from a line or trunk, for example, to any idle server. Thus, a business that employs many attendants to answer a large volume of calls could use a call distributor to give each call access to all attendants. This kind of call distributor is described further in Section 12.3.

5.1.3 BASIC SWITCHING FUNCTIONS

The preceding sections described the basic connecting function of a switching system. This section defines six additional functions that were implied by the basic connecting function, but not specifically stated. Some of the many auxiliary functions of switching systems also are listed.

Six functions implicit in the basic connecting function are:

(1) *Alerting*—Signaling a change of state; for example, a customer going off-hook to originate a call or a switching system ringing the called party.

(2) *Attending*—Monitoring for the response to a change of state; for example, the ability to recognize customers going off-hook and signals over trunks from other offices.

(3) *Information Receiving*—Accepting instructions for call handling from customers or other switching systems; for example, receiving dialed digits.

(4) *Information Transmitting*—Sending information for call handling to other offices. Sending digits is an example.

(5) *Busy Testing*—Testing lines or trunks for a busy condition before any switching path is established. The reason for busy testing is, of course, to ensure privacy.

(6) *Supervising*—Monitoring a talking connection for a disconnect signal from either end. Supervising differs from attending in that supervising occurs after a connection has been established.

Some of these six items involve activities at the station as well as in the switching system, and most involve the interchange of information, which is known as *signaling.*

The auxiliary functions (i.e., those that are subsidiary to the basic connecting function) can be classified as functions relating to:

(1) Customer services.

(2) Operational features.

Some examples of functions associated with customer services are:

(1) Routing a call for a nonworking number to an intercept operator.

(2) Returning deposited coins at a coin telephone when the called party does not answer.

(3) Routing a call to a line other than the one dialed, under certain circumstances.

(4) In centrex service, identifying the calling line on outgoing calls for billing purposes.

Functions associated with operational features include recording traffic data, recognizing and recording trouble conditions, carrying out alternate routing, and providing billing information. Billing information is recorded by automatic message accounting (AMA) apparatus, either at the local office (LAMA) or at some central location such as a tandem office (CAMA). In the CAMA case, the calling number may be determined either by an operator or by automatic number identification (ANI) apparatus at the local office.

5.2 STRUCTURE OF TRAFFIC NETWORKS

Although there are many traffic networks, this section focuses on the largest and most complex, the public telephone network (PTN). Network structure will be described in terms of the structure and nomenclature of the PTN. The description starts with a local network and progresses through the nationwide toll network. A brief explanation of why the structure for each of these networks was chosen is included.

For simplicity, most of the discussion assumes a time-snapshot of the structure of the PTN, but it should be recognized that a very important characteristic of this network is its explosive growth rate. As a practical matter, design work on the PTN is work on growth and rearrangements. To give some insight into design work and to acquaint the reader with networks other than the PTN, there is a brief discussion of design considerations and tradeoffs. A more detailed approach to some of the aspects of network design is given in Chapter 14.

5.2.1 THE PUBLIC TELEPHONE NETWORK

5.2.1.1 Local Networks

Chapter 2 discussed a call involving several switching offices. Fig. 5-3 shows a simple local network that would handle such a call. Now, efficiency in the use of trunks and the resulting network structure will be discussed.

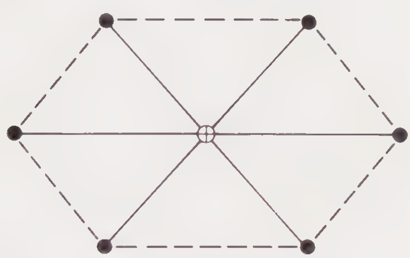


Fig. 5-3. A Simple Local Network

The trunks between a pair of offices act as a group of servers handling the total traffic between the offices. When the traffic is large, so is the trunk group, and it can be engineered to have a low blocking probability without sacrificing efficiency; that is, the average utilization of the trunks will be high[1]. This is not the case, however, where point-to-point traffic is low. The resultant problem of small, inefficient local trunk groups may be solved by additional sharing in either of two ways.

1. See Chapter 14 for a derivation of trunk blocking formulas. An illustration of trunking efficiency as a function of blocking and group size is given in Section 5.2.2.2.

In Fig. 5-3, the solid circles represent central offices serving customer loops, and the hollow circle stands for a tandem office (which also might be the central office for some group of customers). Many small parcels of traffic between a given office and several others can be pooled into a big parcel of traffic on one large tandem trunk group (indicated by a solid line) connecting the given office to the tandem office. At the tandem office, the parcels are distributed via the other tandem trunks to the other offices to complete the connections. The term "tandem" denotes that the call is routed through two or more successive trunks between offices. The overall probability of blocking for a customer making a tandem call is approximately the sum of the blocking probabilities for the trunk groups and other apparatus along the tandem calling path.

A more sophisticated solution to the problem of small trunk group inefficiency can be obtained by the technique of alternate routing described in Chapter 2. The dashed lines in Fig. 5-3 represent direct trunk groups joining certain pairs of offices. The cost of a direct trunk is less than that for two tandem trunks and their tandem office apparatus. If a small group of direct trunks is engineered to work efficiently (that is, to operate at a high average load per trunk), many calls will find all trunks of the group in use during busy periods. In this arrangement, a call is offered first to the direct group, and, if that is busy, it is then alternate-routed to the tandem office.

The direct trunks in this scheme constitute a high-usage group, and the tandem trunks form a final group. In general, the term "final" applies to whichever group is the last alternative in routing a call from an office to some particular destination. A final group must be engineered to have sufficiently low blocking to ensure a satisfactory quality of service, usually 1-percent blocking on the final groups during the busy hour.

When the number of central offices is large, it may be advantageous to group central offices in sectors, each served by a different tandem office located near the center of its sector. This shortens the total length of tandem trunking, particularly if there is a greater community of interest within each sector than between sectors. The penalty is that some calls may now require three consecutive tandem trunks to complete and may encounter additional delay in setup.

More complicated routing choices appear in the sector tandem scheme, as, for example, with the two sectors shown in Fig. 5-4. A call from office A to office B is offered first to a direct high-usage group to B, if such a group is present. (High-usage groups are shown as dashed lines.) If that is busy, the call is offered next to the high-usage group to tandem office C, if such a group is present. If that is busy, the call is routed to the (solid) final group to tandem office D and offered to a high-usage group from D to B, if such exists. When that is busy, the call is routed through final groups to C and thence to B. Thus, there is one try to make a one-trunk connection, two tries for a 2-trunk path, and, when all else fails, the 3-trunk final route is used. Note that at least three different trunk groups must be busy before the call itself becomes blocked.

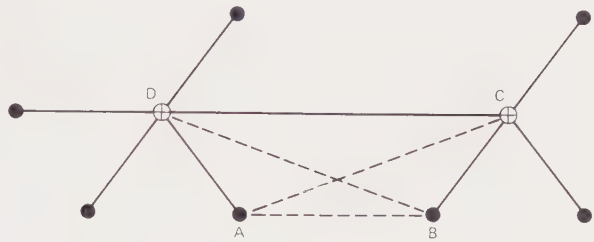


Fig. 5-4. A 2-Tandem Local Network

The matter of a busy trunk group has been emphasized, and little has been said about a busy switching system. In general, a path through a switching system costs less than a trunk, and so it makes sense to engineer the switching systems "more liberally" than the trunks. However, in well-designed networks, blocking sometimes does occur in switching systems.

5.2.1.2 The Toll Network

The economic and service considerations leading to the local network structure described in Section 5.2.1.1 apply even more strongly to the toll network. Routing is more complex, and some of the elements of cost are larger.

The program followed by offices in the toll network is the automatic alternate-routing scheme already outlined. For a toll call to any particular destination, each office has a prescribed list of high-usage groups that it tries in a specified order. As a last resort, it typically tries the final group or, in some cases, another kind of trunk group, called a *full group*, from which overflow is not permitted. (The definition of and rationale for full groups will be found in Section 5.2.2.2.) When all listed options are busy, so that the call cannot be forwarded, a reorder signal is returned to the customer.

Most local networks in metropolitan areas have two levels in their hierarchy: central offices and tandems. The toll network, however, has a 5-level hierarchy, as shown in Fig. 5-5. In the Bell System, there are about 9900 class 5 end offices serving customer loops, with many more belonging to independent telephone companies. Each end office homes on a class 4 toll center (which also may serve as an end office itself), although sometimes end offices may home directly on offices of class 3, 2, or 1. The home office is that to which the final groups lead, as indicated by solid lines in the figure. If the end office is not equipped for alternate routing and toll billing, any toll traffic must be sent directly to the toll center, or higher office, on which it homes.

About 800 Bell System toll centers home on 230 class 3 primary centers, 67 class 2 sectional centers, and ten class 1 regional centers. The primary centers home on class 2 and class 1 offices. Sectional centers home on the 10 regional centers, which are fully interconnected by final trunk groups. Note that a

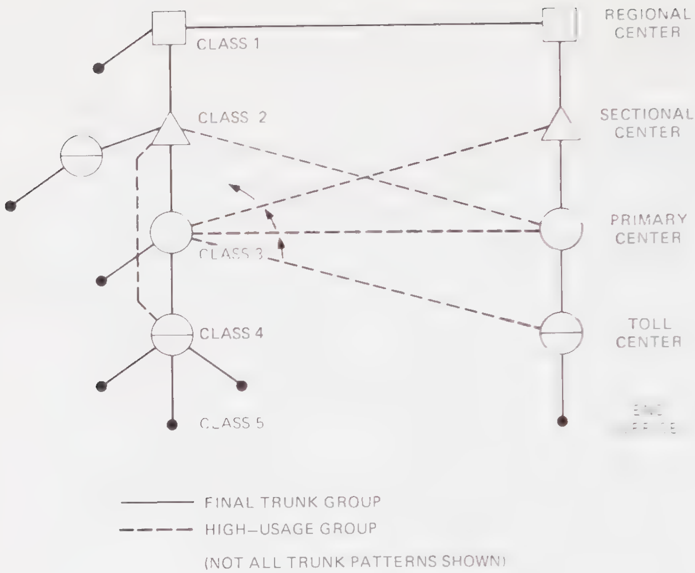


Fig. 5-5. Nominal Toll Network Pattern

class 5 office is the lowest class in the hierarchy, and a class 1 office is the highest class. Keeping this numbering anomaly in mind, it can be seen that the class of any toll office is numerically one less than that of the highest class (lowest number) office that homes on it. This formal network structure assures that the longest calling path (the "backbone" route of final trunks) will not contain more than nine trunks in tandem.

Traffic between distant end offices is often small, and long direct trunks to serve this traffic would be quite expensive. Successively higher offices in the toll hierarchy concentrate such traffic by combining it from larger and larger geographical areas as it moves up the finals. Typically, offices in a homing chain (shown as a vertical column in Fig. 5-5) are relatively near each other. Indeed, the choice of where to home an office might be made to minimize the length of the final group. Many final trunk groups are no more than a few miles long. The final and high-usage trunk groups joining the two columns in the figure are the long-haul trunks of the toll network. These are placed high enough in the hierarchy to have sufficient traffic to operate efficiently.

Fig. 5-5 shows a few high-usage groups as dashed lines. Network rules encourage their installation between offices of the same class or differing in class by one. When there is enough traffic between two such offices, it becomes less expensive to put in high-usage trunks than to send the traffic by some roundabout path. If the traffic is very large, a full group may be used. Full and final groups in the toll network are presently engineered to a 1-percent blocking probability.

The basic rule for routing a toll call is to complete the connection at the lowest possible level of the hierarchy, thus using the fewest trunks in tandem.

To this end, the call passes up its homing chain, with each office searching for an available trunk in high-usage groups to offices in the distant homing chain (from lowest distant office to highest, as indicated by arrows), before overflowing up the final group. At the terminating chain, the call passes down its shortest route to the desired end office. Each regional center may have several 4-level chains of offices homing on it through sectional centers. Calls between two such chains would be routed by the same strategy as above (and so on down).

At this point the reader may wonder how local networks (described in Section 5.2.1.1) and the toll network fit together. There are many ways, three examples of which are:

(1) A single office may perform dual functions as a tandem for local traffic and as a class 4 toll center for toll traffic.

(2) Each end office may segregate traffic, sending local traffic to the tandem and toll traffic to the toll center. This option requires more trunking and is, in general, more costly. It may be necessary, however, if the end offices cannot perform billing functions.

(3) An asymmetric combination of the above may be used, in which outgoing toll traffic is routed via the toll center (for billing) but incoming traffic is routed directly from the primary center to the local tandem office for distribution to the end offices.

5.2.2 TRAFFIC NETWORK ENGINEERING CONSIDERATIONS

Although the detailed engineering processes that provide a traffic network to meet the demand are beyond the scope of this section, the following paragraphs present some examples of factors that influence the network configuration.

5.2.2.1 Customer Calling Patterns

Efficient use of hardware through sharing is basic to keeping costs low. In a traffic network such as the PTN, designing and arranging for efficient use of elements which are used first by one customer and then by another require knowledge of the expected traffic. As will be seen in Chapter 14, calling patterns are used to configure the PTN on a time scale ranging from years (for construction) to minutes (for network management).

Since a traffic network must be established to handle the traffic offered, the network designer must know how much traffic to expect and how it will be distributed in time and across the network. When designing a new network, the traffic must be forecast or estimated. For an existing network, necessary additions can be designed by making traffic measurements and then by making projections from these. (See Chapter 14, "Traffic".)

Calling patterns vary with the time of day. The volume of business calling reaches peaks in the mid-morning and afternoon, exceeding the daytime average by perhaps 30 percent, while residential calling may peak in the evening. Where distances permit, costs are reduced by arranging to share equipment between business and residential calls. The PTN is engineered to provide satisfactory service during typical peak busy hours of average busy days.

A traditional unit for describing the usage of channels or equipments is CCS, which stands for hundred call-seconds per hour. A typical trunk, for example, might carry 20 CCS in the busy hour. Since there are 3600 seconds in an hour, it would be in use 20/36 = 0.56 or 56 percent of the time, its load then being described as 0.56 Erlangs of traffic. A typical residential loop, however, might average 2 CCS in the busy hour, only one-tenth the usage of the trunk. A typical business customer might provide 5 CCS of traffic, and a reasonable average figure over all loops would be 3.5 CCS of busy-hour traffic.

The average duration or holding time of calls is measured in seconds or minutes. Local calls average about 160 seconds and toll calls 200 seconds per attempt, but this can be misleading. The measurements include calls that are not answered, reach a busy line, are abandoned by the caller, or otherwise fail. These incomplete calls represent perhaps one-third of all attempts. If these are assumed to be very short, holding times for completed calls could be in the vicinity of 240 seconds local and 300 seconds toll. For long distance toll calls of 1000 miles or more, the average holding time is still longer, with an average of 7.8 minutes, or 470 seconds.

Average holding time per attempt is the quotient of the traffic (in CCS) and the attempt rate. Hence, the trunk carrying 20 CCS could have 12.5 local or 10 toll attempts, and the average loop with 3.5 CCS, 2.2 attempts in a busy hour. The importance of characterizing traffic with two parameters, attempt rate and CCS, stems from the need to estimate load in different portions of the traffic network. Some parts of the network, such as trunks, are used for the duration of each call, so their capacity is specified in CCS. Other parts, such as operators or billing equipment, may act for a short time only (at the beginning or end of a call) and then be free to handle other calls, so their capacity is specified in attempts.

In general, the load on an end office can be determined by the number of customers of each type and their average usage in CCS and attempts.

The loads on tandems and all other intermediate offices and the numbers of trunks required between offices depend on the actual traffic distribution, which must be obtained by measurement. Switching system attempts and trunk-group CCS normally are monitored on a routine basis. Additional traffic distribution data also are obtained from analysis of toll billing records.

5.2.2.2 Trunking Design

A traffic network must be designed to carry the traffic, but also must be designed to operate efficiently. One important aspect of this is trunking efficiency. This may be defined as the average busy-hour utilization of the trunks provided.

Because of the random nature of offered traffic, it is necessary to provide more equipment than will be needed to match the average traffic load unless very high blocking is permitted. In fact, because the average is exceeded about one-half the time, such a design would block 50 percent of the attempts. Since calls are blocked only when all trunks are in use, it follows that the probability of all trunks being busy decreases as a function of group size, even though the load per trunk (that is, the probability of each individual trunk being busy) remains constant. This result, which is obtained more rigorously from the Erlang B blocking formula, is illustrated in Fig. 5-6. Note that the curves are plotted in two ways as an aid to understanding the relations.

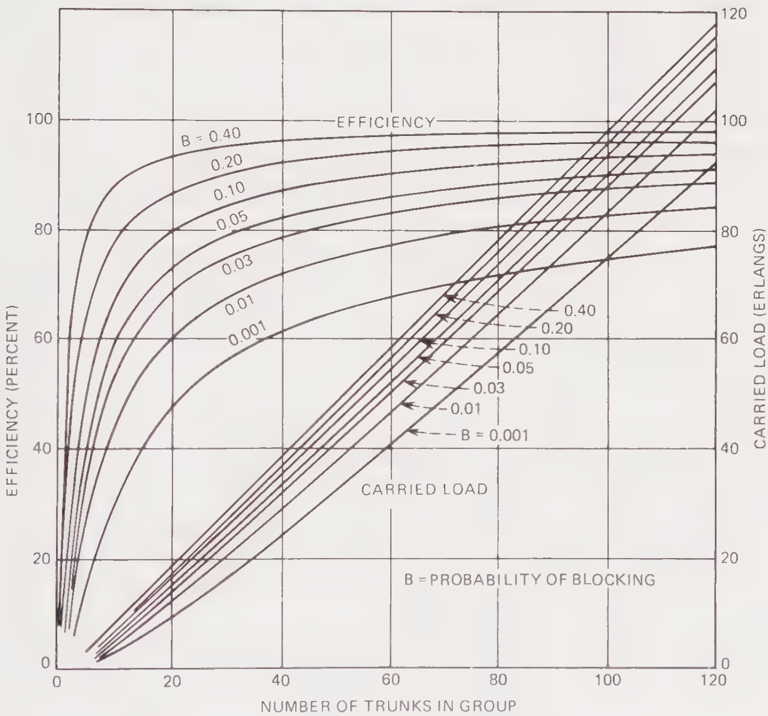


Fig. 5-6. Carried Load and Efficiency as Functions of Trunk Group Size (for First-Choice Routes)

As can be deduced from this figure, very significant gains in performance can be achieved by combining traffic via tandems and by employing alternate routing. Alternate routing employs high-usage groups operating at a high overflow level and carries the overflow calls over final groups. The final groups also can operate efficiently, since many small parcels of traffic from different sources may be carried. Lest the reader be misled, it should be noted that the characteristics of overflow traffic (greater variability than first-routed traffic) limit the efficiency of overflow routes. Further discussion of this topic is included in Chapter 14.

A final point may be made regarding efficiency and alternatives in trunk system design. Once a high-usage group has been established, traffic growth may be accommodated either by increasing the size of the high-usage group or by allowing more traffic to overflow, thus increasing the size of the final route. Adding trunks to the high-usage group is usually cheaper and preferable. This process will make the high-usage group larger and more efficient. At some point (when this group has grown to the order of 20 trunks) it may become desirable to make it a full group; that is, a trunk group from which no traffic is alternate-routed. This prevents large volumes of traffic from going up the hierarchy, thus protecting final-route traffic (some of which may have no other choice of routes) from being swamped by potentially large overflows from the larger high-usage trunk groups. Full groups are designed to provide no more than 1-percent blocking in the nominal busy hour.

5.2.2.3 Tradeoffs Between Transmission and Switching

In many practical situations, the network designer may be faced with the possibility of a tradeoff between providing more switching equipment or more transmission paths to provide a given service at minimum cost.

The most common instance of this tradeoff is *concentration* (mentioned in Section 5.1). Here, switching is used to reduce the number of transmission channels necessary to provide a given service. This principle is applied extensively in the PTN. It might be asked, "Can things go the other way, with transmission used to save switching?" As traffic grows, this might become a reality. In fact, there is already growth in the number of high-usage groups, and the time may come when most class 2 offices will be interconnected and most class 1 offices will no longer be needed.

When one expands his view to encompass all the voiceband traffic served by the Bell System, it appears that some traffic patterns are better served on networks other than the PTN. For example, when there is enough traffic between a pair of points, a private line without switching may be the best traffic network. There are a great many so-called multipoint traffic networks in which each network is a single private line reaching several different locations of the customer. Here the switching (if there is any) is rudimentary and is performed on customer premises.

Another tradeoff involving an alternative to the PTN can be found in tie-trunk networks. A call from the Bell Laboratories Holmdel location to the Whippany location on a tie line uses no switching equipment other than the central office systems that provide centrex service to the two locations. Because the cost of switching is thus minimized, this kind of scheme can prove economical, even though the cost of transmission may be more than on a PTN call. (The cost of transmission may be more because the tie line may not be as well loaded with traffic as PTN transmission channels, and the cost of administering a special channel may be higher.) Thus, as compared with the public telephone network, a tie-line arrangement may involve more cost for transmission, less cost for switching, and a net saving.

A case of using transmission to save switching is the foreign exchange (FX) line. Even though the line may be lightly loaded as compared with PTN trunks (and thus the transmission cost per call may be higher), switching costs are lower because fewer offices are involved in a call.

A form of network sometimes used for data is called *store-and-forward.* One purpose of storage of messages in the switching center is to smooth out traffic peaks and thereby permit very high utilization of transmission channels. One penalty is the delay of some messages. In the past, Bell System offerings in this field have been limited to private systems. One of the motivations for using a store-and-forward system is to save transmission, which is accomplished through the addition of storage capability to the switching equipment.

As noted in Section 5.2.2.1, the handling of traffic can be viewed in terms of the attempts and the holding times. The cost incurred in handling a call in a switching system like No. 5 Crossbar or No. 1 ESS can be divided into two parts. The first is the cost of establishing the call (which briefly involves complex computer-like equipment) The second is the cost of holding the call (which involves relatively simple switches and logic circuits). As a result, there is a fairly substantial cost just to reach a destination, even if it turns out to be busy. It can be seen that very short calls will incur a cost that is a great deal higher per second of communication than for calls of ordinary length. Thus the growth of traffic consisting of short calls, such as certain types of reservation and credit-checking calling, introduces new considerations for network design and tariff structure.

A recent and quite remarkable example of the use of switching to save transmission is the high-capacity mobile telecommunications system being developed. Radio channels are, of course, in short supply. The system will use switching to achieve utilization of radio channels that increases by 10 to 30 or more times what can be obtained without switching.

In summary, network designers have used, and will continue to use, various combinations of switching and transmission to tailor traffic networks to traffic patterns and to minimize costs.

5.3 STRUCTURE OF THE FACILITIES NETWORK

The traffic networks, including the public telephone network and private networks, are made possible by a network of communications facilities. The elements of the facilities network, that is, station equipment, transmission facilities, and switching facilities, were introduced in Section 3.5. Station equipment is located on the customer's premises, and the amount and type of equipment are dictated by the services that an individual customer elects to order. This section will focus on the network structure of transmission and switching facilities, which are shared by customers.

Detailed discussions of the systems that make up the facilities network appear in subsequent chapters. For now, it will be enough to mention the broad categories of communications facilities that exist today. In the transmission category, there are cable, analog and digital cable carrier systems, radio systems, coaxial cable systems, and satellite systems. The switching category includes Step-by-Step, Crossbar, and Electronic Switching Systems. Open-wire transmission facilities and Panel switching systems, although not completely extinct, are not a significant part of the modern facilities network.

The structure of the facilities network is governed by a number of factors, including the location of the customers, performance objectives, the available communication technologies, the cost and availability of land, and the need for redundancy in the network as a protection against disasters. A factor of special importance is the economy of scale associated with the set of available transmission facilities. In utilizing this economy of scale to minimize the network cost, required circuits are routed so as to build up large cross sections rather than being routed on shortest-distance paths which tend to spread the circuits over more and smaller facilities.

The notion of economy of scale relates to the set of available facilities that can be installed. Specifically, it means that the larger the facility size (ultimate capacity), the smaller the unit cost when completely filled. For example, a microwave radio system with a 16,500-circuit capacity has a unit cost of about $2 per circuit-mile, whereas a waveguide system having a 459,648-circuit capacity may have a unit cost of about $0.80 per circuit-mile. As a result, one can see that significant savings can be achieved if many required circuits are funneled together to efficiently utilize a large facility, rather than each being handled on a more direct route with a smaller facility.

The structure of the facilities network is quite complex and can best be discussed in terms of three separate levels:

(1) Local facilities.

(2) Exchange area facilities.

(3) Long-haul facilities.

These levels correspond to the three classes of transmission facilities: loop systems, exchange area systems, and long-haul systems as defined in Section 3.5, with the associated switching facilities.

The significant aspects of each of these levels will be discussed, including the general type of facilities used. Examples of the network structure will be illustrated with facilities maps. Also discussed will be a subclass of the facilities network, the digital facilities network, which is becoming a reality with the introduction of new digital transmission and switching systems.

5.3.1 LOCAL FACILITIES

Local facilities are the local switching systems and the loop systems through which customers are connected to the central offices. Fig. 5-7 is an illustration of the local facilities network structure for an urban area. Feeder networks extend from a central point, known as a *wire center,* and fan out in a tree-like manner into the serving areas associated with the wire center. Several feeder routes may be associated with a wire center; only one is shown in detail in Fig. 5-7. This loop network topology consolidates transmission facilities to achieve economies of scale. One or more local switching systems are located at the wire center.

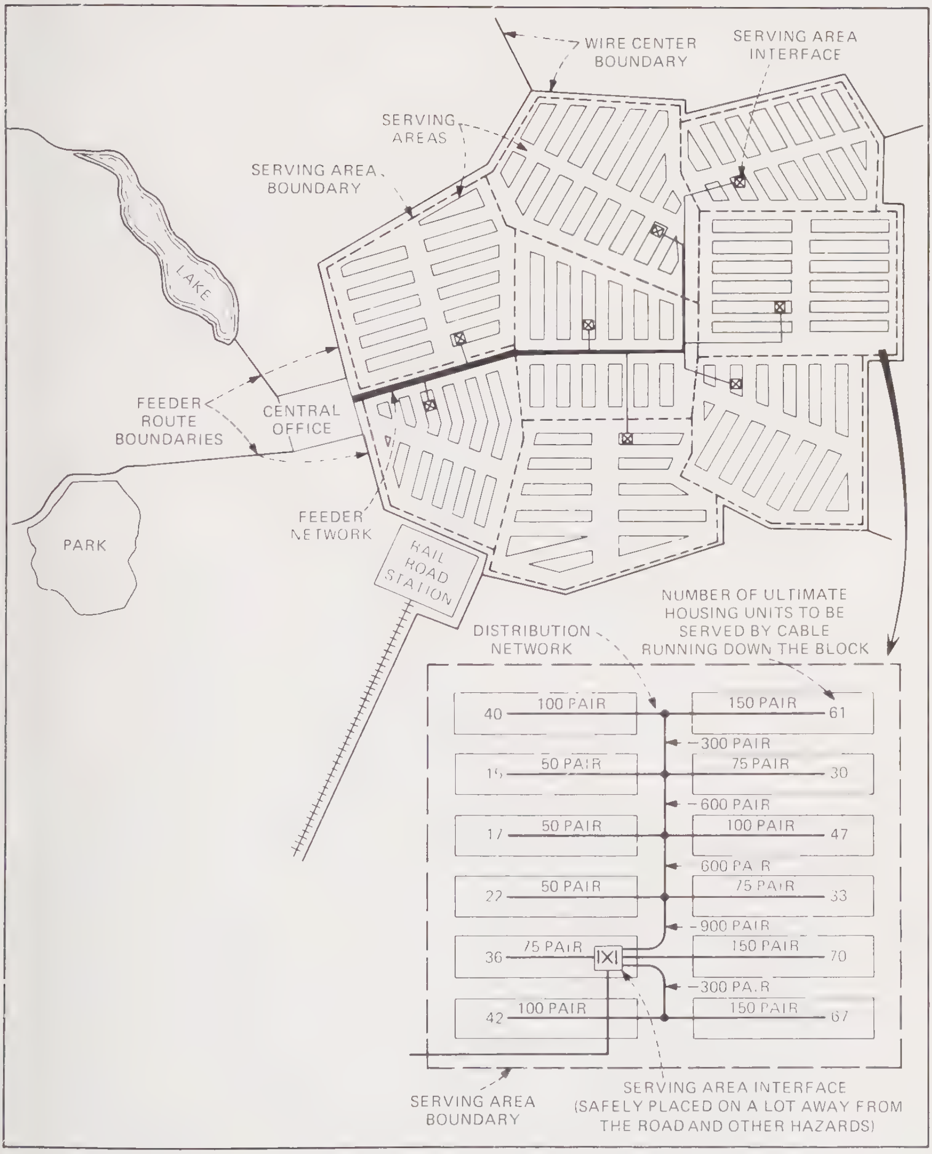


Fig. 5-7. Local Facilities Network Structure

Multipair cable, along with the associated splices, terminals, and conduit systems, is the primary type of facility in loop transmission today, although open wire is still in use in some rural areas. Subscriber carrier and concentrator systems also are beginning to play a significant role. Loop transmission systems will be discussed in more detail in Section 10.1. Step-by-Step, Crossbar, and Electronic Switching Systems, all discussed in Chapter 9, are used for local switching. The size of the switching system depends on the number of customers in the area served and on the area's growth rate. The type of system is determined by characteristics of the area served, the era in which the system was installed, and, to some degree, the policies of the operating company.

Table 5-1 provides a quantitative view of wire centers in the urban, suburban, and rural environments. The table lists the average values of some parameters of the facilities network on a wire-center basis. It gives an indication of the number of loops and trunks terminated at a wire center and associated with the public telephone network; the trunks are provided on exchange area facilities, which will be discussed in the following section. Additional circuits are provided, of course, for private services.

TABLE 5-1
AVERAGE WIRE-CENTER PARAMETERS
FOR THE PUBLIC TELEPHONE NETWORK

PARAMETER	URBAN	SUBURBAN	RURAL
Number of Entities	2.3	1.3	1.0
Area Served	12 sq mi	110 sq mi	130 sq mi
CCS/MS*	3.1	2.7	2.1
Intracalling	31%	54%	66%
Working Lines	41,000	11,000	700
Trunks	5000	700	35
Trunk Groups	600	100	5

* Hundred call seconds per main station.

In densely populated urban areas, the number of loops, or lines, and the quantity of traffic that must be handled by a wire center often exceed the capacity of a single switching system. Moreover, because of the limited availability and high cost of urban land, there is a tendency to expand existing wire centers rather than to create new ones. Thus, the urban sector is characterized by large, multisystem wire centers which sometimes contain both Crossbar and Electronic Switching Systems. A suburban wire center, on the other hand, generally requires no more than a single Crossbar or Electronic Switching System. Rural areas are most often served by small, unmanned, Step-by-Step or Crossbar community dialing offices (CDOs).

The average area served increases as we move from the urban to the rural environment. Although greater switching economy might be achieved in rural areas by serving even larger areas, the low loop-resistance limit of the CDO without loop electronics tends to limit the size of the area served.

Approximately 85 percent of the loops served by a rural CDO fall within what is known as the *base rate area.* The base rate area, which is defined in a tariff and beyond which customers pay higher rates, typically includes those customers located within 2 miles of the wire center. The average length of those rural loops that extend beyond the base rate area greatly exceeds the overall rural average. Many of these loops require range extending equipment as described in Section 10.1.

Calling patterns also vary uniformly as we go from rural to urban areas. The quantity of traffic per main station increases, and there is a corresponding decrease in the percentage of intraoffice calls. This aspect of traffic is reflected in the facilities provided. The number of lines per trunk decreases from 20 in rural wire centers to 16 in suburban wire centers and to 8 in urban wire centers. Also, the trunk-group size tends to be larger in the urban sector. Note that trunk-group size is a traffic network aspect discussed here for background and completeness.

These wire-center statistics illustrate how such factors as geography and population density affect the structure of the facilities network at the local level. As will be seen, these factors are significant at the exchange and long-haul levels as well.

5.3.2 EXCHANGE AREA FACILITIES

The exchange area level of the facilities network is intermediate between the local facilities network structure and the long-haul facilities network structure, which will be described in the next section. It can be thought of as a network consisting of local and tandem switching systems and the transmission systems, of the types ordinarily used to provide relatively short trunks, that tie them together.

Fig. 5-8 and 5-9 are maps of the exchange facilities networks of downtown Chicago and of the Greenwood district in Mississippi. The locations of wire centers and the routes of principal exchange transmission systems are shown. These examples represent two extremes of exchange facilities network structure. The number and types of facilities, as well as the topological structure of the network, vary considerably between the two extremes.

In Chicago, the network has a grid structure following the street pattern. Voice-frequency transmission on cables and digital carrier systems on cables are employed in the Chicago exchange network. Most of the cables are in conduit. Digital carrier is used in transmission spans whose length exceeds a threshold ranging from 6 to 16 miles, depending on economic considerations. A route section may contain both voice-frequency and digital carrier on cable and may have a total cross section of over 20,000 channels. The Chicago exchange network also includes tandem switching systems; their locations are indicated in Fig. 5-8.

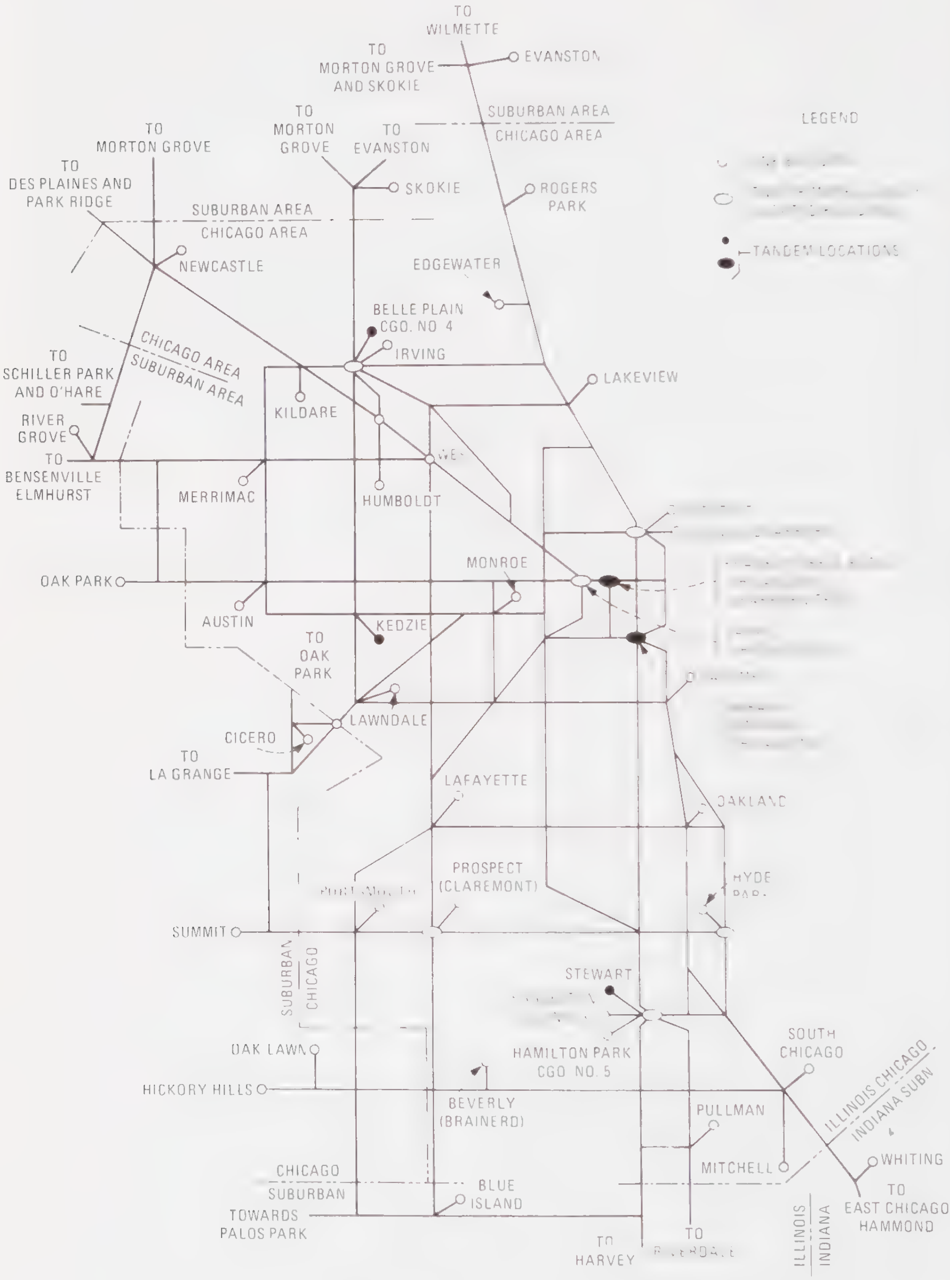


Fig. 5-8. Exchange Facilities Network—Chicago Area

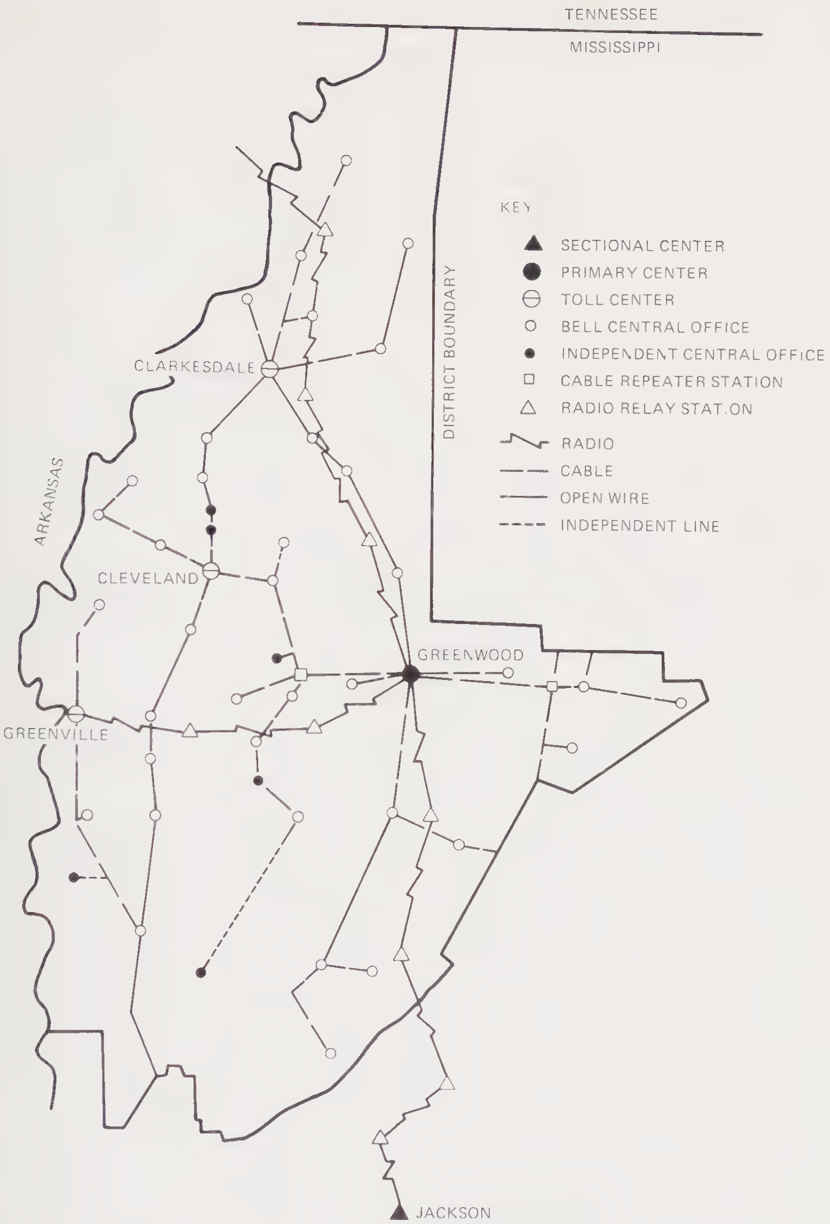


Fig. 5-9. Exchange Facilities Network—Greenwood, Mississippi District

In the Mississippi example, there is less of a distinction between exchange facilities and long-haul facilities. The Greenwood district is reasonably analogous, however, to the Chicago example. In comparison with Chicago, the Mississippi network has more of a tree structure, with transmission facilities following major highways. In a sparse network such as this, there are few direct trunks between local central offices. Since both the volume of traffic and the percentage of interoffice calls are low in a rural area, direct trunks are not economically justified, and the facilities network reflects this fact. The area shown covers approximately 20 counties and contains 46 Bell System and independent central offices serving 120,000 telephones. Open wire and cable are the dominant transmission media; radio also is used. Because of the length of the spans, the cable facilities are extensively augmented by analog carrier. Cross sections are in the hundreds of voiceband channels.

5.3.3 LONG-HAUL FACILITIES

The long-haul facilities network consists of long-haul transmission systems and toll switching systems. The long-haul transmission systems include various coaxial cable and microwave radio systems. The toll switching systems include No. 4 Crossbar, No. 5 Crossbar, Crossbar Tandem, No. 4 ESS, and Step-by-Step.

Fig. 5-10 and 5-11 illustrate the major transmission routes and junction points, called junction offices on the maps, in the nationwide long-haul network. These maps are fundamental planning maps and include projected as well as existing facilities. Virtually all continental long-haul transmission is by means of radio and coaxial cable; satellite systems and submarine cables extend the network to global proportions.

The structure of the network is a consequence of the desire to minimize cost through economy of scale and of the need for redundancy; it represents a balance between these objectives. Transmission routes are selected to achieve high cross sections and thus realize the economic benefits of high-capacity systems. Major routes therefore connect the nation's population centers. Multiple long-haul routes increase the degree of survivability in the event of a disaster, but decrease the size of cross sections. In addition, several population centers are surrounded by metropolitan junctions in a subnetwork. This allows traffic to be routed around, rather than through, the center and provides multiple routes. The St. Louis area is an example of this. Each route, of course, provides channels for many traffic networks.

Coaxial and radio systems, once placed in service in the long-haul network, normally are not retired. As new technology evolves, older systems may be brought up to date by modification of the electronics rather than by replacement of the basic facilities, such as cable and antennas.

The long-haul network, like the exchange and loop networks, must continue to grow in response to the increasing demand for all kinds of service. The network must expand in an orderly and economical manner; long-range planning is therefore essential. In view of this fact, a fundamental plan for the growth of the long-haul transmission facilities over the next 15 years is updated periodically by Long Lines and the associated companies in conjunction with the independent companies. Similar plans for the growth of switching facilities also are made for projections over various numbers of years.

5.3.4 THE DIGITAL FACILITIES NETWORK

The facilities network has evolved as an analog network. Transmission facilities were of the analog type, and all switching systems were designed to switch voiceband analog channels. When digital data signals are transmitted on present-day traffic networks derived from this facilities network, it is necessary to convert the signals to analog form by modulation techniques such as those described in Section 6.1.

At the present time, the influences of economic advantages and advancing technology are causing more and more components of the facilities network to be digital. Generally, the advantages of digital facilities must be realized for voice traffic to make them attractive, because the major portion of traffic on the facilities network is voice.

A short-haul digital carrier system, T1, was introduced into the network in the early 1960s, and it has grown rapidly because it provides low-cost and reliable transmission. Although T1 was designed to use digital transmission, digital-to-analog converters were required at the terminals of the T1 system to accept and transmit signals in voiceband analog form for switching and to allow interconnection with other types of facilities. In general this situation still prevails.

In the early 1970s, another digital carrier system, T2, was introduced. T2 was designed to have more capacity than T1 and to operate over distances up to 500 miles. It too promises to be installed extensively throughout the network. T1 and T2 represent the introduction of digital transmission facilities into what is still primarily an analog network.

The T4M Digital Carrier System, introduced in 1975, also was designed to operate over distances up to 500 miles and has much greater capacity than T2.

The No. 4 ESS toll switch, developed using time-division and digital technologies, switches digital voice channels derived from PCM analog-to-digital converters which are either local to the switch or at distant offices. After the first installations in 1976, it is expected that No. 4 ESS switches will be rapidly deployed across the nation.

The principal motivation for the use of digital facilities, T1, T2, T4M, and No. 4 ESS, is economy. Each of these facilities is less expensive than a corresponding analog implementation would be and equals or exceeds the performance of its analog counterpart. This is largely because the processing of the signals in digital form can best take advantage of integrated circuit technology. There are also present and potential advantages in transmission quality, signaling, and simplified maintenance.

When No. 4 ESS is installed in areas where there has been a substantial growth of T1 and T2 digital transmission facilities, digital switches will be interconnected by digital transmission facilities. Thus, integrated digital subnetworks will be formed. The term "integrated" implies No. 4 ESSs interconnected with digital transmission systems without intermediate digital-to-analog conversion. Additional economy and improved transmission will result from the integration of digital facilities because of elimination of certain items of terminal equipment, such as converters. Studies have shown these savings to be substantial.

Note that a digital facilities network is not separate from the overall facilities network, but is an integral part of it. Analog facilities will interconnect with it at No. 4 ESSs and at terminals of digital transmission systems.

It appears that regional digital facilities networks will come into being in the late 1970s. There is a good likelihood that long-haul digital transmission systems will be deployed eventually. When this takes place, a nationwide integrated digital facilities network, called the Toll Switched Digital Network, will become a reality. If it became attractive to develop a digital local switching system and, with appropriate local digital transmission arrangements, to extend the digital facilities network to customer premises, it then would be practical to transmit high-speed data (up to 56 kilobits per second) over the public telephone network. Economic studies so far, however, have not supported implementation of this concept, and there are no plans at this time for a digital local switching system for the PTN.

One new challenge in the creation of an interconnected digital facilities network is the necessity for synchronization of facilities. The current plan is to synchronize all digitally interconnected switching systems and 64-kilobit-per-second channels to the Bell System reference frequency, which is distributed from an atomic clock in Hillsboro, Missouri. No. 4 ESSs will have internal crystal-controlled clocks of sufficient accuracy so that loss of the reference frequency for periods of several weeks could be tolerated.

Even today, without No. 4 ESS, the synchronization problem arises in multiplexing bit streams at the T1 rate, called *digroup channels*, into higher rates (see Section 6.2). In this case, it is solved by a process called *stuffing*, rather than by overall synchronization to the reference frequency. In the Toll Switched Digital Network, the stuffing process will be retained and the digroup channels will be synchronized to the reference frequency as will be No. 4 ESS.

The reader should distinguish between the Toll Switched Digital Network and the Digital Data System described in Section 12.4. The Digital Data System provides a new service, DATAPHONE digital service, by means of a synchronized network made up of digital facilities.

5.4 NUMBERING PLAN

Dial telephone service has many prerequisites, but none more fundamental than a numbering plan. Before a connection can be established to a distant telephone, a means to identify that telephone is essential. Since 1947, this need has been met in most of North America on an integrated, unified basis. As a result, both customers and operators have grown familiar with a standardized means to "instruct" switching equipment. The numbering plan consists essentially of a unique decimal address augmented in some instances by a prefix, a suffix, or both. While the numbering plan is often discussed in terms of customer direct distance dialing (DDD), its scope is considerably larger, providing not only for all customer-to-customer traffic, but also for:

(1) Customer-to-operator calls (e.g., directory assistance calls).

(2) Operator-to-customer calls (e.g., delayed calls).

(3) Operator-to-operator calls (e.g., calls to nondialable numbers).

In the paragraphs that follow, all references will be to numbering in the national and international public telephone network. Numbering plans used in other traffic networks are generally less complex.

5.4.1 NOMENCLATURE

Fundamentally, a numbering plan establishes the structure within which dialing procedures may be applied. Specific dialing procedures are influenced by the dialing device. Customers typically use rotary dial and TOUCH-TONE telephone sets, while operators rely largely on keysets. The numbering plan must accommodate all authorized address-input devices and all authorized users, including those concerned with system testing and maintenance.

Dialing must follow a prescribed sequence. First, there may be a need for one or more prefix digits. Next, the address must be transmitted. Finally, a suffix may apply. To illustrate, a customer served by a PBX may dial the prefix 9 to gain access to the public telephone network. A DDD call may then require the additional prefix 1 and a 10-digit address. In this case, there is no suffix. An operator interested in reaching the same number would begin with the prefix KP (for key pulse), a keyset signal that unlocks the device provided to register the address digits to follow. (The risk of dialing before dial tone and thus reaching a wrong number under certain circumstances, a risk with which customers must contend, is thereby avoided in operator dialing since nothing is accepted in the absence of a KP.) The same 10-digit address is used by both customers and operators. The operator, however, indicates end of dialing by the suffix ST (start).

The following set of symbols is used commonly in discussing dialing procedures:

N: Any of the eight decimal values 2 through 9.

X: Any of the ten decimal values 0 through 9.

0/1: A decimal value limited to either 0 or 1.

Some related commonly used terms are as follows:

(1) *NPA (Numbering Plan Area)*—A geographical division within which telephone directory numbers are subgrouped. In North America, a 3-digit, N0/1X code is assigned to each NPA. (See Fig. 5-12.)

(2) *HNPA (Home NPA)*—The NPA within which the calling line appears at a local (class 5) switching office.

(3) *FNPA (Foreign NPA)*—Any NPA outside the boundaries of the home NPA.

(4) *Central Office Code*—A 3-digit identification within which up to 10,000 station numbers are subgrouped.

(5) *Station (or Line) Number*—The final four digits of a standard 7- or 10-digit address. These digits define a connection to a specific customer's line within a central office.

(6) *Prefix*—Any dialed signal that is input prior to the address. Prefixes are used to place an address in proper context, to indicate service options, or both.

(7) *Service Code*—A code, typically of the N11 series, that defines a connection for a service, such as 411 for directory assistance or 611 for repair service.

(8) *System Code*—A 3-digit code of the form 0 1XX available to operators or automatically associated with certain toll calls to modify routing or call-handling logic.

Based on a unique partitioning of numbering plan area codes and central office codes that generally has been used and is still used in most locations, Table 5-2 shows the number of 3-digit codes available for system, service, area, and central office codes.

5.4.2 FORMAT

The basic address format used in most of North America for customer telephone identification consists of ten digits. Within this 10-digit format a "3-3-4" subdivision has been established, corresponding to the NPA code, the central office code, and the station number, respectively. Symbolically, the full format is N0/1X-NXX-XXXX. In most NPAs, the 7-digit directory number is still limited to the format NNX-XXXX, but the NXX-XXXX directory number format has been introduced on a limited basis and will find increasing application. The less restrictive NXX format embodies the concept of interchangeable codes, wherein central office codes and area codes will no longer be characterized by mutually exclusive formats. Evolution of the 10-digit format is shown in Table 5-3.

Telephone numbers grew from an alphanumeric tradition, but all-number calling (ANC) is now the system standard. Despite the personal appeal of


BRITISH COLUMBIA
604
ALBERTA
403
SASKA
907
ALASKA
509
206
WASHINGTON
406
MONTANA
503
OREGON
208
IDAHO
307
WYOMING
916
707
702
NEVADA
801
UTAH
303
COLORA
415
209
408
808
HAWAII
805
CALIFORNIA
213
714
602
ARIZONA
505
NEW MEXICO
903
NORTHWEST MEXICO

Fig. 5-12. Numbering Plan for North America

name equivalents to ANC codes, names and letters were a basic barrier to use of the full range of dial code sequences and to international address uniformity. Directory numbers prior to ANC were commonly referred to as "2L+5N" to call attention to the alphanumeric usage, despite character subgrouping such as AB2-3456.

In the toll network, many calls are carried in formats that differ from the standard 10-digit DDD address. An operator call to an inward operator may require only the digits 121. Conversely, an operator-dialed call to Mexico may be served most conveniently with an 11-digit address. Most toll switching systems can process calls with any address in the range of 3 to 11 digits.

TABLE 5-2
CODE PARTITION

200 System Codes

000 099
100 199

152 Area Codes	8 Service Codes	152 Area Codes	640 Central Office Codes
200 . . . 210	211	212 . . . 219	220 299
300 . . . 310	311	312 . . . 319	320 399
400 . . . 410	411	412 . . . 419	420 499
500 . . . 510	511	512 . . . 519	520 599
600 . . . 610	611	612 . . . 619	620 699
700 . . . 710	711	712 . . . 719	720 799
800 . . . 810	811	812 . . . 819	820 899
900 . . . 910	911	912 . . . 919	920 999

TABLE 5-3
EVOLUTION OF 10-DIGIT CODE

PERIOD OF APPLICATION	AREA CODE	LISTED DIRECTORY NUMBER	
		OFFICE CODE	STATION CODE
Recent	N0/1X	NNX	XXXX
Present	N0/1X	NXX	XXXX
Ultimate	NXX	NXX	XXXX

X = 0 through 9.
N = 2 through 9.

5.4.3 RELATIONSHIP TO TOLL HIERARCHY

Clearly, both the toll hierarchy and numbering plan are linked to geography. Directory numbers are assigned within NPAs. It could follow that NPA boundaries and regional boundaries must be drawn in some compatible manner. If this were not done, inspection of an NPA code with associated boundaries spanning two regions would not define the hierarchical chain of destination. In practice, to avoid constraints in establishing either regional or NPA boundaries while retaining the ability to make toll routing choices by inspection of not more than three digits, the *principal city* concept was introduced, with one principal city toll office for each NPA code. The principal city toll office has a fixed position in a specific hierarchy. It normally ranks above other toll offices in the NPA served, thereby acting as a natural conduit in a standard routing chain. The principal city toll office for a given NPA need not be located within that NPA, and in practice a single toll office may provide principal city services for more than one NPA. If a call is directed to the principal city and, upon inspection there, is found to require transfer to another region, the principal city must provide routing options to complete the call. The principal city concept has been useful in confining administrative effort in the activation of new office codes. A code recently activated can be served through the principal city until routing changes are accomplished in foreign areas.

5.4.4 LONG-RANGE PLANS

If telephone service is to grow, there must continue to be an adequate supply of telephone numbers. To avoid a difficult and traumatic transition for both telephone companies and their customers, the growth must be accommodated within the limits of the 10-digit format. To ensure sufficient capacity, particularly in the number of area codes, the concept of interchangeable area and office codes was incorporated in the plan in 1962. At that time, it appeared that the basic set of 152 N0/1X NPA codes (see Table 5-2) would be exhausted by the mid-1970s. Careful code management, however, has extended this date to about the turn of the century. In contrast, the limit of 640 central office codes per NPA has become an immediate issue in several areas. Accordingly, network preparation for the additional office codes was completed in 1971, with the expectation of significant application commencing in 1974.

When there is no longer an economic alternative, the normal procedure to accommodate growth is to split an NPA when it requires relief. A recent split occurred in 1973 in Virginia, when NPA 703 was reduced to make room for NPA 804. Since the process of splitting involves substantial expense, requires changes likely to produce customer annoyance, and imposes a need for networkwide coordination, decisions to split are subject to close scrutiny. Transition plans are a principal consideration.

In some cases the format of a dialed number is not evident until the last digit has been dialed, and the only way to identify the last digit is to wait a predetermined interval to see if another digit follows. Long-range plans will involve the elimination of such timing. When format alone is not definitive, as with 0 for operator and 0+NPA+7 digits for a dialed person-to-person call, the symbol # will be made available as a "cancel timing" indication. Applications in international dialing and custom calling services already exist.

5.4.5 INTERNATIONAL NUMBERING

International DDD (IDDD) depends as directly on numbering as does national DDD, but standards now become a matter of global concern. The International Telegraph and Telephone Consultative Committee (CCITT) foresaw this need and organized a study effort to satisfy it. The result, approved in 1964, establishes 11 digits as a preferred maximum length for international numbers. (Twelve digits are allowed in exceptional cases.) The international number is flagged by a dialed prefix, not internationally standardized, that alerts the switching equipment. The international number itself consists of a country code and a national number. The country codes are standardized and vary in length from one to three digits. The countries or zones anticipating the greatest telephone population by the year 2000 were assigned the shortest country codes to allow for longer national numbers. Specifically, the unified North American zone is labeled 1 and the U.S.S.R. is 7. Other zones contain a mix of 2-digit and 3-digit country codes. Three-digit codes occur in blocks of ten, since inspection of the initial two digits must define country code length. To illustrate the total sequence, consider a call from England to the U.S. The customer in England would dial 010-1-NXX-NXX-XXXX, where 010 is the international subscriber dialing (ISD) prefix used in England, the 1 identifies North America, and the remaining digits are the familiar 10-digit address used in North America. The Bell System has authorized two prefixes for outward-bound IDDD. Prefix 011 flags paid station, coin, or noncoin automatic calls. Prefix 01 directs calls to a TSPS operator for assistance. World zone assignments are summarized in Table 5-4.

TABLE 5-4
WORLD ZONE ASSIGNMENTS

WORLD ZONE	PRINCIPAL AREAS COVERED
1	Canada, United States
2	Africa
3,4	Europe
5	South and Central America, Mexico
6	South Pacific
7	U.S.S.R.
8	North Pacific
9	Far and Middle East
0	Spare

Note: Specific country code assignments are tabulated in the current CCITT volume covering "Telephone Signaling and Switching." Assignments tend to be stable, but may be changed by mutual agreement.

6 Transmission

The basic aspects of transmission are presented in this chapter. The first section describes characteristics of common types of signals, introduces the concept of channels, describes the transmission media that are used, and identifies modulation techniques used in the Bell System. Section 6.2 describes multiplexing, the techniques by which a number of independent signals share the same transmission path, and discusses problems associated with multiplexing. Section 6.3 outlines the factors that are considered in the transmission plan for a traffic network with specific reference to the public telephone network.

6.1 SIGNALS, CHANNELS, MEDIA, AND MODULATION SYSTEMS

This section outlines the concepts, principles, and elements involved in engineering Bell System transmission facilities and provides a background for the discussion of specific systems and equipment in Chapter 10. The material presented here is organized into four major subsections, covering:

(1) The characteristics of various customer signals.

(2) Channels and the voice-frequency and carrier transmission arrangements used to provide them.

(3) The properties and limitations of the media used or contemplated for use in voice-frequency and carrier transmission applications.

(4) The modulation methods employed to convert signals into a form suitable for transmission over the available media and channels.

References 1 through 11 for supplementary reading are listed at the end of this chapter.

6.1.1 SIGNALS

6.1.1.1 Speech

The most common signal transmitted over Bell System facilities is the speech signal, the electrical analog of the acoustical wave generated by the telephone user. This signal carries most of its information in the frequency band between 200 and 3500 Hz. The energy in the speech spectrum peaks near 500 Hz, with most of the articulation being in higher frequencies. Transmission of speech energy above 3500 Hz would improve naturalness, but is normally not done for economic reasons.

In the time domain, the speech signal energy is highly variable. First, the peak-to-rms ratio of the instantaneous speech waveform is quite large, about 19 dB. Second, the differences between speakers and how loud a person talks at any given time result in a significant spread in the short-term average power distribution. Finally, speech is a succession of talk spurts with interspersed silent intervals.

Because of these variations, accurate measures of speech signal characteristics are difficult to obtain. Nevertheless, the magnitude of the telephone speech signal must be measured and characterized in a fashion that can be used in designing and operating transmission systems, so that acceptable voice-channel characteristics can be obtained. In multichannel frequency-division-multiplex carrier systems, in which a number of speech signals are added together, the principal considerations are overload and intermodulation distortion. In the design of these systems, the value normally used for estimating the total speech load is an average power per voice channel during talk spurts of -16 dBm0 (dBm at 0 TLP[1]).

6.1.1.2 Digital Data and Facsimile

Data signals transmitted over Bell System facilities involve machine-to-machine or man-to-machine communication. The basic data signal usually consists of a train of binary pulses that represent, in coded form, the information to be transmitted. In one form of transmission, the pulses may occur only at regularly specified times, in which case the transmission is referred to as *synchronous*. An alternative form, *asynchronous* transmission, puts no restriction on the pulse lengths or times of transition. In either case, the maximum rate at which the transitions or pulses occur determines to a large extent the bandwidth required for the transmission channel. Data transmission speeds in the Bell System vary from a few pulses per second (for supervisory control channels) to over a million pulses per second.

Data signals are seldom in a form suitable for transmission over regular Bell System network channels and usually require some form of signal processing or modulation (see Section 6.1.4.2). The processing normally takes place at the station set and also, as with speech signals, at carrier transmission terminals. Since these signals usually are carried in combination with ordinary telephone speech signals on multichannel carrier systems, the processed data signals must conform to certain restrictions on average power, peak power, energy concentration, and pulse density in order to be compatible with

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1. 0 TLP refers to the zero transmission level point, an arbitrary reference along a transmission path. The transmission level at any other point is the nominal design gain in dB relative to 0 TL at 1000 Hz or a corresponding frequency obtained by modulation. See Section 7.2.1.

the characteristics of telephone speech, for which the Bell System transmission systems and channels primarily are designed.

6.1.1.3 Video

There are basically two types of video signals carried over Bell System facilities: television and PICTUREPHONE. To translate either television or PICTUREPHONE material into an electrical signal for transmission, the picture to be conveyed must be scanned in a systematic manner. The basic process consists of a series of scans in nearly horizontal lines from left to right, starting at the top of the image field. When the bottom of the field is reached, the process is repeated, with lines from alternate fields interlaced.

For successful decoding of the picture at the receiver, it is necessary to transmit a key to the scanning pattern. This is accomplished by interleaving short-duration synchronizing pulses with the information-bearing signal. These pulses indicate characteristic points in the scanning process, such as the beginning of scanning lines and fields. During the horizontal and vertical retrace time, the picture signal is replaced by a block signal known as a blanking pulse. The synchronizing information is superimposed on the transmitted signal in these intervals.

Both television and PICTUREPHONE signals use a field rate of 60 per second and a frame rate of 30 per second. Table 6-1 shows a comparison of the two signals in other important respects.

TABLE 6-1
COMPARISON OF TELEVISION AND *PICTUREPHONE* SIGNALS

SIGNAL	HORIZONTAL LINE SCAN RATE (kHz)	LINES PER FIELD	BANDWIDTH (MHz)
Television	15.75	525	4.3
PICTUREPHONE	8.0	250	1.0

The scanning process determines the basic distribution of energy in the signal band. Most of the energy is concentrated at harmonics of the line scan frequency, with 60-Hz sidebands about each line scan harmonic. The presence of these discrete spectral line components makes combined multichannel voice and video transmission over a common wideband channel difficult because of the tone interference that would be introduced into the voice channels by cross modulation.

6.1.1.4 Program

Program signals include radio program material, wired music system signals, and the audio portion of television program material. Program signals may include speech and a wide range of musical material. At the present time, most program transmission networks of the Bell System can accommodate a band of frequencies from about 100 to 5000 Hz, compared with the nominal 200- to 3500-Hz band of the standard voice channel. Other less frequently used program services cover the frequency ranges from 50 to 8000 Hz and 50 to 15,000 Hz.

Besides bandwidth, program signals differ from telephone speech signals in having a wider range of transmitted sound powers. Also, they are frequently handled on one-way channels. Some program signals are also more susceptible to delay distortion than telephone speech and therefore require greater control of the delay characteristics of program channel bands.

6.1.2 CHANNELS

6.1.2.1 General Description

A channel is a transmission path dedicated to providing communication between two points. A specific channel may be an analog frequency band or its digital counterpart in the time domain[2], a sequence of time slots, or a combination thereof.

In addition to voiceband channels, many types of channels are employed in the Bell System. These include narrowband channels, approximately 100 or 200 Hz in bandwidth, used in the provision of telegraph and low-speed data service, private-line (nonswitched) 4-kHz voiceband channels specially treated to meet 9600-bit-per-second data or facsimile transmission requirements, and the 48-kHz and 240-kHz channels in the analog message multiplex hierarchy (see Section 6.2.1), used for high-speed data transmission. Wider-than-voiceband channels also are provided for program and video signals.

In all cases, each type of channel must be designed to have a transmission response that will satisfy the objectives set for the type of service to be provided. Transmission objectives are discussed in Section 6.3.

6.1.2.2 Voice-Frequency and Carrier-Derived Channels

Channels in the Bell System network are provided with either voice-frequency or carrier transmission arrangements. The voice-frequency arrangements are frequently operated so that both directions of transmission are carried on the same wire pair, as shown in Fig. 6-1. The 2-wire mode of voice-frequency transmission is used wherever practical in order to save copper and to be compatible with local switching systems that provide 2-wire transmission paths. The 2-wire mode is found almost exclusively in loops and commonly in short trunks between central offices. However, when trunks are long or when the required channel bandwidth is significantly greater than the nominal 4 kHz used for ordinary speech transmission, the technical problems are such that 4-wire operation (a separate pair for each direction of transmission) is necessary. Net losses can be held at lower values, and there are fewer echo and singing paths (see Section 6.3). As channel length becomes greater,

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2. Digital channels for voice communication are derived through pulse code modulation as discussed in Section 6.1.4.

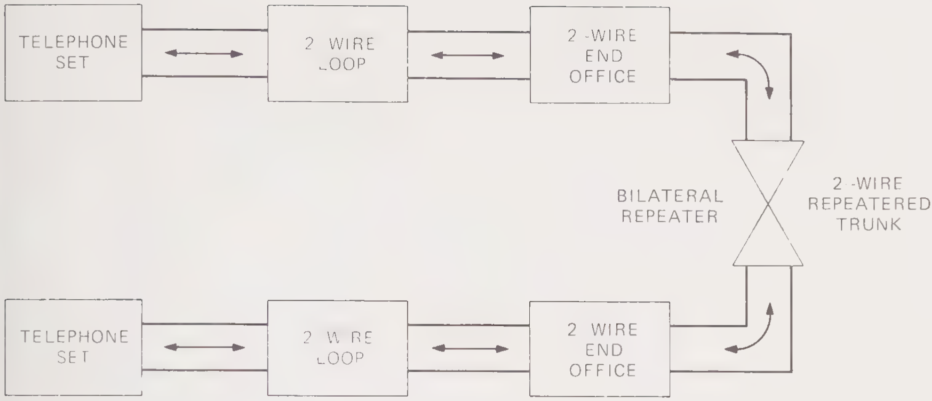

Fig. 6-1. Two-Wire Voice-Frequency Channel

there are applications for 4-wire voice-frequency circuits before carrier transmission becomes economical.

Carrier systems are broadband systems that employ 4-wire transmission. The individual channels, the dedicated band of frequencies or sequence of time slots, derived from the carrier system also are referred to as *4-wire channels.* Systems designed for submarine cable operation and some short-haul carrier systems use a mode of transmission called *equivalent 4-wire.* In this mode, the two directions of transmission are separated in frequency on a single pair of wires, rather than in space on separate wire pairs. The advantage of this mode, of course, is that only one pair is required for both directions of transmission. Waveguide systems also operate in the equivalent 4-wire mode on a single pipe.

A number of types of carrier systems have been developed in order to use the various transmission media more efficiently. A carrier system, as shown in Fig. 6-2, may be regarded as consisting functionally of three major parts:

(1) High-frequency line equipment that, with the transmission medium, provides a broadband channel of specified characteristics to permit the simultaneous transmission of a large number of communications signals.

(2) Modulating equipment that processes signals from whatever form they are received into a form suitable for transmission over the high-frequency line.

(3) Multiplexing equipment that combines at the system input and separates at the system output the various signals sent through the system.

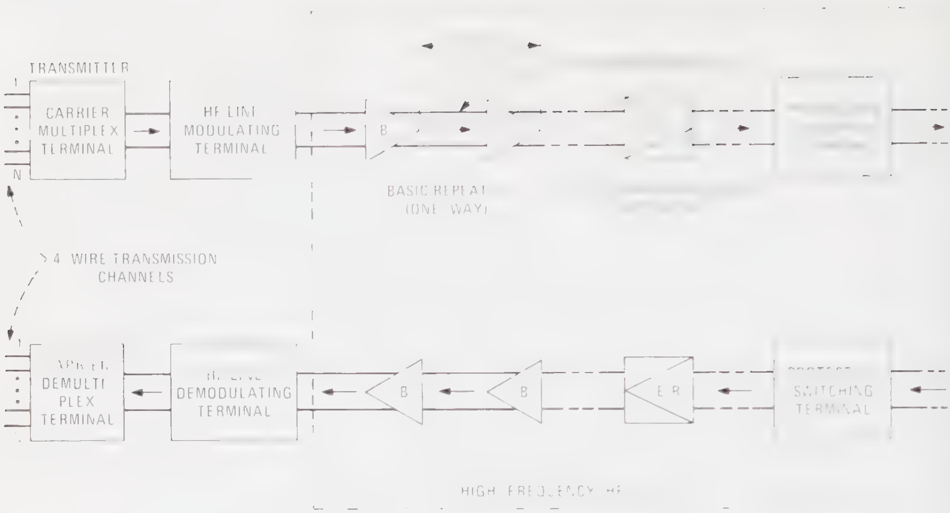

Fig. 6-2. Four-Wire Carrier-Derived Channel

Together, the three major parts that constitute the carrier system provide a 4-wire broadband transmission channel having controlled gain, low echo delay[3], and acceptably low noise and distortion. The broadband channel accommodates a multiplicity of narrower-band channels for the transmission of speech, data, or other signals. In this way, carrier systems provide economic benefits through the substitution of electronics for copper.

6.1.3 TRANSMISSION MEDIA

There are six principal types of transmission media used or under consideration for providing transmission channels:

(1) Open-wire lines.

(2) Paired cable.

(3) Coaxial cable.

(4) Radio (terrestrial and satellite paths).

(5) Waveguide.

(6) Optical fibers.

The following sections discuss the broad physical and electrical characteristics of each of these media and their present or expected application in the telephone plant.

3. The round-trip echo delay on satellite connections is typically 0.6 second, which is more than an order of magnitude larger than that experienced on transcontinental terrestrial carrier systems.

6.1.3.1 Open Wire

Open-wire lines consist of pairs of uninsulated wire strung on poles. The wires, which range in size from 0.080 inch to 0.165 inch, may be copper, copper-clad steel, or galvanized steel and require about 12 inches of separation to prevent momentary shorts during high winds. Five open-wire pairs may be mounted on a crossarm, and most poles are limited to about ten crossarms.

Although open-wire pairs may have a loss as low as 0.03 dB per mile at voice frequencies, the limited number of pairs per pole, the susceptibility to storm damage, and the high cost of maintenance make open wire unattractive for modern transmission systems. Open wire is still in use in the telephone plant, primarily in rural areas; it is giving way to cable, with the higher losses being offset by electronics.

6.1.3.2 Paired Cable

To achieve a higher circuit density than that possible with open-wire lines, paired cable is used. Paired cable consists of wood pulp or plastic-insulated wires, typically 0.016 inch (26 gauge) to 0.036 inch (19 gauge) in diameter. Most existing cables contain copper wire; however, aluminum is now available as an alternate to copper. The wire is twisted in pairs with 2 to 6 inches per 360-degree twist and is then stranded in binder groups of 25, 50, or 100 pairs, with a number of different twist lengths for adjacent pairs in a binder group. Cables may have sheaths of plastic, aluminum, steel, lead, or combinations of these and may contain from 6 to 2700 pairs. Fig. 6-3 shows a typical paired cable. As will be discussed in Sections 10.1 and 10.2, paired cable is used mainly in the loop and exchange plants. In these applications, the cables may be strung on pole lines, installed in underground conduit, or buried directly in the ground.

The large number of pairs per cable results in a considerably lower installed cost per pair compared with open wire. However, the close spacing results in substantially higher loss and a greater loss slope with frequency than open wire, because of the high capacitance between the wires of the cable pair. For example, 19-gauge, 0.036-inch diameter paired cable has a loss of about 1.1 dB per mile at 1000 Hz, and the loss increases approximately as the square root of frequency. As shown in Fig. 6-4, this may be modified for voice-frequency transmission by introducing periodic lumped inductive loading into the line to compensate for the distributed capacitance. The addition of loading coils can reduce mid-voiceband loss by as much as 80 percent. With loading coils, the loss is nearly constant over much of the voiceband, but the loss increases very rapidly above a high-frequency cutoff. Inductive loading is frequently used on cable pairs longer than about 3 miles, when gain devices are not used.

The twisting of balanced pairs with staggered twist lengths provides high crosstalk coupling loss between pairs at low frequencies. However, increased circuit demands have led to carrier applications on cable pairs; the higher frequencies used have resulted in transmission being limited by high-frequency

Fig. 6-3. Typical Paired Cable

coupling between pairs. Isolating the pairs with grounded shields around each pair (as is done for some video pairs) reduces the coupling, but is prohibitively expensive for most applications.

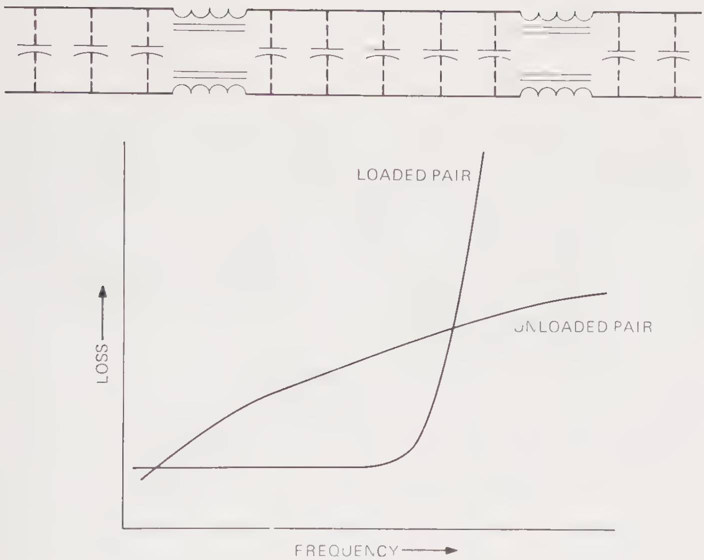

Fig. 6-4. Effect of Periodic Lumped Inductive Loading in Twisted Cable Pairs

6.1.3.3 Coaxial Cable

The present standard coaxial structure consists of a 0.100-inch copper wire inner conductor, insulated from a 0.375-inch inner-diameter cylindrical outer conductor of 0.012-inch copper tape, seamed lengthwise. Although the insulation may be solid dielectric, the usual insulation consists of polyethylene discs with 1-inch spacing. The outer conductor is wrapped with 0.006-inch steel tapes for added strength and magnetic shielding.

A cable may contain a single coaxial structure or tube, or a number of coaxial tubes may be combined in a cable along with twisted pairs as shown in Fig. 6-5. The most commonly used cables contain 8, 12, 20, or 22 coaxial tubes and employ twisted pairs to pass control and alarm signals to or from remote line repeaters.

A standard coaxial tube has a loss of about 3.9 dB per mile at 1 MHz, and the loss increases essentially as the square root of frequency. The outer conductor of a coaxial tube is grounded, providing a self-shielding feature that enables the coaxial tube to be useful at much higher frequencies than paired cable or open wire; but this self-shielding is not effective at low frequencies. Although the per-tube cost for coaxial cable is high, the cost per Hertz of useful bandwidth is substantially lower than for either paired cable or open wire. Coaxial cable is used principally for circuits hundreds or thousands of miles long and where large bandwidth capacity is required. Coaxial cable and microwave radio (discussed next) provide most of the communication paths on high-density intercity routes in the long-haul network. Systems using these media for long-haul transmission are discussed in Section 10.3.

Fig. 6-5. Coaxial Cable With Twisted Pairs (Actual Cable Diameter Approximately 2-5/8 Inches)

6.1.3.4 Terrestrial Radio and Satellite

In the case of radio transmission, the medium is unshielded, and the available received power is limited primarily by transmitter power, obstructions, path length, and antenna patterns. The main advantage of radio over wire transmission is the absence of any need for physical facilities between the two points of communication. Consequently, the need for a continuous right-of-way between the two points is avoided. Furthermore, radio is better adapted to spanning natural barriers such as water and mountainous or heavily wooded terrains, where buried wire systems would be difficult to install. The radio systems used today or planned for Bell System applications operate mainly in the 4-, 6-, 11-, or 18-GHz common carrier bands, with repeater spacings varying between 1 and 30 miles along the earth's surface (depending on the frequency band) and up to 23,000 miles for satellite communications. The frequency spectra used by these systems (see Table 6-2) are in the public domain and are administered by the Federal Communications Commission.

TABLE 6-2
RADIO FREQUENCY BANDS

BAND	FREQUENCY SPECTRUM (GHz)
4	3.7 to 4.2
6	5.9 to 6.4
11	10.7 to 11.7
18	17.7 to 19.7

Path Characteristics

The radio transmission mode utilized in these bands is line-of-sight. An "optical" path is essential between transmitter and receiver, and a reasonable clearance above the minimum horizon is needed (largely because the path of a radio beam does not follow a straight line, except for the special case of a uniform atmosphere). Under normal propagation conditions, the transmission loss on a line-of-sight path is relatively constant with frequency over wide bandwidths and increases about 6 dB each time the distance is doubled.

One of the principal problems affecting terrestrial transmission is the variation in received signal level caused by changes in atmospheric conditions. The severity of this fading generally increases as either the frequency or path length increases. There are two general types of fading, caused by multipath transmission and by inverse bending. Multipath transmission can result in phase interference effects, which are the principal causes of fading on well-engineered line-of-sight paths at 4 and 6 GHz. Fortunately, the resulting deep and rapid fading exists for only relatively short portions of the year, and since its effect is generally frequency selective, it can be minimized by use of frequency diversity. On the other hand, an inverse bending fade is caused by a bending of the transmission path so that the normal path clearance is overcome and the expected line-of-sight path is transformed for a time into an obstructed one. This type of fade may last for several hours, and the use of frequency diversity is of little or no value. It can be avoided by appropriate short spacing between antennas.

In the case of satellite transmission in the 4- and 6-GHz bands, the combination of high path-elevation angles and narrow-beam antennas on the ground minimizes the fading that is caused by atmospheric variations. However, moisture in the air or on the antenna tends to prevent the attainment of very low receiver noise, and this effect is more important than variable path attenuation.

For both terrestrial and satellite paths there are other problems, such as appreciable absorption by rain at frequencies above 10 GHz. The effect of rain attenuation on radio propagation in the 4- and 6-GHz bands is small relative to the path losses introduced by other sources of fading, but is an important consideration in system reliability at 11 and 18 GHz. Rain attenuation over any individual microwave band is almost independent of frequency, and therefore no protection is offered by the use of inband frequency diversity. Space diversity can offer protection on satellite paths; heavy rain occurring simultaneously at two widely separated ground stations is unlikely.

Antennas

An efficient antenna system is a vital part of any successful radio system. The transmitting antenna radiates as much of the transmitter's energy as possible toward the receiver, and the receiving antenna collects as much of this energy as possible. The efficiency of this process depends primarily on antenna directional properties; that is, the ability of the antenna to concentrate the radiated or received energy. The measure of this ability is known as the *gain* of the antenna. Formally, this is defined as the ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity in the same direction from an isotropic radiator (that is, an antenna radiating equally in all directions).

One of the most attractive properties of microwaves is that their centimeter wavelengths are small compared with antenna structures. Consequently, it is feasible to focus microwaves, like optical waves, into a narrow beam by various lens or reflector arrangements. This is the basis for much present-day microwave antenna design. The horn reflector structure used widely in the 4- and 6-GHz bands is shown in Fig. 6-6.

All of the energy radiated from an antenna does not lie in the direction of the main beam. Some of it is concentrated in minor beams, called *sidelobes*, which are potential sources of interference or crosstalk with other microwave paths. In receiving, there are corresponding sidelobes in the pattern of sensitivity. Generally, the avoidance of excessive interference in microwave radio systems requires not only great care in antenna design but also careful consideration in the location of repeater and terminal stations. Interference effects are the principal limitation on the number of radio routes permitted to converge at any given radio junction.

6.1.3.5 Waveguide

A transmission system operating over circular waveguide has a potential for future use in long distance communications because of the very wide bandwidth that can be achieved. The attractiveness of the waveguide medium stems from the low-loss transmission characteristics of circular guide when excited in the TE01 mode. This mode has the unusual property that, above its cutoff frequency, its loss varies inversely with frequency to the 3/2 power. Therefore, in theory, as low a loss as desired can be obtained merely by using a sufficiently high operating frequency. In practice, however, the required frequencies are so high that hundreds of other modes also are propagated. These unwanted modes are coupled to the desired TE01 mode by geometrical imperfections in the guide (caused by dimensional tolerances, curvature, etc.) and eventually cause its loss to rise with frequency and give rise to transmission deviations. The mode conversion process is dominated by the bends that are necessary to follow any practical right-of-way alignment or hilly terrain. Accordingly, the design of a circular waveguide medium involves tradeoffs among waveguide structure, waveguide size, operating frequency band, and the precision with which the waveguide can be manufactured and installed.

Two types of waveguide, shown in Fig. 6-7, are expected to be employed to reduce mode coupling and conversion. Helix waveguide (Fig. 6-7, upper drawing) uses very fine copper wire backed by lossy material as the lining of a steel tube. This design supports the TE01 mode in a low-loss manner, while other modes, which generally have a longitudinal component of wall current, couple into the lossy dielectric around the outside of the copper helix and

Fig. 6-6. Horn Reflectors Atop a 4-GHz Radio Station

thus are attenuated. This high attenuation substantially reduces the spurious mode energy coupling back into the TE01 mode and therefore reduces transmission deviations. However, the intentional bends needed to conform to a practical route tend to introduce significant losses in helix waveguide, particularly at the higher frequencies. For this reason, dielectric-lined waveguide, shown in the lower drawing of Fig. 6-7 and consisting of a steel tube copper-plated on the inside and lined with a thin layer of polyethylene, is expected to be used on 98 percent of a waveguide route. The dielectric lining is designed to minimize the mode coupling that occurs in bends and thereby minimize the losses. The addition of sections of helix waveguide at periodic intervals will limit both the magnitude and frequency of the transmission deviations that would accumulate if only dielectric-lined waveguide were used.

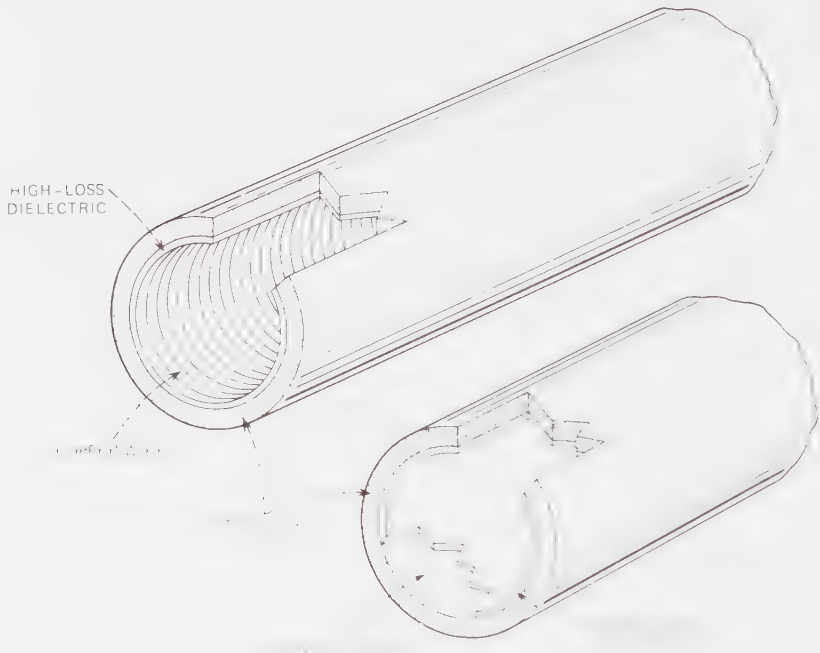

Fig. 6-7. Millimeter Waveguides

Both helix and dielectric-lined waveguides have been designed with inside diameters of 60 millimeters. This value was chosen to provide minimum loss across the frequency band from 40 to 110 GHz. Losses from 1 to 2 dB per mile are anticipated, which, as discussed further in Section 10.3, will permit waveguide repeater spacings in the 25-mile range, using currently available millimeter-wave power sources and digital modulation techniques.

6.1.3.6 Fibers

The use of fibers as a transmission medium for optical communication systems was not considered to be a practical possibility until 1966, when researchers in England pointed out that within the visible and near-infrared parts of the spectrum the fundamental loss mechanisms in glass fibers add up to only a few dB per kilometer and that the measured bulk loss of some varieties of fused quartz is only a few tens of dB per kilometer over wide bands. These observations ushered in the field of fiber optic communication. Because of their small physical size and large bandwidth capability, optical fibers have numerous potential applications, such as intraoffice interconnections, medium-capacity interoffice trunks, and large-capacity intercity routes.

As shown in Fig. 6-8, optical fibers consist of two coaxial transparent glasses surrounded by a light-absorbing jacket. The fiber will guide light if the refractive index of the core material is larger than the refractive index of the cladding. The core diameter of the single-mode fiber (Fig. 6-8, top) is only a few microns, but that of the multimode fiber (Fig. 6-8, bottom) is a few mils. The thickness of the cladding in both cases is less than 10 mils and is determined more by the handling properties of glass than by optical factors. Both single-mode and multimode fibers are potentially important; the choice is dominated by the problem of efficiently launching light energy. Lasers will work with either type of fibers, but light-emitting diodes (LEDs) are practical with only the multimode variety.

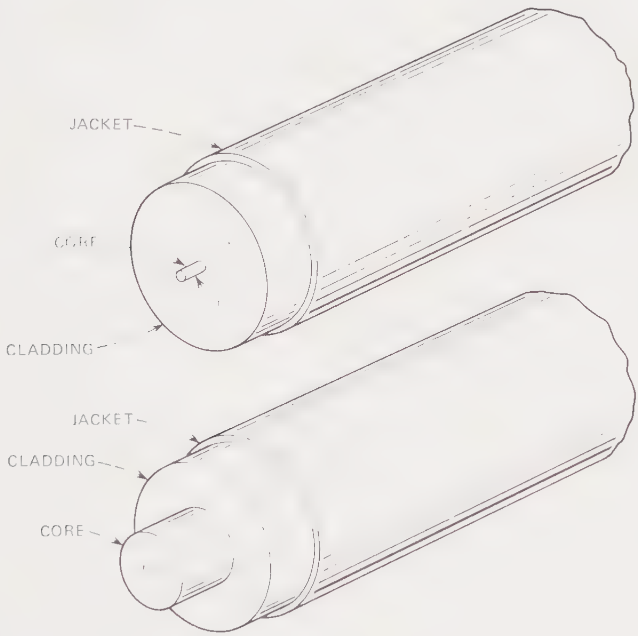

Fig. 6-8. Optical Fibers

Glass fibers have been made with a total loss less than 4 dB/km. The losses are caused principally by absorption, by scattering due to imperfections at the core-cladding interface, and by minute dielectric inhomogeneities frozen in the glass at the time it solidifies. Losses caused by curvature of the guide axis also occur, but these can be made small by proper design. With proper cladding design, crosstalk is not expected to be a problem in fiber systems.

As the techniques to fabricate long low-loss fibers are developed, the major problems in making fibers a viable transmission medium probably will be installation, handling, repair, and splicing with low joining losses. Further work also is needed on lasers and LEDs for use as sources and on system configurations for modulating these sources. One possible configuration is shown in Fig. 6-9. In this system, the signal to be transmitted is applied directly to the LED through a driver that provides the necessary current gain. Because of loss in the fiber, repeaters are used to boost or regenerate the signals along the way. Each fiber requires its own repeater, which converts the optical signals to baseband signals and amplifies or regenerates the baseband signals. These are then reapplied through another driver to modulate the transmitting LED. With integrated circuits, the repeaters would be small and inexpensive. For applications such as interoffice trunks in metropolitan areas, it may be possible to use a cable in the order of a centimeter thick that contains a few hundred fibers, each of which carries a channel of a few megahertz bandwidth. Thus, fibers might afford a simple method of spatial multiplexing that could be more economical than multiplexing via frequency or time. Commercial use of optical fibers as a transmission medium will appear when a system cost advantage can be established.

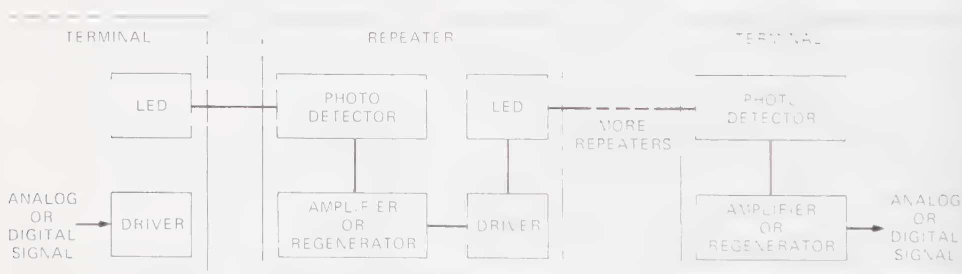

Fig. 6-9. A Possible Optical Fiber System Configuration

6.1.4 MODULATION SYSTEMS

Although most of the energy in communication signals is contained within bounded frequency bands, it is rarely in the best form for direct transmission over the frequency spectrum available on the medium or channel connecting the transmitter and receiver. Efficiency of transmission, therefore, requires that the information be processed in some way before being transmitted. In some cases, processing is required to permit any transmission at all. The processing referred to is called *modulation* and is used to accomplish a number of possible basic objectives:

(1) To enable a number of signals from separate channels to be transmitted simultaneously over a common wideband medium, thereby reducing the per-channel cost.

(2) To shift the signal frequencies upward to simplify the design of repeater components and, in the case of radio communication, to translate the signal spectrum into one of the common carrier bands allocated by the FCC. The opposite process (demodulation) shifts the signals down.

(3) To convert a voice or voice-like signal to digital form to achieve lower noise or distortion and to achieve economies in system implementation.

(4) To enable digital signals to be transmitted over analog channels that would destroy the digital waveform.

The following material covers modulation methods commonly used to realize these objectives for voice and data communication over the Bell System network. Section 6.1.4.1 deals with modulation methods for voice signals in which either the amplitude or phase of a carrier is varied continuously in accord with the baseband waveform to be transmitted or, alternatively, pulse code or delta modulation is used to convert analog speech to a digital format prior to transmission. Section 6.1.4.2, on the other hand, focuses on the modulation methods employed for transmitting signals that are inherently digital, such as binary data. The uses and system applications of particular modulation arrangements for both voice and data are identified and summarized in Table 6-3, and their advantages in these applications are discussed in the sections mentioned.

6.1.4.1 Modulation Systems for Voice Communication

Double-Sideband Amplitude Modulation (DSBAM)

One of the more common forms of modulation used for processing analog speech signals is double-sideband amplutude modulation (DSBAM). For example, DSBAM is used in AM broadcasting. The DSBAM process is often referred to as *product modulation,* since the modulated wave is the product of the baseband speech wave $a(t)$ and a sinusoidal carrier at the radian frequency ω_c; that is,

$$M(t) = a(t)\cos \omega_c t.$$

As shown in Fig. 6-10, the effect of product modulation is to translate the frequency components of $a(t)$ so that they are reflected symmetrically about the carrier without distortion. The process is therefore a linear translation, but the carrier frequency f must be chosen sufficiently high so that the lower sideband does not overlap the baseband signal.

If separate carrier frequencies are chosen for each of several baseband speech signals and the carrier frequencies are separated by at least twice the

TABLE 6-3
EXAMPLES OF MODULATION METHODS AND SYSTEM APPLICATIONS

SPEECH AND OTHER ANALOG SIGNALS

MODULATION METHOD	PURPOSE (NOTE 1)	CARRIER SYSTEM	TRANSMISSION MEDIUM
DSBAM	1, 2	N1, N2	Paired Cable
SSBAM	1, 2	N3 L1, L3, L4, L5	Paired Cable Coaxial Cable
SSBAM-FM	1, 2	TD2, TD3, TH1, TH3, TN1, TL2, TM1	4-, 6-, and 11-GHz Radio
PCM	1, 3	T1, T2 T4M	Paired Cable Coaxial Cable
PCM-PSK	2, 3	WT4	Waveguide
Δ-Mod	1, 3	SLM, SLC-40	Paired Cable

DIGITAL DATA

MODULATION METHOD	PURPOSE (NOTE 1)	DATA TERMINAL	TRANSMISSION CHANNEL
FSK	1, 4	43A, 43B Telegraph Terminals	4-kHz Voice Channel
DPSK	4	Data Sets 201	4-kHz Voice Channel
QAM	4	Data Sets 209	4-kHz Voice Channel
VSBAM	4	Data Sets 203	4-kHz Voice Channel
	1	LMDT (Note 2)	2.5-MHz Coaxial Mastergroup Channel
FM-DPSK	2	1A-RDT (Note 3)	Data Under Voice (DUV) on TD or TH Radio
FM-DPSK	2	2A-RDT (Note 3)	20-MHz TD Radio Channel

Notes

1. The number in the **PURPOSE** column indicates which of the four basic modulation objectives listed on page 135 applies.
2. LMDT = L Mastergroup Digital Terminal.
3. RDT = Radio Digital Terminal.

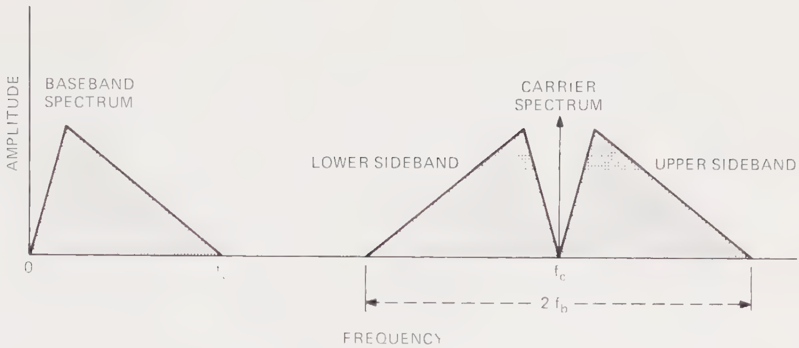

Fig. 6-10. Double-Sideband AM

highest baseband frequency, a number of speech channels may be combined on a frequency-division-multiplex (FDM) basis as shown in Fig. 6-11.

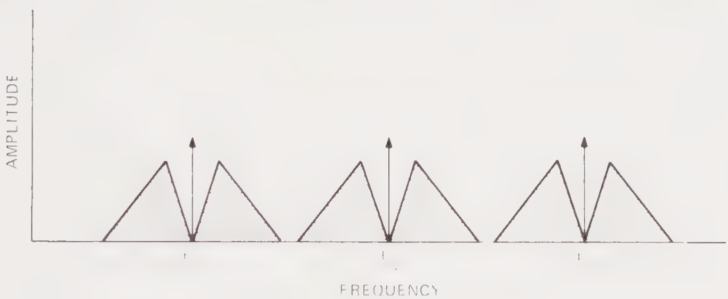

Fig. 6-11. Double-Sideband AM With Frequency-Division Multiplexing

When this composite signal arrives at the receiver, the individual channels are separated by filters centered at the carrier frequencies and just wide enough to pass the sidebands associated with each carrier. In order to product-demodulate the signals in the receiver, a carrier-frequency component must be present. Because speech signals contain no dc energy, they do not produce a signal component at the carrier frequency; all the energy is in the sidebands. Therefore, in telephone practice, a reduced-level carrier tone is usually added to each transmitted DSBAM signal. This allows product-demodulation of the speech signals to baseband signals after they are separated by receiver filtering. This transmitted carrier can be used directly in a product-type demodulator at the receiver if its level is sufficiently high. If its level is not sufficiently high, it is used to generate a strong receiver carrier of the proper frequency and phase.

The attractiveness of DSBAM carrier transmission lies in the fact that speech multiplex terminals are relatively inexpensive since no transmitting filters are required, and the receiving filters to separate out the channels are relatively simple. If a strong carrier is transmitted, no receiving terminal carrier supply is required, further reducing the terminal costs. However, the inclusion of a strong transmitted carrier for each multiplexed signal increases the power-handling requirements of the repeaters on the high-frequency line. Also, DSBAM transmission requires twice the bandwidth of the baseband signal per multiplexed channel. Both of these factors tend to make the line costs per voice circuit high. This combination of low terminal costs and high line costs makes DSBAM primarily useful for relatively short-haul systems such as N1 or N2 carrier. As discussed in Section 10.2.3, these systems use open wire or cable pairs and are generally more economical on a per-circuit basis than separate voice-frequency pairs for distances of about 20 miles or more.

Single-Sideband Amplitude Modulation (SSBAM)

When the line exceeds several hundred miles in length, line costs begin to outweigh terminal costs for DSBAM systems. It then becomes more economical, for speech transmission, to spend more money on terminals to reduce the line-cost component. Since all of the information in the baseband speech signal is contained in one of the sidebands in the DSBAM wave, using single-sideband (SSB) transmission reduces the bandwidth required per voice channel by one-half, thus allowing twice as many voice channels to be stacked in a given band as with DSBAM. The individual carrier frequencies are not transmitted in SSB modulation. This raises the ratio of information power to total transmitted power and allows a significant reduction in the cost of line repeaters. Although SSB modulation is used in N3 carrier paired cable applications in the exchange plant, its principal use is in long-haul transmission systems operating in the 200- to 4000-mile range and employing either coaxial cable or microwave radio for the wideband medium. Many hundreds of frequency-division-multiplexed voice channels can be transmitted on these systems, as discussed subsequently in Sections 6.2 and 10.3.

Although either sideband could be selected for transmission, in most systems the lower sideband of each multiplexed signal is used. In either case, filtering out one of the sidebands shown in Fig. 6-10 results in a transmitted SSB carrier signal that inherently contains quadrature distortion components; that is,

$$M(t) = 1/2a(t)\cos \omega_c t + 1/2\hat{a}(t)\sin \omega_c t.$$

The $\hat{a}(t)$ signal is the Hilbert Transform of $a(t)$ and may be thought of as being produced by a filter that shifts the phases of all frequencies in $a(t)$ by 90 degrees.

Ideally, to avoid quadrature distortion in a product-demodulated SSB signal, the demodulating carrier should be at the same frequency and in phase with the modulating carrier. Practically speaking, precise frequency and phase control of the demodulating carrier is not critical for speech signals; however, data signals transmitted over SSB-derived voiceband channels are more sensitive. Improved control of the phase and frequency of the demodulating carrier in SSB systems is provided by a nationwide network synchronization plan which is based on transmitting a single pilot frequency along with the multiplexed voice channels to derive all the carriers used by the receiving demultiplex terminal (see Section 6.2).

Frequency Modulation

Another type of modulation used in voice transmission systems is angle modulation, which has the following representation:

$$M(t) = A\cos[\omega_c t + \phi(t)].$$

Several varieties of angle modulation, one of which is *phase modulation,* are possible, depending on the relationship between the angle $\phi(t)$ and the baseband modulating wave. The one most commonly used in microwave radio transmission is *frequency modulation* (FM).

In FM, the transmitted carrier wave is generated by varying the frequency of an oscillator so that the angle $\phi(t)$ is proportional to the integral of the modulating function or frequency deviation $f(t)$. That is,

$$\phi t = 2\pi \int_{-\infty}^{t} f(t)\,dt.$$

The demodulation process at the receiver is independent of any reference carrier amplitude or phase and is accomplished in a device called a *discriminator* which extracts the derivative of the phase angle $\phi(t)$. The ease of generating the modulated signal and the relatively simple demodulation process are two of the reasons that FM is attractive for radio transmission in the 4-, 6-, and 11-GHz common carrier bands. Of far more importance, however, is the fact that the total transmitted power in the FM wave is constant and independent of the modulation. This constant-envelope property provides immunity from nonlinear distortion caused by compression in microwave amplifiers.

Except in the case of video, FM is not used in Bell System microwave applications to modulate individual signals directly. The arrangement used for voice is to frequency-modulate a large group of frequency-division-multiplexed (FDM) SSB channels into an intermediate frequency range and then to shift this FM signal (by AM) to radio frequencies for transmission. Thus, in radio transmission, both FM and AM are used for processing blocks of voice channels.

Where the size of the phase or frequency deviation is arbitrary, the rule of thumb generally used to estimate the required bandwidth of a radio channel carrying an FDM-FM signal is given by

$$B = 2(f_t + f_d)\text{Hertz.}$$

In this expression, f_t is the highest baseband frequency in the modulating signal, and f_d is the peak frequency deviation. This expression (called *Carson's*

Rule) gives results that agree quite well with the RF channel bandwidths actually used for FDM voice transmission in the 4-, 6-, and 11-GHz common carrier bands. It should be recognized, however, that this is only an approximate rule and that the actual bandwidth required is to some extent a function of the modulating wave and the desired quality of transmission.

From the above discussion it is evident that FM transmission requires more bandwidth than DSBAM. On the other hand, it can be demonstrated that for a sufficiently high frequency deviation, the baseband signal-to-noise ratio after demodulation, as compared with an equivalent AM system, increases with the square of the required bandwidth B. This aspect of FM is not used to any great extent in Bell System microwave applications, because of the very wide bandwidths required and the need to conserve the radio-frequency spectrum.

Pulse Code Modulation

The preceding sections have discussed modulation systems in which the amplitude or phase of a carrier is varied continuously in accord with the analog baseband signal to be transmitted. In pulse code modulation (PCM) systems, continuous analog signals such as speech are converted to binary pulses to provide a more rugged signal for transmission. Such a signal has a higher immunity to noise or other interference and can be completely regenerated at each repeater point, which usually permits simpler repeater designs than analog carrier systems using AM or FM transmission. Furthermore, regeneration in digital transmission significantly reduces the accumulation of signal degradation, with the result that voice-channel transmission impairments are controlled largely by PCM terminal design. The price paid for this ruggedness is an increase in transmission bandwidth required relative to that needed for the original signal, but the system is tolerant of impairments in the medium, and the bandwidth-performance tradeoff often results in significant economies in system design.

PCM allows a number of speech signals to be combined on a time-division-multiplex (TDM) basis as discussed in Section 6.2. Time-division-multiplex terminals are usually less expensive than their counterparts in FDM systems, and for short-haul carrier applications (where terminal costs play an important role in overall system cost), PCM has a significant advantage over other modulation methods for speech transmission. The features and advantages of the T1, T2, and T4M PCM Carrier Systems used in these applications are covered in Section 10.2. In the following paragraphs, the functions of sampling, time-division multiplexing, quantizing, and encoding required in a PCM terminal (and illustrated in Fig. 6-12) will be discussed.

Sampling and Time-Division Multiplexing—In sampled systems, the unmodulated "carrier" is a series of regularly recurring pulses of equal amplitude. In considering the feasibility of converting continuous analog signals to a train of samples, it is important to recognize that continuous transmission of information describing the modulating function (input signal) is unnecessary, provided that the modulating signal is bandlimited and samples are taken often enough. The necessary conditions are expressed by the sampling theorem which states:

> If a signal time function is sampled instantaneously at regular intervals and at a rate at least twice the highest significant signal frequency, the samples contain all the information of the original message.

For example, a signal bandlimited to f_t Hertz is completely specified by its amplitudes at any set of points in time spaced $T = 1/2ft$ seconds apart. Hence, to transmit such a bandlimited signal, it is only necessary to send $2f_t$ independent samples per second. For speech transmission, a sampling rate of 8 kHz generally is considered satisfactory.

As shown in Fig. 6-12, the duration of the samples of any particular voice signal need not occupy the entire sampling interval T. Thus samples from a number of channels can be interleaved in time (time-division-multiplexed) on a common bus. Clearly, as the number of voice channels is increased, the time that can be allotted to each is reduced, and the samples must be placed closer together. Closer spacing requires greater transmission bandwidth, so that bandwidth limitations restrict the number of channels that can be time-multiplexed.

Quantizing—As discussed, the sampling process converts a continuous signal to one that is discrete in time. Pulse code modulation requires that the signal be made discrete in amplitude as well, so that it can be represented by a finite number of binary digits. Reducing a signal to a limited number of discrete amplitudes is called *quantizing*. This process inherently introduces an error in sample amplitudes. This error is called *quantizing noise* and is the dominant signal impairment in PCM transmission.

In PCM terminals, the amplitude quantizing device operates on the composite stream of pulse samples from all n channels, as indicated in Fig. 6-12. The simplest form of quantizing divides the input peak-to-peak signal amplitude range into N steps of equal widths. Thus, in this case, an input sample amplitude falling between X_i and X_{i+1} would be quantized to level Y_i as shown in Fig. 6-13. For sampled speech signals, however, the smaller amplitudes are more probable, and therefore a lower overall mean square quantizing error results if the quantizing intervals are made smaller near the origin in Fig. 6-13, at the expense of larger intervals for the less probable larger sample amplitudes. This can be achieved by predistorting the input signal by using an instantaneous compressor device[4], prior to passing it through a uniform quantizer. With a compression characteristic $F(z)$, such as is shown in Fig. 6-14, this arrangement gives preferential gain to weak signals and, for quantized speech, provides a signal-to-distortion ratio improvement of about 20 dB.

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4. Complementary expansion is employed at the receiver to restore the original sample amplitudes. The overall process is referred to as *companding*.

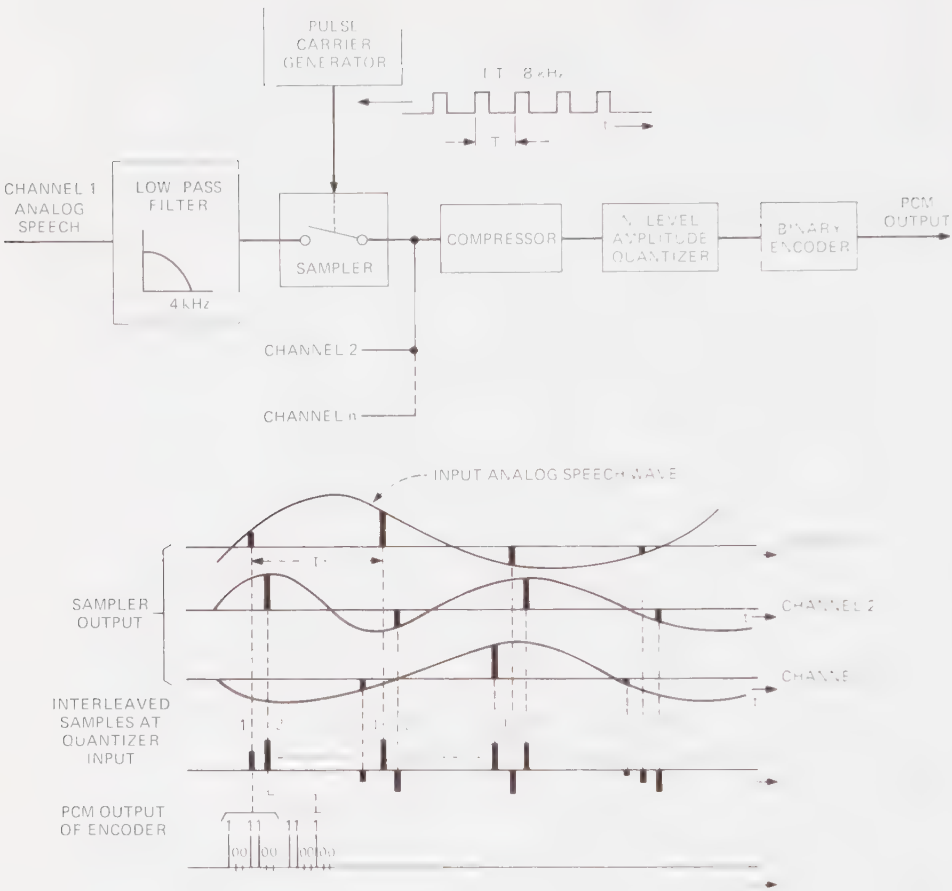

Fig. 6-12. Formation of Speech Samples and PCM Signals

Encoding—A quantized sample can be sent as a single pulse having any one of N discrete amplitudes, where N is the number of possible values. However, if N is large, it is difficult to design repeaters that can distinguish between amplitudes. On the other hand, circuits that recognize only whether a pulse is present or not are relatively simple. Therefore, in PCM systems, quantized samples are typically encoded into binary numbers called code words for transmission over the high-frequency line. This conversion process is illustrated in Table 6-4. In general, an N-level quantizer requires $\log_2 N$ binary digits for the transmission of each quantized sample, and therefore $2f_t \log_2 N$ binary digits per second are required to transmit an analog speech signal bandlimited to f_t Hertz. A corollary to the sampling theorem shows that a

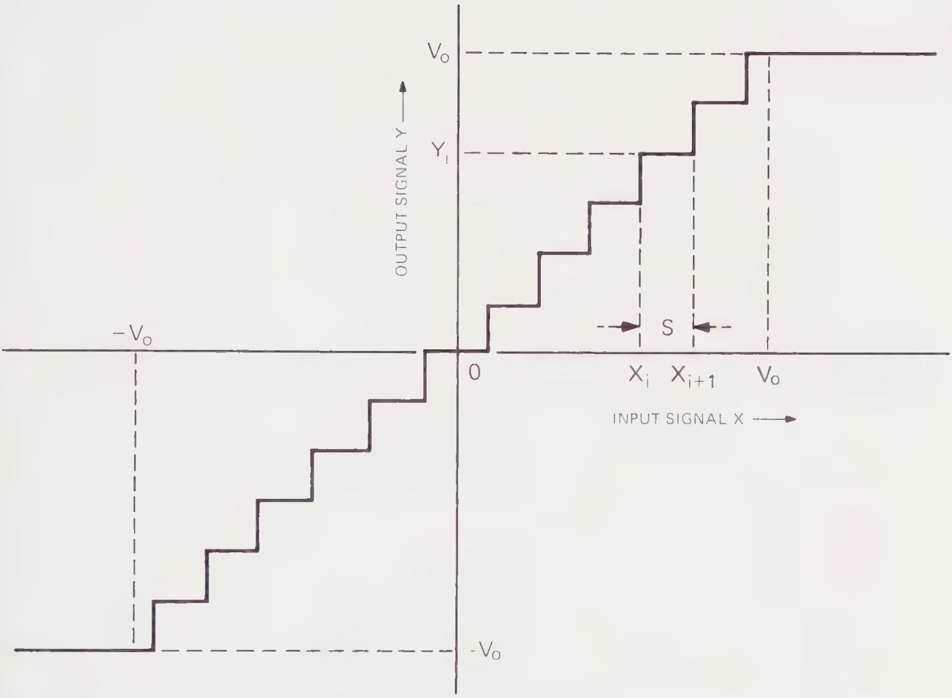

Fig. 6-13. Uniform Quantization

maximum of $2f_t$ independent binary[5] pulses per second can be transmitted successfully at baseband through a bandwidth of f_t Hertz. Thus if f_t Hertz is the highest frequency in the voice channel and $\log_2 N$ is the number of binary pulses per code group, approximately $\log_2 N f_t$ Hertz of bandwidth per voice channel is required. This is $\log_2 N$ (typically 7 to 9) times the bandwidth required for analog voice transmission, either at baseband or using SSB amplitude modulation.

PCM Transmission Using Phase-Shift Keying (PCM-PSK)—PCM-PSK is an example of modulation especially suited to specific media and their associated technologies. Digital phase modulation, sometimes referred to as *phase-shift keying* (PSK), is an attractive method for transmitting time-multiplexed PCM voice signals over certain bandpass channels. It combines some of the desirable features of both linear AM systems and frequency modulation. In

5. The principle is not limited to binary pulses. In systems where noise is low enough, multilevel symbols rather than binary pulses can be used to increase the bit rate. This is discussed further in Section 6.1.4.2.

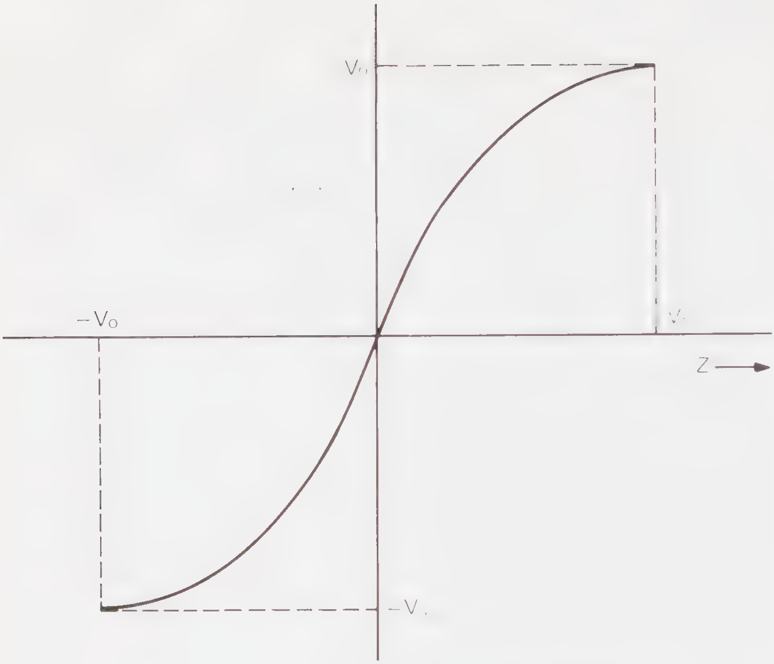

Fig. 6-14. Instantaneous Compression Characteristics

differential phase-shift keying (DPSK) systems, the digital information is conveyed in the form of carrier phase changes, and signal detection is accomplished by comparing the carrier phases in two adjacent pulse intervals. Alternatively, coherent phase-shift keying (CPSK) systems carrying the digital information in the absolute carrier phase and, therefore, requiring an absolute carrier phase reference for detection, may be used. Ideally, the error rate performance achieved with coherent detection in the presence of receiver noise and interference is superior to that achieved with differential detection, because the phase reference derived is not subject (as it is in DPSK) to the same disturbances as the signal.

For waveguide and 18-GHz radio transmission, PCM-PSK is attractive because the oscillator has only to furnish carrier power and has no requirements on modulation sensitivity, linearity, etc. Also, a rugged signal format is desirable for these media, because low-noise devices and precise equalization of the media are difficult to obtain. PCM-PSK modulation is particularly well-suited for 18-GHz radio applications because the short repeater spacings (1 to 5 miles) required for reliable operation at these frequencies in the presence of rain fading would lead to an excessive accumulation of signal distortion if analog modulation methods were used. Moreover, the inherent resistance to interference of the PCM-PSK signal permits liberal reuse of frequencies in the 18-GHz band, thereby allowing the design of relatively dense radio networks.

AMPLITUDE REPRESENTED	BINARY CODE
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

TABLE 6-4
BINARY REPRESENTATION OF AMPLITUDE

Delta Modulation (Δ-Mod)

Like PCM, delta modulation involves an encoding process, and its simpler implementation makes it more attractive than PCM where a single speech signal is to be encoded. This form of modulation is employed in the Subscriber Loop Multiplexer (SLM[6]) System and the Subscriber Loop Carrier (SLC−40[6]) System (see Section 10.1).

The Δ-mod transmitter is illustrated in Fig. 6-15. It operates by encoding the difference between the present and previous speech sample into a single binary digit. The output digit stream therefore conveys the polarity of the difference signal, and the receiver reconstructs the speech wave using an integrator identical to that shown in the transmitter feedback loop. Because the coder can follow only input signal changes equal to one quantizing step S between sampling times, large errors can occur when the slope of the input signal exceeds S/T. To avoid such errors, delta modulation uses a higher sampling rate than straight PCM encoding, and the S/T ratio is adjusted to optimize both quantizing noise and slope-overload performance. Companding, which is desirable for speech processing, is achieved by varying the step size in response to the slope of the speech waveform.

Simple systems such as the one shown require bit rates in the 300-kilobit-per-second region. More elaborate Δ-mod schemes operate at rates below 60 kilobits per second.

6.1.4.2 Modulation Systems for Data Communication

The modulation systems to be discussed in this section are those used for transmitting baseband digital data signals over bandpass analog channels. The modulation method used in any particular application depends on the available channel bandwidth and is generally a compromise between simplicity of instrumentation and high-efficiency transmission (bits per second per Hertz of bandwidth).

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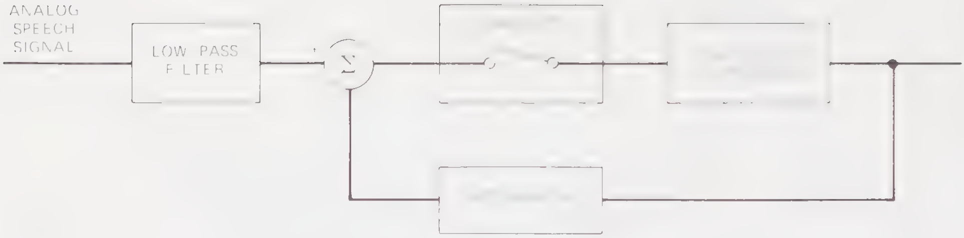

Fig. 6-15. Delta Modulation Transmitter

Frequency-Shift Keying

In data modulation applications where hardware economy and simplicity are more important than efficient utilization of available channel bandwidth, binary FM in the form of frequency-shift keying (FSK) is the usual choice. Typically, the frequency shift in Hertz is from one-half to three-quarters of the maximum bit rate, and the required channel bandwidth in Hertz is nearly equal to twice the maximum bit rate. This permits the recovery of the baseband data wave (based on the rate of occurrence of carrier zero-crossings or other techniques) without excessive perturbation of the timing of the data transitions. It also allows the system to be operated asynchronously at any data speed up to the maximum capability. FSK has been used successfully in voiceband data applications at speeds up to 1800 bits per second.

Phase-Shift Keying

For medium bandwidth efficiency, coupled with moderately simple signal generation and detection, differential phase-shift keying (DPSK) is a good modulation choice. It has become the worldwide standard for 2400-bit-per-second data transmission over voiceband channels and has been used for high-speed data transmission ($\approx$20 megabits per second) over radio frequency channels that normally carry analog FDM-FM signals in the 4-GHz common carrier band. In both cases, 4-phase signaling is used; that is, each symbol has four possible states, $\pm 45°$ and $\pm 135°$. This allows two bits per symbol to be transmitted and results in a required channel bandwidth that is somewhat less than the bit rate.

In 4-GHz radio applications, an FM deviator is employed to generate the broadband DPSK signal, and the modulation plan is therefore often referred to as FM-DPSK. This method of DPSK transmission has great appeal, because it permits the use of digital terminal additions to existing analog FM radio systems. The FM-DPSK signal is completely compatible with the nonlinear properties of microwave amplifiers mentioned previously and can operate through a number of analog radio repeaters before being regenerated.

Digital Amplitude Modulation

The two most common types of digital amplitude modulation used in Bell System data applications are vestigial sideband (VSB) and quadrature AM (QAM). Both of these systems are used in voiceband data transmission for speeds between 4800 and 9600 bits per second. VSB modulation is also attractive for high-speed ($\approx$13-megabit-per-second) data transmission over 2.5-MHz mastergroup assignments on modern coaxial cable systems using L mastergroup digital terminals (LMDTs) (see Section 10.3.2).

Vestigial sideband modulation is a modification of DSBAM in which part of the frequency spectrum is suppressed. As shown in Fig. 6-16, this is achieved with a special transmitting filter having a symmetrical gradual roll-off in the carrier frequency region. Since coherent detection of VSB signals is required, low-frequency energy in the data signal baseband spectrum usually is also removed at the transmitter (and restored at the receiver[7]) to clear a small region for the insertion of a carrier pilot for signal demodulation. When the VSB signal is demodulated, the vestige of the missing sideband fills out the attenuated portion of the other sideband to fully recover the original baseband data wave.

In the quadrature amplitude modulation (QAM) approach, two DSBAM carrier signals are transmitted in quadrature phase and then separately coherently demodulated. This allows two independent baseband data signals to be transmitted in the same channel bandwidth. This can be done because with DSBAM there is no quadrature component as there is in SSB or VSB AM systems, and thus there is no interference between the two signals[8].

Increasing the Data Transmission Rate

The concept of a symbol that carries more than one bit is a very important one; this was mentioned in connection with PSK and will now be examined further. In the case of coherent PSK (CPSK), the information is found in the phase of the received wave with respect to the phase of a reference wave. The expected state of the received wave can be +45°, -45°, +135°, or -135°, corresponding respectively to 00, 01, 10, and 11. Thus, when the symbol has been received, two bits of information have been received. If 8 nominal phases are defined, the symbol will carry 3 bits, and with 16 phases, 4 bits. Of course, with more phases there is a greater likelihood that noise will cause an incorrect symbol to be received. The result is shown in Fig. 6-17, which gives the signal-to-noise ratio required for one error in 10^4 bits for 4-, 8-, 16-, and 32-level CPSK symbols. PSK has been discussed for simplicity. Multiple levels also can be applied with other types of modulation; in fact, for the very highest signaling rates over telephone channels, VSB and QAM are more attractive in theory and in practice.

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7. Using quantized feedback or other techniques.

8. Provided the frequency response of the channel is symmetrical about the carrier frequency.

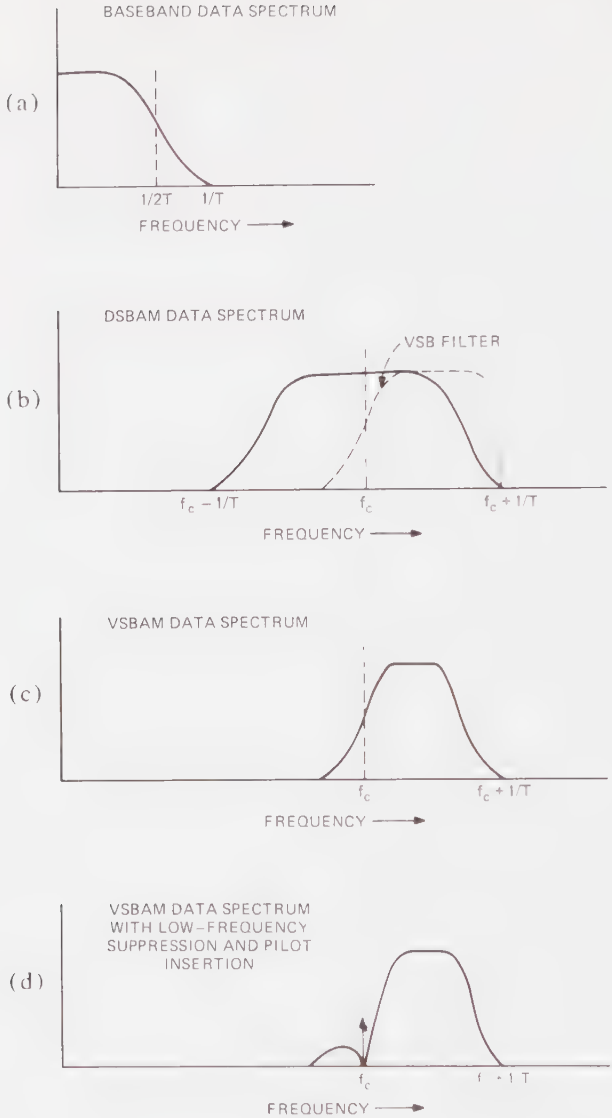


Fig. 6-16. VSB Signal Spectrum

In striving for the maximum rate in view of the signal perturbations found on real channels, a useful tool is the signal space diagram described in Reference 1. It is desirable that the received signals in the set of normal signals, as perturbed, be at a maximum distance from each other in this 2-dimensional signal space diagram. The modulation systems discussed previously can be thought of as producing patterns of points called *constellations* in a signal space diagram. It is to be noted that the process of producing maximum dis-

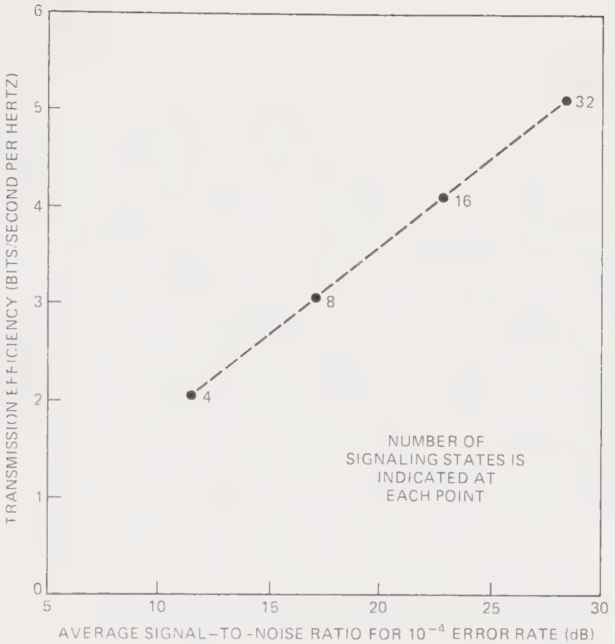


Fig. 6-17. Transmission Performance of Multilevel CPSK

tances in a constellation may result in signals that do not quite correspond with any of the types of modulation discussed such as QAM or VSB.

6.2 TRANSMISSION MULTIPLEXING

As indicated in Section 6.1.4, modulation provides a means by which signal multiplexing can be accomplished. Multiplexing allows many different users to be served by the same transmission path. For voice transmission, both frequency-division and time-division multiplexing (FDM and TDM) are used in Bell System carrier equipment. This section discusses the hierarchical multiplex organizations that have evolved for both the FDM and TDM carrier systems and the challenge of efficient multiplex utilization to minimize the combined cost of multiplex and line facilities. It also considers arrangements for synchronizing multiplex operations in FDM and TDM equipment.

References 2 and 12 through 14 for supplementary reading are listed at the end of this chapter.

6.2.1 THE FDM HIERARCHY

The practical implementation of frequency-division multiplexing in the Bell System involves several steps of analog modulation and demodulation. Fig. 6-18 depicts the Bell System SSB-FDM hierarchy and its relationship to the broadband analog transmission systems commonly used. The discussions that follow refer to this figure and will attempt to clarify how and why this particular plan evolved.

The basic building block of the multiplex hierarchy is the voice channel. From a network operation standpoint, the voice channel is administered and maintained independently of the transmission facilities that are used to provide it. The basic voice channel, although originally intended for speech transmission, can be adapted for data transmission in the speed range of several kilobits per second by using FSK, PSK, VSB, or QAM modulation techniques. It also can be fed from the 43-type multiplex terminal to provide a multiplicity of low-speed FM telegraph channels.

In the first multiplexing step for voice channels, SSBAM is used to combine 12 channels into a set called a *group*. The 12-channel modulating equipment is known as an *A-type channel bank* and is the standard building block for almost all long-haul broadband analog systems. The modulation plan for the A-type channel bank is based on a uniform voice-channel spacing of 4 kHz, and the frequency band occupied by a 12-channel group is 60 to 108 kHz[9].

The group, then, represents another basic building block in the FDM hierarchy. The next step is the combining of five groups, again using SSBAM, into a 60-channel supergroup occupying the band from 312 to 552 kHz. There are several practical reasons for forming the supergroup in this manner, instead of continuing the modulation of separate carriers by individual voice channels. One reason is that economical SSB filters of the required characteristics are available only over a limited frequency range. Another important consideration is the number of different filter designs and carrier supplies needed. By using a group bank, five sets of A channel banks can be used in parallel, thereby simplifying the problems of equipment maintenance and providing spare parts in the field.

In a similar manner, the combination of 10 supergroups forms a 600-channel mastergroup. In the formation of a mastergroup by a supergroup bank, two slightly different methods have been used, as shown in Fig. 6-18. The L600 mastergroup occupies the 60- to 2788-kHz band and is the broadband signal originally developed for transmission on the L1 Coaxial System and TL and TM Radio Systems (see Sections 10.2 and 10.3). The U600 mastergroup occupies slightly higher frequencies (564 to 3084 kHz) and is of more recent vintage. It is used as the standard building block for modern radio and coaxial systems that support even larger groupings. It is planned to use the U600 mastergroup in all new installations.

Larger groupings are established with mastergroup multiplex (MMX) equipment and were developed to be consistent with the usable bandwidth available on radio and coaxial media as electronic technology advanced. For example, on L3, the successor to L1, three mastergroups and one supergroup

9. The 48-kHz-wide group band is sometimes used for either synchronous or asynchronous data transmission at about a 50-kilobit-per-second rate, using the 303-type VSB data terminal. These data terminals are used in encrypted voice transmission as well as in computer data applications.

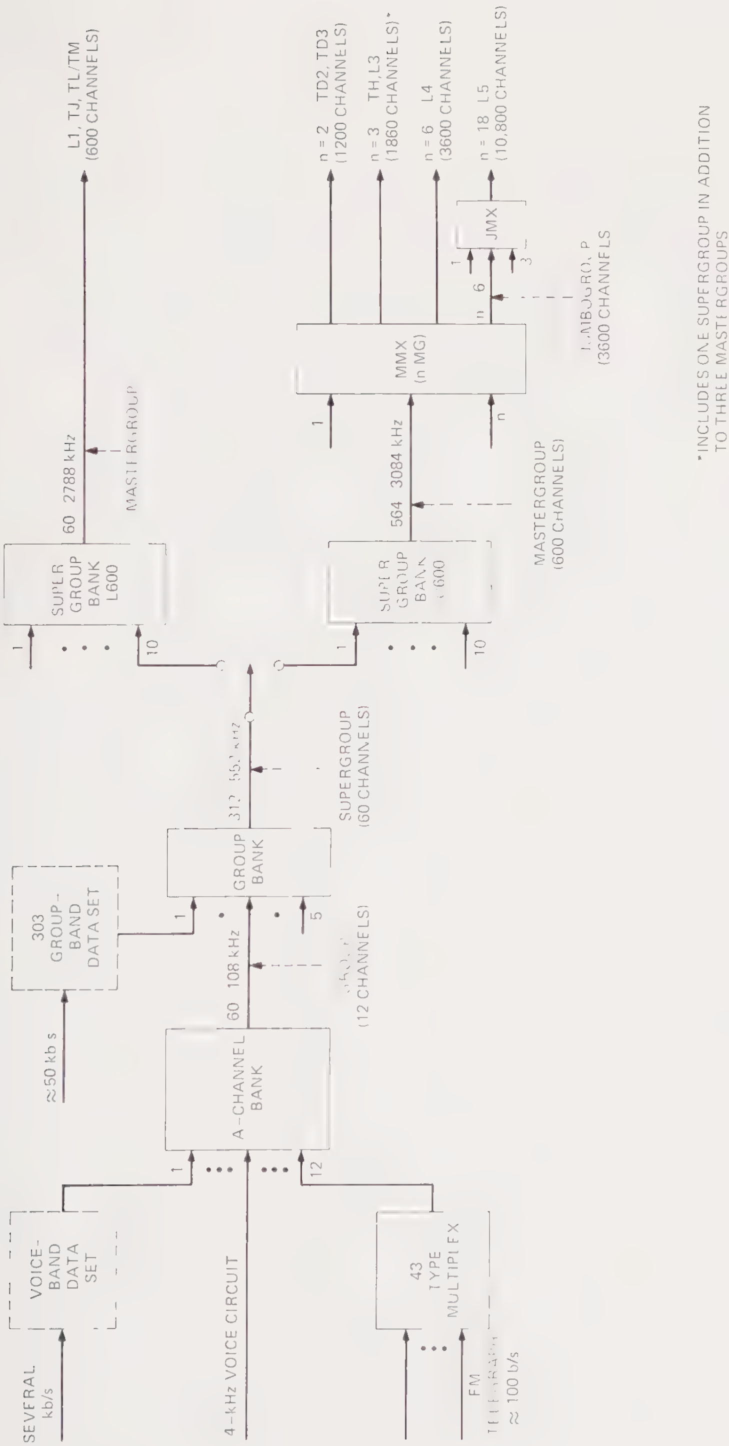


Fig. 6-18. Long-Haul SSB-FDM Hierarchy

comprising 1860 channels are combined for transmission over a single coaxial tube. Likewise, in the TD and TH Radio Systems, MMX equipment was developed to form two and three mastergroup bundles for FM transmission over 20- and 30-MHz channel assignments in the 4- and 6-GHz common carrier bands. Furthermore, modifications to radio MMX equipment to allow expanded capacities of 1200 circuits on TL and TM, 1500 circuits on TD, and 2100 circuits on TH also are now available. The features of all the systems and multiplex equipment shown in Fig. 6-18, including the jumbogroup multiplex (JMX) which combines up to 18 mastergroups for transmission on a single coaxial tube in the L5 system, are covered in more detail in Chapter 10.

6.2.2 THE TDM HIERARCHY

As in frequency-division-multiplex systems, time-division-multiplex transmission involves several hierarchical stages of signal combining. At present, a 4-level hierarchy has been established, DS-1[10] to DS-4 (see Fig. 6-19). Each level of the hierarchy has a fixed bit rate, a maximum number of voice circuits that can be carried, and a circuit designation. The 1.544-megabit-per-second PCM signal delivered by the D channel bank is the DS-1 level signal, and the associated 24-voice-channel group is referred to as a *digroup* (*di*gital *group*).

Digital voice channels available within the TDM structure also can be used for data transmission. In the synchronous data transmission mode, the efficiency of digital channel utilization approaches 90 percent. For example, in the Digital Data System (DDS) (covered in Section 12.4) a single 56-kilobit-per-second data signal replaces only one 64-kilobit-per-second PCM speech signal in a DS-1 bit stream. Furthermore, lower-speed synchronous data at 2.4, 4.8, and 9.6 kilobits per second can be combined in submultiplex arrangements to produce a bit rate combination of up to 48 kilobits per second for transmission over a single 64-kilobit-per-second voice channel. Thus, digital channels in the TDM hierarchy are much more efficient than analog channels in the FDM hierarchy in the substitution of data for voice. Of course, special multiplexing equipment is required to combine data channels and to combine data with voice channels (see T1DM and T1WB4 in Fig. 6-19) to make use of the digital facility. Other arrangements must be provided to extend the circuit to the customer's premises.

As shown in Fig. 6-19, the time-multiplexing of data with PCM voice signals is accomplished with a T1WB4 data terminal used as an adjunct to a D channel bank. These terminals insert data signals into a DS-1 stream in 8-bit bytes and can multiplex up to twelve 56-kilobit-per-second circuits in the place of a like number of PCM voice circuits. Higher DS-1 data fills are provided with a T1DM data multiplexer which will accommodate up to twenty-three 56-kilobit-per-second data circuits. Long-haul DDS transmission will be

10. DS-1 is a contraction of "digital signal number one".

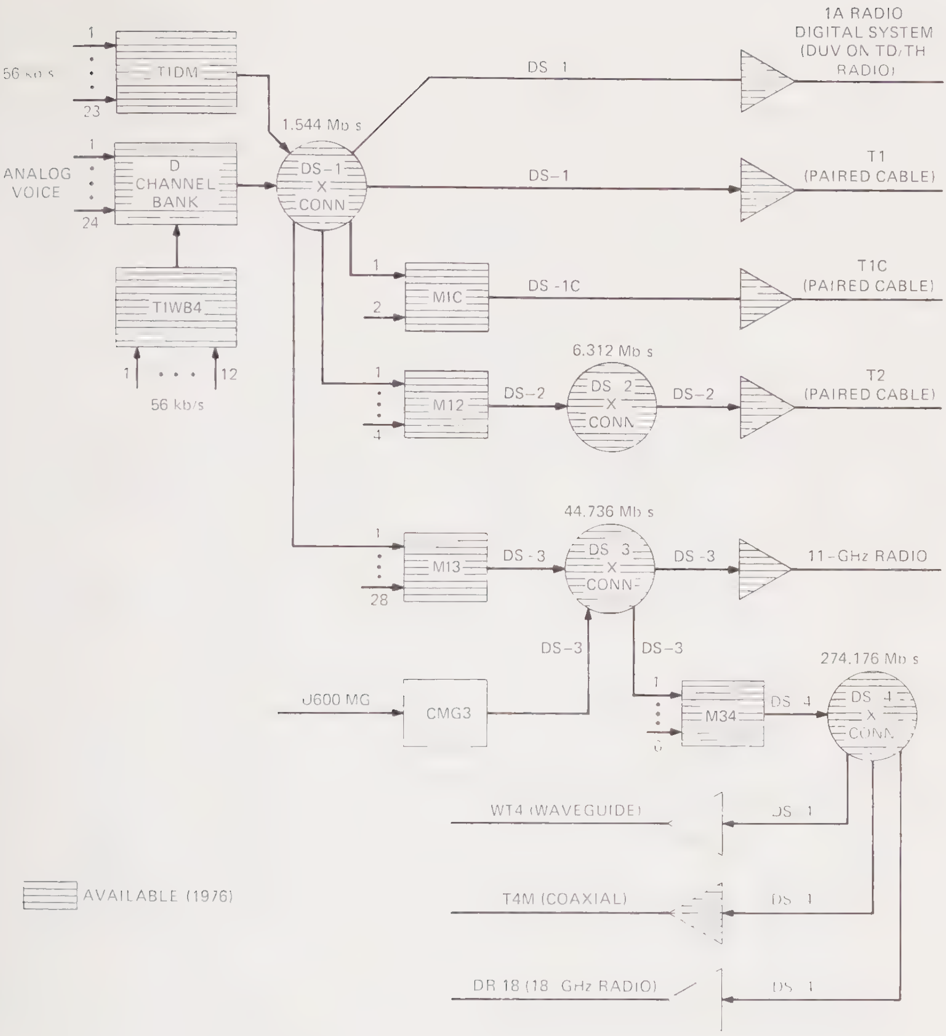


Fig. 6-19. TDM-PCM Hierarchy

provided mainly with the 1A Radio Digital System (1A-RDS) using the data under voice (DUV) technique. (See Section 10.3.3.)

Multiplexers used to combine PCM signals at levels above DS-1 are named for the rates they bridge. Multiplexer M12, for example, is designed to combine four DS-1 signals into a DS-2 signal, and multiplexer M13 combines 28 DS-1 signals into a DS-3 signal. The multiplex hierarchical organization in relation to the digital carrier systems in use or planned and the rates at the various levels are determined largely by the capabilities of the paired cable, coaxial cable, radio, and waveguide media used for high-speed digital transmission. Of particular importance is the DS-3 rate, which was established primarily to allow interconnection between the TDM and FDM hierarchies without demultiplexing each channel to voice frequencies (that is, back-to-back A and D channel banks). To provide this interconnection capability, the CMG3 mastergroup terminal in Fig. 6-19 encodes a U600 mastergroup into a 44.736-megabit-per-second stream using 8-digit PCM. This option, referred to as FDM-PCM, will be especially important as digital transmission over waveguide in the long-haul network evolves, because many voice-channel connections are expected to be provided over a mix of digital waveguide, analog radio, and coaxial systems. For such connections, the added cost of using a PCM format for 64-kilobit-per-second voice transmission over analog carrier systems or of introducing a complete FDM and TDM multiplex array for 4-kHz voice-frequency interconnection at each digital-to-analog cross-connect point would be prohibitive.

When voice signals travel end-office-to-end-office entirely on digital facilities, D-type channel banks are used. In this case, the M13 multiplex allows 672 TDM-PCM voice circuits (a master digroup) to be transmitted on a DS-3 rate channel. Thus, a 12-percent higher voice capacity is achieved on broadband digital facilities when totally digital network paths are used. This increase stems primarily from the fact that the companding advantage cannot be realized when a nondigital mastergroup is encoded.

6.2.3 CIRCUIT BUNDLING AND MULTIPLEX ADMINISTRATION

A challenge in multiplex administration in the Bell System network involves the tradeoff between using extensive multiplexing, which may involve significant costs but produces high circuit fills on transmission facilities, and using less multiplexing, which obviously costs less but results in a lower line fill. This phenomenon arises because of the hierarchical structure of both the existing FDM systems and the planned TDM systems. For example, in the analog plant it is possible to cross-connect circuits between or within facilities at the mastergroup, supergroup, group, or voice-channel levels. Cross-connection at the higher levels is much cheaper, but when these higher-level cross-connections are used, the line fill decreases. This is due to the combinatorial nature of bundling smaller packages into one large one; because of the circuit routings in the network, there may be fewer than 600 channels to be cross-connected. Thus, there will be a tradeoff similar to that illustrated in Fig. 6-20 between the cost of line facilities and the cost of multiplexing or cross-connection.

An example may provide better insight into the problem. Suppose in Fig. 6-21 an integral number of supergroups X between A and B were needed, where $1 \leqslant X \leqslant 10$. Since 10 supergroups can form one mastergroup, for $X = 10$ it is obviously better to send a single mastergroup between A and B. However, for values of X less than 10 the decision is quite complicated. If one were to route X supergroups via a through mastergroup, there would be considerable multiplex savings at the intermediate nodes. However, the savings

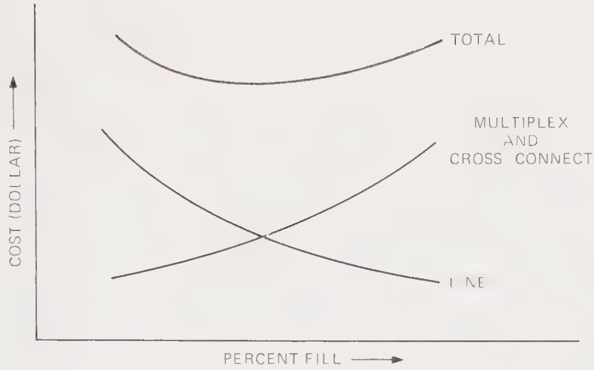


Fig. 6-20. Line Versus Multiplex Cost Tradeoff

are counterbalanced by the increase in line costs because the fill factor of the mastergroup is only $X/10$. A simple decision criterion is based solely on the value of X; if X exceeds some threshold value X_m, route as a mastergroup; otherwise, route as X supergroups, with intermediate supergroup multiplex. Such a simplified decision, however, ignores many relevant factors, such as:

(1) How many links are on the A-B path, and what are the length and type of transmission facilities employed on each link?

(2) Are there growth possibilities available as a result of previous multiplex installations?

(3) How long will it take to fill the multiplex equipment contemplated for installation?

(4) How is the circuit routing in the network likely to change in subsequent years?

Fig. 6-21. Supergroup Routing Versus Through Mastergroup Routing

To solve the problem exactly with all the above factors included is a difficult task, and any complicated decision rule would be difficult to implement in practice. The present policy at AT&T Long Lines for the FDM hierarchy is: if there are nine or more supergroups, route as a mastergroup (that is, $X_m = 9$). Similarly, for decisions regarding group versus supergroup routing, if there are four or more groups, route as a supergroup. This high-fill policy has been evaluated in the network; the shallowness of the cost optimum with respect to variations in the assumed decision rule indicates that the factors ignored do not significantly affect overall network cost.

Similar network modeling is currently under way to determine an appropriate fill policy for the TDM hierarchy in the evolving long-haul digital network. There is some evidence, with the expected lower per-circuit cost of waveguide in the long-haul network, that a lower fill policy will be preferred. This will lead to reduced maintenance costs, since the number of units in the plant is reduced, and rearrangement to meet unexpected demands for service will be easier because of the availability of unused line equipment.

6.2.4 MULTIPLEX SYNCHRONIZATION

The SSB FDM hierarchy requires a source of carrier power for each channel or group of channels modulated from one frequency band to another. Moreover, these carriers must be accurately resupplied for demodulation as noted in Section 6.1.4.1. To synchronize the modulation and demodulation operations in SSB carrier terminals, a nationwide network synchronization plan has evolved. Until very recently, this consisted of the following three elements:

(1) A quartz oscillator reference frequency standard located at Murray Hill, New Jersey and used to generate a precise reference frequency for distribution over the network.

(2) A reference distribution system originating with the reference frequency standard and transmitting single pilot frequencies over most long-haul analog carrier systems. The synchronizing pilots also are used for other transmission system functions and are often regenerated in local frequency supplies.

(3) Local frequency supplies, each of which selects the incoming reference, adjusts its internal oscillator to correspond to the reference and harmonically generates the necessary carriers used by the local multiplex equipment. Local frequency supplies are highly centralized installations common to as many as several thousand channels, thereby making redundancy and automatic protection necessary.

Most of the problems that exist in this synchronization plan lie in the response of network channels to perturbations of the synchronization reference. These perturbations may be transient phase disturbances caused by electromagnetic pulse interference, by the action of protective switches in the transmission system carrying the reference, or by maintenance activity, or they may be outright failures of the synchronization pilot caused by system failure or the failure of a frequency supply used as a regenerator in the synchronization chain. Because of these problems and because of the expected growth of increasingly sensitive services, improvements in the nationwide FDM synchronization plan have been under consideration for some time.

The improvement program currently under way is aimed at both reducing the sensitivity of the synchronization network to perturbations in transmission and ensuring adequate frequency precision even during loss of reference. The changes include:

(1) A new reference frequency standard using a cesium beam source, located at Hillsboro, Missouri. This standard was introduced in late 1973, coincident with initial L5 service between Pittsburgh and St. Louis.

(2) New reference signals disassociated from other transmission system pilots. These reference signals are at frequencies of 20.48 and 2.048 MHz. The former is being used by the L5 system, and the latter will be transmitted on lower-capacity cable and radio systems. Since these signals will be transmitted throughout the network without regeneration, whenever the reference signal is present at an office its precision is assured because it is supplied directly from the reference frequency supply.

(3) A new office master frequency supply modeled after the jumbogroup frequency supply (JFS) developed for use with the L5 Coaxial System. This supply is highly accurate and has the ability to disregard phase and frequency disturbances on the reference tone and to bridge a protracted loss of reference while maintaining excellent frequency precision.

6.2.4.1 The TDM Synchronization Plan

The main problems in TDM multiplex design are synchronizing the several input pulse streams so they can be properly interleaved in time and framing the composite bit stream so the component parts can be properly identified at the receiving end. Interleaving is not a problem in multiplexing that takes place in D banks, since all 24 voice signals are sampled with a common clock. Note that the signals are returned to voice form upon leaving the receiving D bank; they may then be combined with other voice signals in other D banks by repeating the sampling process. The multiplex framing problem at the DS-1 and higher levels in the digital hierarchy is handled quite simply by adding a deterministic framing pattern to the composite bit stream. The major problem, therefore, is how to interleave pulses from digital signal sources that can be separated by large distances.

The solution to this problem in digital multiplexers with output rate above the DS-1 rate is to allow all digital signal sources of the same nominal frequency to operate with independent clocks and to use pulse stuffing. As illustrated in Fig. 6-22, the concept is to cause the outgoing rate of the multiplexer to be somewhat higher than the sum of the incoming rates by stuffing in additional dummy pulses. All incoming signals are stuffed with a sufficient number of pulses to raise each of their rates to that of the locally generated multiplex clock. When a pulse is stuffed, however, an additional communication channel is required to inform the receiver of the location of the stuffed pulse. For this purpose a common data channel, time-multiplexed with the information pulses, is provided to send stuffing control information for all signals entering the multiplexer. Redundant transmission of this information minimizes the possibility of transmission errors that might cause the receiver to lose sync.

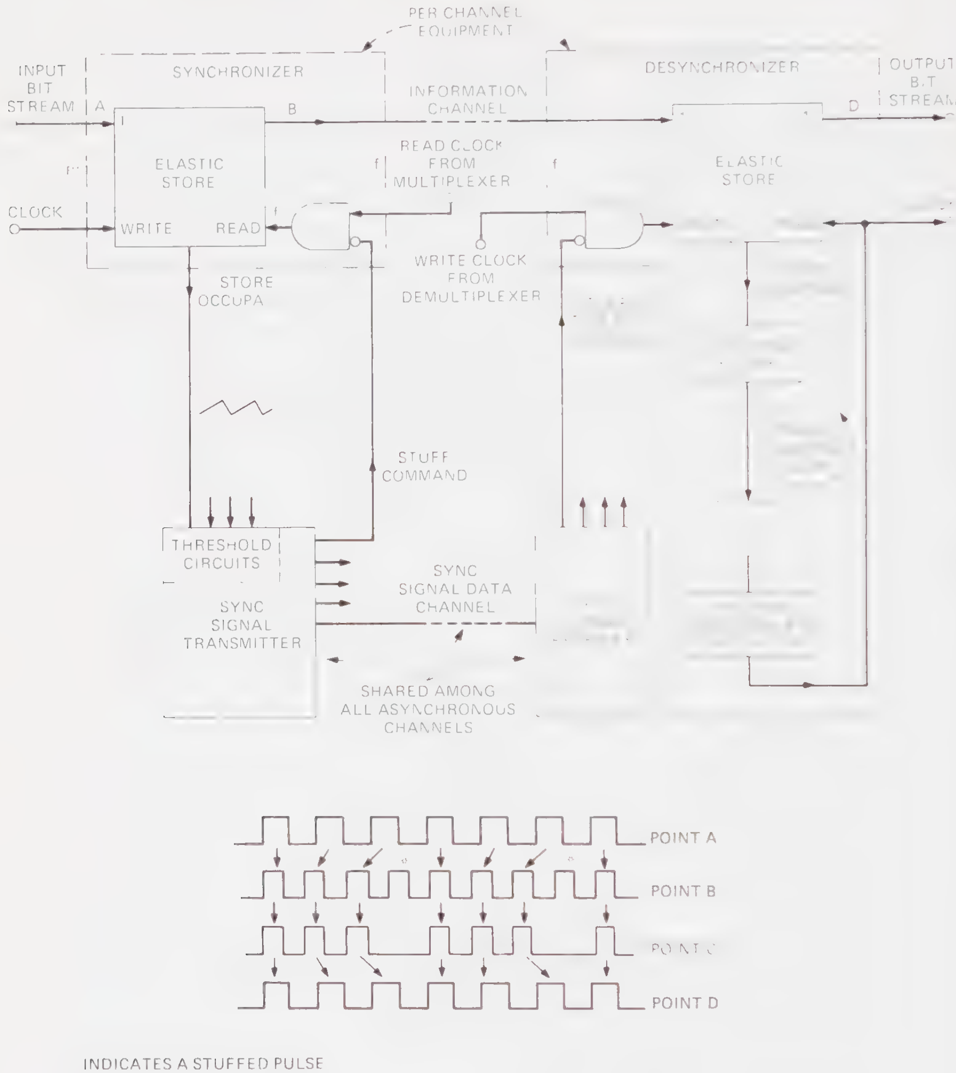


Fig. 6-22. Pulse-Stuffing Synchronization

The pulse-stuffing method of synchronizing a TDM network is attractive compared with other possible approaches because it needs the least amount of buffer storage for processing the multiplex input signals. This is particularly important at the higher digital bit rates because even if all signal sources were mutually synchronized, delay variations in the various transmission media could cause a surplus or deficit of pulses at any location. This discrepancy could be in the order of 100 pulses and must be absorbed by buffers (which are expensive at the higher bit rates). With stuffing, these pulse differences are made up immediately, so that only one or two cells of storage are needed to handle such variations. An additional advantage of pulse stuffing is that the timing at each multiplexer is independent, and therefore failure of a single multiplexer or the transmission facility it feeds will affect only those signals at its input.

The plan for synchronizing T1WB4 and T1DM data multiplex operations in the DDS network is similar to that used to synchronize carrier terminals in the SSB FDM hierarchy. Specifically, a master source using the new Bell System frequency standard as a reference will provide clocking to data multiplex oscillators at all DDS network hub offices (see Section 12.4) through a tree distribution system. Data sources on customer premises are clocked by this signal. The method of slaving at the multiplex is based on extracting synchronization from an incoming DS-1 data stream and phase locking an ultra-stable quartz oscillator to the DS-1 frame rate (8 kHz). No reconfiguring of the network in the event of failure is necessary. Under failure conditions, a free-running timing supply in conjunction with the data buffers provided as part of the multiplex will add or delete bits from a customer data stream only a few times a day at worst.

For the DDS, the synchronous network plan is more attractive than pulse stuffing because, at this level, the number of channels is large, and synchronization avoids the signal processing required with stuffing on each multiplexed channel. While large buffer stores are required to absorb variations in transmission delay in the synchronous plan, storage is relatively cheap at digital speeds below the DS-1 rate.

6.3 TRANSMISSION PLANS

Transmission planning for networks[11] includes:

(1) Identifying the transmission characteristics that need to be controlled.

(2) Specifying methods for measuring and quantifying each characteristic.

(3) Evaluating the effect of these characteristics on services.

(4) Formulating end-to-end performance objectives for the various characteristics that will provide a satisfactory quality of service.

(5) Allocating the end-to-end performance objectives to the parts of the network in terms of design objectives for equipment, engineering rules for application of equipment, and maintenance objectives for use of plant forces.

11. References 15 and 16.

(6) Establishing methods to monitor network performance to check whether objectives are being met.

The following paragraphs focus on transmission planning for the public telephone network. Similar considerations enter into the planning of private switched voice networks, but they will not be discussed here. Brief mention will be made of transmission objectives for data and television services.

It is important to recognize that transmission plans are not static. They must be responsive to technological improvements, to changes in customer subjective evaluation of service, and to changes in services such as the introduction of data transmission.

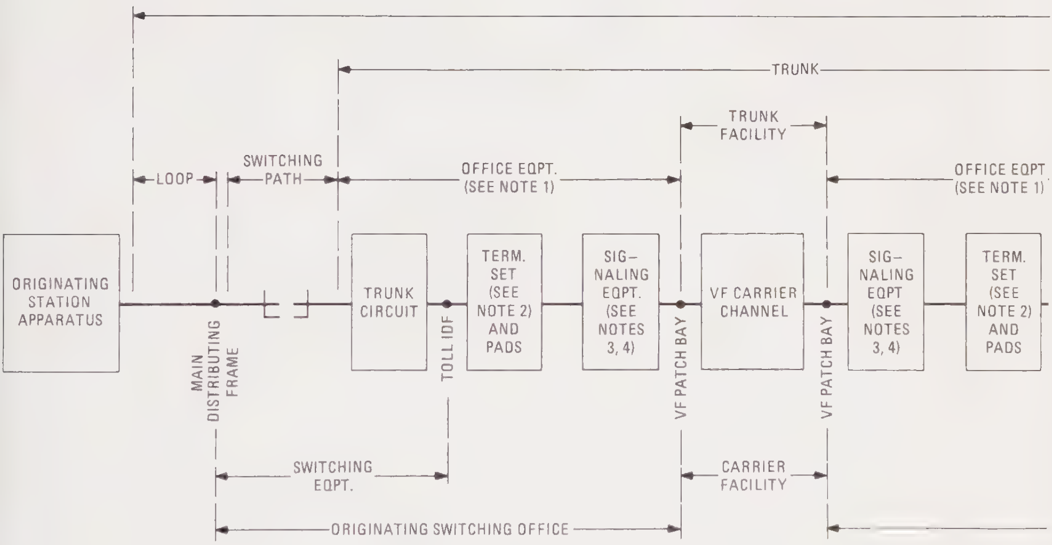
Early in this century, emphasis was on the conquest of distance; the principal objective was to achieve intelligible telecommunications spanning the North American continent without great concern for quality. Once this goal was achieved, increased attention was given to improving the quality of transmission. Whenever technological advances made it possible to transmit more channels for longer distances at lower cost, part of the benefit was converted to transmission improvements such as less attenuation distortion, lower loss, and lower noise.

Fig. 6-23 is a schematic diagram of a customer-to-customer connection for a typical telephone call similar to that discussed in Chapter 2. The diagram is introduced at this time to give the reader a general understanding of all the items involved in an end-to-end telephone connection. Some, but not all, of the items have been mentioned previously; others will be mentioned in the following chapters.

6.3.1 ECHO AND HOW IT IS CONTROLLED

Transmission planning for short connections, such as loop-to-loop and one-trunk connections, is concerned primarily with control of loss and noise. These need to be controlled to provide high-quality speech transmission. In addition, trunk loss must be sufficient to prevent instability or singing. For longer toll connections, a third parameter, echo, becomes important. Echo results when speech signals travel large distances over transmission facilities having finite propagation velocities and then are reflected at impedance discontinuities. Fig. 6-24 depicts a simplified diagram of a long telephone connection, together with the principal signal path and echo paths. It has been found that, in general, proper control of talker echo will result in satisfactory listener echo performance.

Note that Fig. 6-24 has been drawn as if all intermediate offices are 4-wire. This is not the case; however, impedance matching at 2-wire intermediate offices is required to limit the contribution of these offices to the total circuit echo. When this is done, the principal source of echo is the impedance mismatch at class 5 offices. This is shown as return loss (*RL* of Fig. 6-24) at the end offices and includes the effects of loop and telephone set impedances. Because of the lack of precise control over the impedances of loops and in



NOTES:

1. TRUNK LAYOUT IS FOR A CARRIER FACILITY. SOME OF THE OFFICE EQUIPMENT MAY BE OMITTED FOR A VOICE–FREQUENCY SYSTEM.

2. IN A 4–WIRE OFFICE THE TERMINATING SET IS OMITTED.

3. SIGNALING EQUIPMENT MAY BE ASSOCIATED WITH TRUNK EQUIPMENT, TERMINATING SET, OR CARRIER CHANNEL.

4. IF THE TRUNK IS EQUIPPED WITH ECHO SUPPRESSORS, THEY ARE PHYSICALLY LOCATED ON THE OFFICE SIDE OF THE SIGNALING EQUIPMENT.

5. IF THE FACILITIES ARE CONNECTED AT GROUP OR SUPERGROUP FREQUENCIES INSTEAD OF AT VOICE FREQUENCIES, GROUP OR SUPERGROUP CONNECTORS REPLACE THE OFFICE EQUIPMENT BETWEEN THE HIGH–FREQUENCY PATCH BAYS.

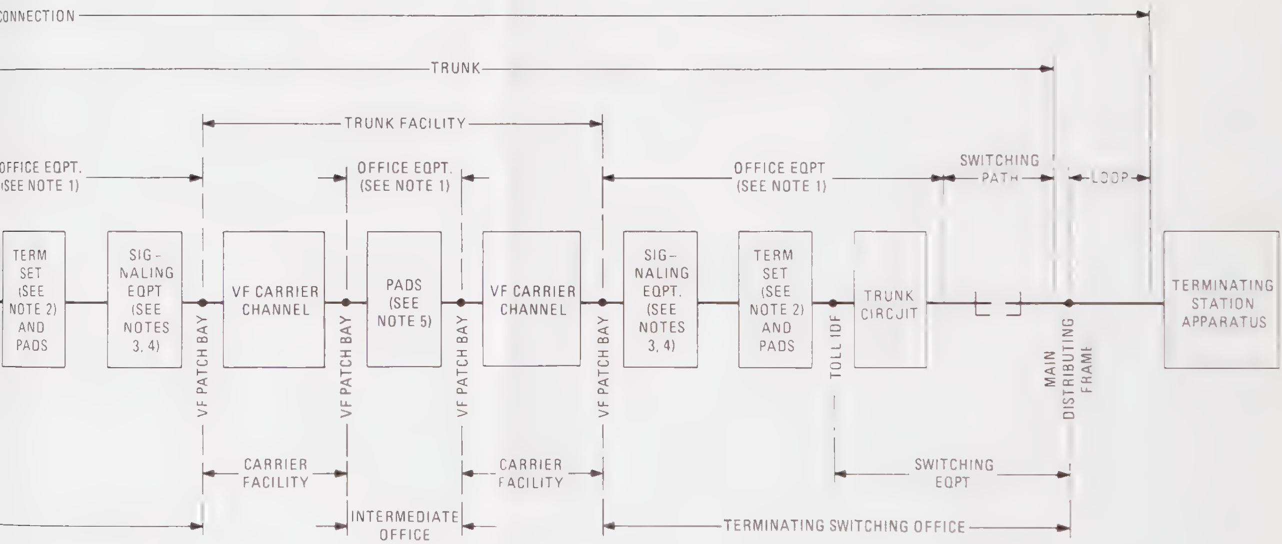
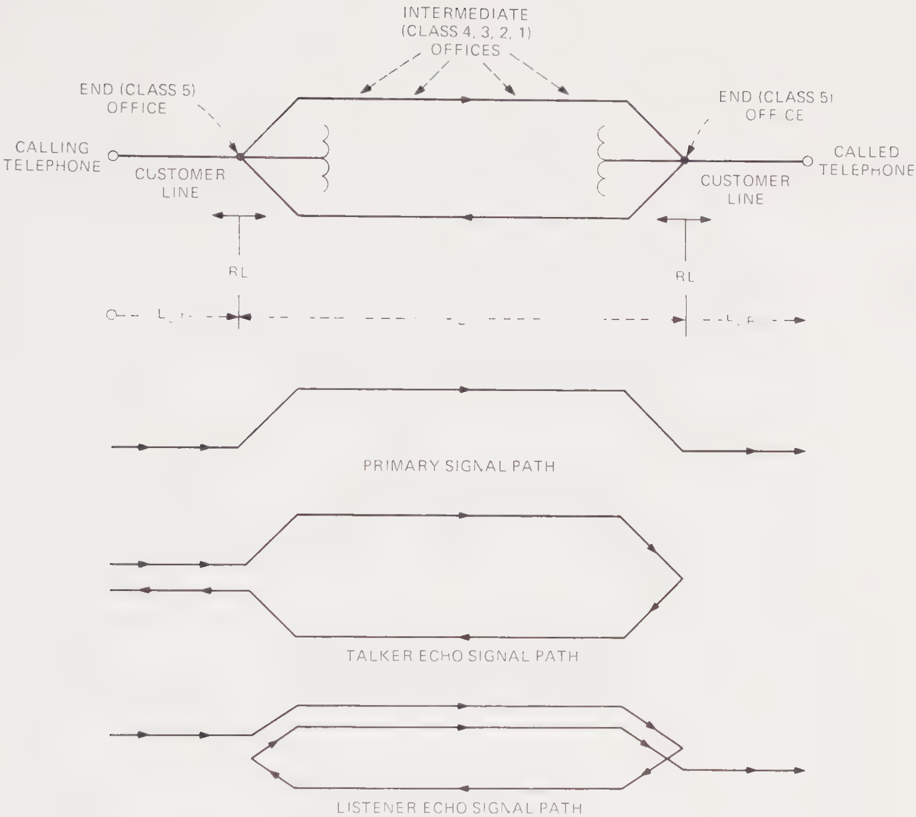


Fig. 6-23. Block Diagram of a Telephone Connection



NOTES: L_{LT} - TRANSMITTING ACOUSTIC-TO-ELECTRIC CONVERSION EFFICIENCY OF A CUSTOMER LOOP

L_{LR} = RECEIVING ELECTRIC-TO-ACOUSTIC CONVERSION EFFICIENCY OF A CUSTOMER LOOP

L - ELECTRICAL LOSS BETWEEN END (CLASS 5) OFFICES

RL - RETURN LOSS: THE RATIO OF REFLECTED POWER TO INCIDENT POWER

Fig. 6-24. Echo Paths in a Long Telephone Connection

view of economic limitations on the degree of impedance matching, the network designer must rely on other means of echo control.

Transmission quality for situations potentially giving rise to talker echo depends on the loss and the delay around the talker echo path. The amount of echo path loss required to achieve a given level of transmission quality increases with increasing delay. The loudness loss[12] of the echo path (see Fig. 6-24) is $L_{LT} + L_{LR} + 2L + RL$. The network designer can go only so far in providing sufficient connection loss (L of Fig. 6-24) to suppress echo before the loss itself becomes objectionable. When the loss required to give adequate control of echo is excessive, echo suppressors are employed instead.

An echo suppressor is a voice-operated switching device that reduces echo by introducing loss in the return transmission path of a 4-wire circuit. Suppose that two customers, A and B, are conversing over a toll connection. When A is talking, the echo suppressor detects the presence of speech from A and introduces loss into the path from B to A. Then, when B talks, the suppressor detects B's speech and introduces loss in the path from A to B. This action greatly reduces talker echo for the customers, although as can be imagined, echo suppressor design is greatly complicated by the problem of what to do when both A and B are talking.

In trunks, loss control of echo is accomplished by assigning a nominal or target value loss to each trunk. In the present analog network, the loss assigned to each intertoll trunk is called *via net loss* (VNL) and is length-dependent, increasing with increasing trunk length. Echo suppressors generally are used on trunks between certain pairs of regional centers and on high-usage trunks with lengths in excess of 1850 miles between offices in different regional areas. This approach ensures that echo suppressors will be provided when required, but prevents multiple suppressors in tandem.

Note that the control of echo will involve additional parameters as the digital facilities network (see Section 5.3.4) evolves. For example, digital intertoll trunks between digital switching systems will have zero loss.

6.3.2 LOSS ALLOCATION IN THE PUBLIC TELEPHONE NETWORK

Loss objectives as such have not been established for loops. Instead, procedures known as resistance design, long-route design, and unigauge design (which will be discussed in Section 10.1) have been devised to provide a loss distribution that, when combined with trunk losses, provides satisfactory performance for all types of calls.

Loss objectives for trunks will be described for the present analog network. The objectives represent a compromise between two factors: (1) the need to hold losses at sufficiently low values to minimize contrast between different

12. Reference 17 describes a method of objectively measuring loss in a manner that reflects loudness perception by human listeners. The method, as now used at Bell Laboratories, permits expressing acoustic-to-acoustic loudness loss in dB-like quantities; i.e., the dB difference between the level of an acoustic signal applied to a telephone set transmitter and the level of the acoustic signal emitted by a telephone receiver. Component ratings (or loudness losses) reflect conversion efficiencies of these components; e.g., the transmit rating of a customer loop (L_{LT} of Fig. 6-24) expresses the efficiency in converting an acoustic signal to an electric signal.

types of calls and to provide satisfactory end-to-end transmission, and (2) the need to control echo, which leads to increasing the trunk loss with increasing trunk length. The loss objectives for several types of trunks are listed in Table 6-5. The types of trunks involved in longer connections in which echo is a consideration contain a VNL component of loss that depends on length; values of VNL are listed in Table 6-6.

TABLE 6-5
LOSS OBJECTIVES FOR TRUNKS

TRUNK TYPE	LOSS
Toll connecting	VNL + 2.5 dB, Alternate design: Min = 2.0 dB, Max = 4.0 dB
Intertoll	VNL
Intertandem	1.5-dB unbalanced offices* 0.5-dB balanced offices*
Direct	Without gain: Min = 0 dB, Max = 5 dB With gain: 3 dB
Tandem	Without gain: Min = 0 dB, Max = 4 dB With gain: 3 dB

* Balance refers to the process of adjusting impedances so that the return losses of hybrids meet a specified objective.

TABLE 6-6
VIA NET LOSS FOR CONTROL OF ECHO ON TRUNKS
(Operating on All Carrier Facilities)

TRUNK LENGTH (MILES)	VIA NET LOSS (0.0015 X AVERAGE LENGTH + 0.4) (dB)
0-165	0.5
166-365	0.8
366-565	1.1
566-765	1.4
766-965	1.7
966-1165	2.0
1166-1365	2.3
1366-1565	2.6
1566-1850	2.9
Any length with echo suppressor	0.0

6.3.3 NOISE OBJECTIVES

Present long-range performance objectives for noise in the public telephone network are based on subjective tests[13]. These tests involved rating various amounts of noise in the presence of speech on a 5-category scale: excellent, good, fair, poor, and unsatisfactory. Objectives were selected to achieve a grade of service for noise of 99 percent good or better for short toll connections, 97 percent good or better for medium length toll connections, and 95 percent good or better for long toll connections. Consistent with these overall objectives, separate allocations have been made for short-haul and long-haul carrier systems:

Short-haul carrier: 28 dBrnC0[14] at 60 route-miles (96 km)

Long-haul carrier: 34 dBrnC0 at 1000 route-miles (1600 km).

Design objectives for carrier systems are based on these performance objectives, but are normally expressed in terms of worst-channel noise in a nominal environment. The current design objective for 4000-mile (6400-km) long-haul coaxial cable systems is 40 dBrnC0, inclusive of multiplex equipment. Performance is expected to be approximately 3 to 4 dB better than that of systems designed to earlier objectives.

In establishing these objectives, it was recognized that noise in loops also must be controlled. The long-range objective for loop noise at the customer set terminals is that it should be less than or equal to 20 dBrnC.

6.3.4 COMPARISON OF PRESENT LOSS-NOISE PERFORMANCE WITH SUBJECTIVE MEASUREMENTS

Present loss and noise objectives evolved over a period of years, and their evolution has resulted in similar evolution of network performance to its present state. Periodically, studies are undertaken to acquire new subjective test data and to reevaluate these objectives.

In this section, present transmission performance will be considered in terms of recent tests. Fig. 6-25 shows smoothed results of recent subjective tests of loss and noise. The ordinate scale is in terms of noise level as measured at the line terminals of the telephone set in dBrnC, and the abscissa scale is acoustic-to-acoustic loudness loss in dB. As an example of interpreting the curves, about 70 percent of the calls with 20-dB loss and 20-dBrnC noise would be rated good or better.

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13. References 18 and 19.

14. dBrnC0 indicates noise measured with a noise meter using a loss-frequency characteristic known as C weighting, expressed in decibels relative to a reference noise (10^{-12} watts) and referred to the 0-dB transmission level point which is defined in Section 7.2.2.

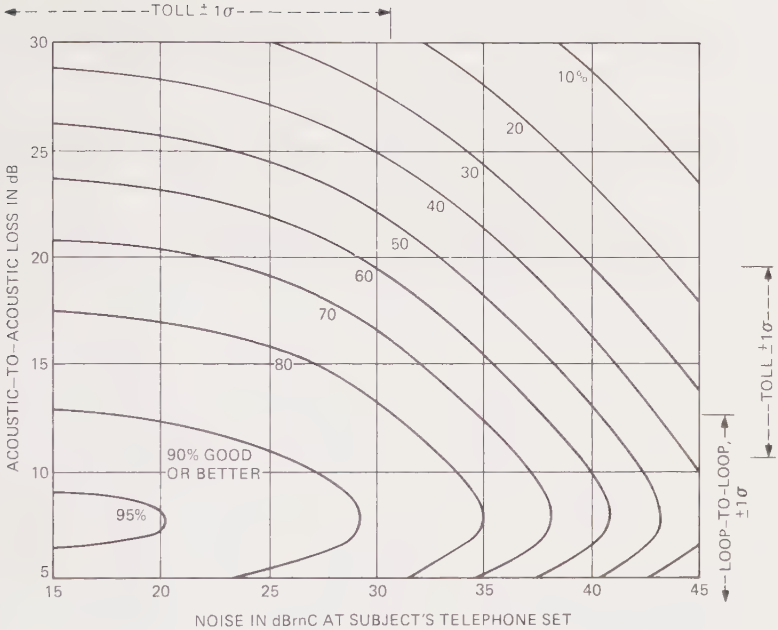

Fig. 6-25. Loss-Noise Grade of Service

The significance of the results shown in Fig. 6-25 can be seen by considering the loss and noise characteristics of the present plant. The acoustic-to-acoustic loss of a connection is equal to $L_{LT} + L + L_{LR}$. (See Fig. 6-24.) Estimated distributions based on modeling results of loop surveys yield for L an average of -18.1 dB (indicating gain associated with the carbon transmitter) with a standard deviation (σ) of 3.6 dB and for L_{LR}, an average of 26.7 dB, with a σ of 1.7 dB[15]. The estimated distribution for L resulting from a recent toll connection survey (see Reference 20) has an average of 6.7 dB, with a σ of 2.1 dB. Note that this distribution reflects both the application of loss objectives and the toll calling patterns. For loop-to-loop calls, the overall loss distribution thus has an average of 8.6 dB and a σ of 4.0 dB. For toll calls, the distribution average is 15.3 dB, and σ is 4.5 dB. Plus and minus 1σ limits (which include about 68 percent of the distributions) for these two classes of calls are indicated along the right-hand margin of Fig. 6-25.

Results of the same toll connection survey indicate that the distribution of message circuit noise power has an average of about 22.0 dBrnC, with a σ of 8.5 dB at the line terminals of the receiving telephone set. Plus and minus 1σ limits are shown along the upper edge of Fig. 6-25.

15. The distributions are normal only over their central portions and in fact have rather skewed tails. They are treated as normal only for purposes of explanation.

Fig. 6-25 shows that local calls are near the optimum region for loss-noise grade of service. Toll calls are in the 50- to 90-percent grade-of-service region. It is obvious that toll calls in general have about 5 dB more loss than optimum, considering only loss-noise grade of service. This reflects a compromise with echo performance and has resulted in sufficient loss in toll connections to give a good grade of echo performance. It is reasonable to ask whether the best compromise has been reached. For example, might a better compromise involve somewhat poorer echo performance on toll calls, with a corresponding improvement in loss-noise performance? This question has been examined in a recent review of toll network transmission design with the result that VNL design was found to be nearly optimum.

6.3.5 OBJECTIVES FOR THE CONTROL OF OTHER IMPAIRMENTS

In addition to loss, echo, and noise, there are a number of other impairments that can adversely affect speech transmission over the public telephone network if not properly controlled. Important among these are crosstalk, carrier frequency shift, and attenuation distortion. In the following paragraphs, objectives for the control of these impairments will be discussed. Objectives for transmission of data on voiceband facilities and for television transmission also will be mentioned.

Crosstalk results when the speech from one circuit (the disturbing circuit) becomes perceptible and/or intelligible in another circuit (the disturbed circuit). Crosstalk objectives in the public telephone network are based primarily on considerations of privacy, rather than on noise or interference caused by the interfering crosstalk signal. Hence, the objectives are in terms of the probability of intelligible crosstalk being audible on a call. Typical objectives are 1 percent for intertoll trunks that interconnect offices of class 1, 2, 3, or 4 and 0.5 percent for toll-connecting trunks that connect class 5 offices with toll offices.

The frequency shift introduced by frequency differences between carrier supplies at the two ends of suppressed-carrier multiplex systems is minimized wherever possible by locking local oscillators to pilots or reference frequencies transmitted over the systems (see Section 6.2.4). Occasionally this is not possible, and a small amount of frequency shift occurs. In general, an attempt is made in system design to seldom exceed ±2 Hz on the longest connections. This objective has been selected as being both tolerable and achievable.

Attenuation distortion, including both bandwidth restriction and inband attenuation distortion, has been controlled primarily by (1) the design rules for loops and trunks, (2) controlling the contribution of office cabling, (3) the design requirements for the individual channel units of carrier systems, and (4) the design requirements for arrangements that are used for the interconnection of carrier systems at bandwidths greater than voiceband.

Transmission of data over the public telephone network, which was initiated about 1960, has now grown to a sizable portion of the traffic. Indications are that the growth will continue. Over the years, it was found that although certain characteristics of the public telephone network covered by existing transmission objectives were suitable for data transmission, other characteristics not critical to speech needed improvement. The characteristics that required additional objectives and mitigative measures were impulse noise, nonlinearity, gain and phase changes, and attenuation distortion.

The television networks provided by the Bell System, although not part of the public telephone network, use the same transmission facilities, and facility characteristics affect television quality in a manner similar to their effect on speech quality. Parameters important in the transmission of television signals include single-frequency interference, random noise, impulse noise, power hum, crosstalk, attenuation distortion, and delay distortion.

6.3.6 ALLOCATION OF OBJECTIVES

Although the previous discussion has to some extent considered transmission objectives and performance estimates for parts of connections, the overriding concern has been with the overall connection from the customer's viewpoint. Overall transmission objectives need to be translated to apply to the different parts of a connection in terms that can be used by the network planner, the facility designer, and the maintenance organizations.

Quality of service can be estimated from computer simulations of hundreds or thousands of representative connections, and the effect of changes in objectives for particular parts of the plant can be determined. The results of such studies can be used to identify the parts of the network that limit transmission performance and to evaluate the effects of alternate methods for improvement. These results, when combined with information on the cost of the various alternatives, indicate the possible tradeoffs between transmission performance and cost and provide the basis for recommendations for transmission objectives. For example, the specification of separate noise objectives for the design of short-haul and long-haul carrier systems (discussed previously) recognizes the economic and technical characteristics of these systems.

Ultimately, the quality of service in the network depends on appropriate design objectives for the facilities, appropriate engineering rules for their application, and appropriate maintenance objectives to ensure that corrective action is initiated when required.

6.3.7 VOICE-CHANNEL SIGNAL POWER LIMITS

Multiplex equipment and carrier systems have been designed to accommodate the power loads normally imposed by telephone channels; an increase in power per voice channel over that normally associated with telephone usage can lead to overload, resulting in impairments to all channels in a facility. It is therefore desirable to establish limits on the amount of power that may be applied to a channel. The growing amount of data transmission and the requirement to allow the interconnection of non-Bell equipment to the facilities network have given still more emphasis to the need for such a limitation.

The objectives for system load capacity and customer load have been established as a per-channel long-term average power of -16 dBm at the 0-dB transmission level point[16]. Channel activity and signal level variations with time need to be considered when these objectives are applied.

The maximum power limit for voiceband data averaged over any 3-second interval is -13 dBm, referred to a 0-dB transmission level point. This results in a data power load per channel roughly equivalent to the long-term average power of speech.

A limit that is lower, -20 dBm referred to a 0-dB transmission level point, is imposed on the signaling tones that are carried by all idle channels. This limit is used so that the signal power present continuously on all idle channels does not dominate the active channel load.

MF tones, which are used for address signaling, are present only for brief periods. The power level for these tones is -6 dBm per tone, referred to a 0-dB transmission level point.

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7 Other Network Functions

Two basic network functions, switching and transmission, have been introduced in the two preceding chapters. Three other classes of network functions will be examined in this chapter. Section 7.1 discusses signaling; the description of a typical telephone call in Chapter 2 clearly indicated that this is an important function. Section 7.2 discusses interfaces, well-defined boundaries between two systems, equipments, or other network elements; interfaces have the function of assuring proper operation when elements are connected together in a complex network. Section 7.3 discusses the functions that operators perform in a communications network with specific reference to the public telephone network.

7.1 SIGNALING

Signaling is the process of transferring information over a distance to control the setup, holding, charging, and releasing of connections in a communications network. The network may be the public telephone network or a switched private network. Alerting stations on a nonswitched private-line configuration is also a signaling process. Most of this section is directed toward signaling in the public telephone network; similar considerations apply in other traffic networks.

Broadly speaking, there are two signaling realms: customer line signaling and interoffice trunk signaling (see Fig. 7-1). Customer line signaling refers to the interaction between the customer and the switching system serving the customer. Interoffice trunk signaling, as the name implies, is concerned with the exchange of call-handling information between switching offices within the network.

Signaling does not include the many and varied call-handling interactions between components within a switching system or within the more complex forms of station equipment. Signaling overlaps with switching in that the elements used to send and receive signals to and from a distant point sometimes are considered to be part of the switching system, and these signaling elements sometimes are designed by switching system designers. Similarly, signaling elements in the telephone instrument are part of the station design, although more complex signaling equipment used on customer premises

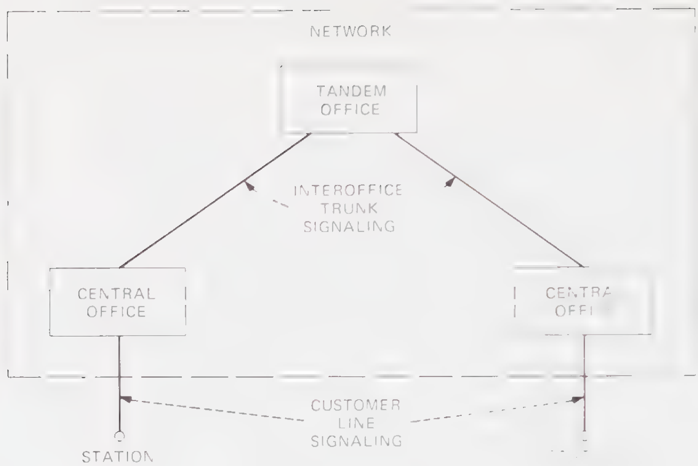


Fig. 7-1. The Two Major Signaling Applications

sometimes is designed by transmission system designers. Transmission system designers also design some (but not all) of the systems used to carry signals between offices.

7.1.1 PRIMARY SIGNALING FUNCTIONS

The primary signaling functions may be understood in the context of a typical telephone connection sequence such as described in Chapter 2. These functions are:

(1) Initiate a request for service.

(2) Indicate that dialing may commence.

(3) Transmit the identity of the called station.

(4) Alert the called station.

(5) Indicate acceptance of the incoming call.

(6) Cease alerting.

(7) Relay charging information.

(8) Indicate that the incoming or outgoing call is finished.

(9) Provide feedback to the originating station:

- (a) Call cannot be completed,
- (b) Called station is being alerted, or
- (c) Called station is busy.

Implementation of these functions on customer lines and interoffice trunks is accomplished by a variety of standard signaling methods which are described in Section 11.3.

7.1.2 RELATION TO SYSTEM OBJECTIVES

A fundamental objective of the Bell System is to make operation of the telephone as simple and universal as is practical. This has resulted in a relatively small number of arrangements for customer line signaling; these usually are seen by the customer as highly standardized procedures. On the other hand, interoffice signaling is essentially a machine-to-machine interaction and is therefore less constrained by consideration of human factors. Rather, the emphasis is on overall operating efficiency and flexibility. Consequently, over the years, interoffice signaling has been generously influenced by new transmission techniques and advances in switching system design. This is reflected in the large variety of signaling arrangements in service.

To satisfy the two objectives of uniformity for customer signaling and flexibility for interoffice signaling, the Bell System has adopted the philosophy of maintaining a high degree of independence between these two areas. This approach has been greatly facilitated by the widespread use of common-control switching systems in local central offices. Such systems provide an effective signaling buffer between lines and trunks.

7.1.3 INFORMATION AND SPEED CONSIDERATIONS

Signals are classified into supervisory, address, information, and network management groups.

Supervisory signals are used to initiate a request for service on lines or trunks, to hold or release an established connection, to initiate or terminate charging, to recall an operator on an established connection, to alert a customer, or to initiate custom calling.

Address signals convey digital information such as the calling or called customer's telephone number, an area code, or PBX tie-trunk access codes.

Information signals usually are in the form of audible tones or recorded announcements and are used to convey call-progress or call-failure information to customers or operators.

Network management signals are not per-call signals, but instead are used to control the bulk assignment of circuits or to modify the operating characteristics of selected switching systems in a network in response to overloads.

This limited description of the four classes of signaling information gives an idea of the amount of information that must be conveyed by signals. The actual number of signals that a particular signaling system must handle depends on the specific service situation, such as an individual customer line, a multiparty line, a coin telephone service trunk, an international trunk, etc.

Another important signaling parameter is speed or its inverse, delay. The calling customer experiences three components of delay in completing a call: dialing time, post-dialing delay, and answer delay; all involve signaling to some degree.

Dialing time, as the words suggest, is the time it takes for the calling customer to dial the desired number, beginning from the time the receiver is lifted (or equivalent) until the last digit is sent. This delay is determined by (1) the central office delay in recognizing the customer's request for service and providing the dial tone, (2) customer reaction time, (3) speed of the customer in manipulating the dial (in the case of manual dialing), and (4) the dial signaling method employed.

Post-dialing delay is the elapsed time from the end of dialing to the start of ringing at the called end. Post-dialing delay depends on many factors, including the number of switched links in the connection, the types of interoffice signaling used, switching system work times, and the traffic load.

Answer delay is the time from the beginning of ringing until the called station answers and is determined primarily by the called customer's promptness in answering and, to a lesser degree, by the alerting method used.

7.1.4 SIGNALING TECHNIQUES

In the Bell System, network operation with automatic switching historically has required that the signaling for a call begin at the originating station and follow the same path as the call itself. The obvious reason for this approach was to avoid the added costs of separate transmission channels for signaling. However, this mode of operation introduces the very real possibility of mutual interference between signaling and voice transmission. The basic rule that has been followed to minimize interference is to keep signaling and talking from overlapping in time on a given connection.

Because there is no separate signaling route or network, voice connections must be established by adding one trunk at a time, starting at the central office that serves the calling customer and progressing toward the central office of the called station. Most of the signaling activity associated with a call takes place before the called station answers. During this time, the transmission path is available for signaling. This signaling technique is referred to as *per-trunk signaling.*

As shown in Fig. 7-2, signaling may in principle be provided on a per-trunk or a common-channel basis. As mentioned, per-trunk signaling is used almost universally in the Bell System at present and will be discussed first. However, Common Channel Interoffice Signaling (CCIS) has been developed and the first installations made in 1976. The principles of CCIS will be covered subsequently in this section.

Usually, a simple pair of wires is the most economical way to provide short interoffice trunks and customer lines. The dc path provided by these transmission conductors comes at no extra cost and therefore is almost always

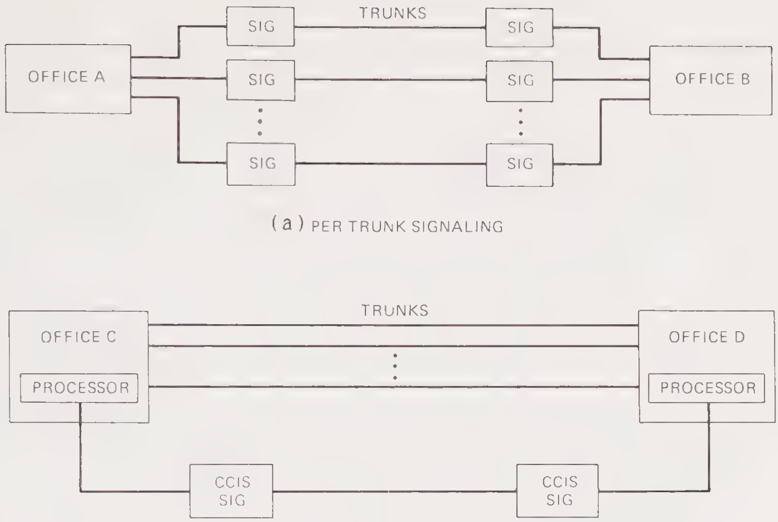


Fig. 7-2. Per-Trunk Versus Common Channel Interoffice Signaling

used for signaling. All switching systems are capable of signaling on a dc basis directly over wire pairs to customer stations or to other central offices.

Most dc signaling is 2-state; for example, current either flows or does not. In one example of interoffice signaling, signals are sent from A to B by current or no-current states; when current is flowing, signals are sent from B to A by normal or reverse current states. The two states, regardless of how they are represented electrically, have been termed *off-hook* and *on-hook*, respectively. These terms are used for trunks as well as for lines. The off-hook state is the one usually identified with the busy or talking state of a line or trunk, and the on-hook state is the one identified with the idle condition. In addition, information is conveyed by the point in a call sequence at which a particular transition occurs and by the time between successive transitions.

Rotary telephone dials and some central office senders transmit address information in dial pulsing form, in which each digit is represented by a sequence of on-hook intervals. The dial pulses are generated at a 10-pulse-per-second rate. The number of dial pulses in a sequence equals the value of the digit, except for the digit zero which is represented by ten pulses. The digits are separated by a relatively long off-hook interval, the length of which depends on how fast the customer can rewind and release the dial.

The TOUCH-TONE dial uses a 2-group code in which each signal is represented by selecting one frequency from each of two mutually exclusive groups of four. For interoffice signaling, the decimal digits and five auxiliary signals are each represented by selecting two frequencies out of a group of six. Maximum transmission rates are about 10 digits per second with the tone signaling methods and 1 digit per second with dial pulsing.

If a dc transmission path is not available, as is the case in signaling over carrier-derived trunks, all dc signals must be converted into a form suitable for transmission over the carrier facility. As indicated in Chapter 2, a method widely used is to convert dc on-hook and off-hook states into corresponding tone-on and tone-off states, using 2600-Hz single-frequency (SF) signaling equipment. In this form, signals may be transmitted inband over any voice circuit regardless of how it is derived. Because signaling takes place within the voice-frequency band, this system is susceptible to accidental talkoff by customer speech or to fraudulent manipulation by customer-generated tones.

An alternative but much less widely used scheme (in the Bell System, at least) is to convert dc signals into an out-of-band tone such as 3700 Hz. Important advantages are low cost per signaling link (because there is no need to provide talkoff protection, for example) and freedom from mutual interference with the voice channel. There are two important disadvantages, however. Some sacrifice in usable voice bandwidth occurs because one edge of each 4-kHz carrier channel must be reserved for signaling. On trunks made up of two or more transmission links in tandem, signaling repeaters are required at the junctions.

In the case of PCM transmission facilities (e.g., T carrier), it is relatively easy to encode the dc signals at the terminals and interleave them with the multiplexed PCM voice bits for transmission over the line. This approach, which is widely used in the short-haul trunk plant, has all the advantages of out-of-band tone signaling, but with a much smaller penalty to the voice channel.

The signal flow for a typical call, using per-trunk signaling is illustrated in Fig. 7-3.

The principle of the CCIS system (see Fig. 7-2) is to transmit all of the signaling information pertaining to a group of trunks over a separate dedicated channel. This approach is particularly attractive for use between Electronic Switching Systems, since all of the signaling interaction between two systems, including network management, can take place between the processors over the CCIS network of voice-grade data links.

CCIS permits a great reduction of call setup time, not only by its inherent speed, but also by signaling the next office in the route before an office has finished switching. Other inherent advantages are flexibility and low cost where the volume of signaling is substantial. These advantages derive from the fact that the signaling function is fully disassociated from the voice path and is handled in a highly concentrated form. By the same token, CCIS could introduce new problems unless special precautions are taken. For example, since signaling does not take place on the talking path, it would be possible to route a call over a defective trunk. To avoid this problem, a test of the voice path is made as part of the procedure for setting up each connection. Another concern is the possibility of simultaneously disabling all of the trunks (perhaps 3000) served by a CCIS data link in the event of failure of that link. Duplication with diversity is used to provide the required reliability.

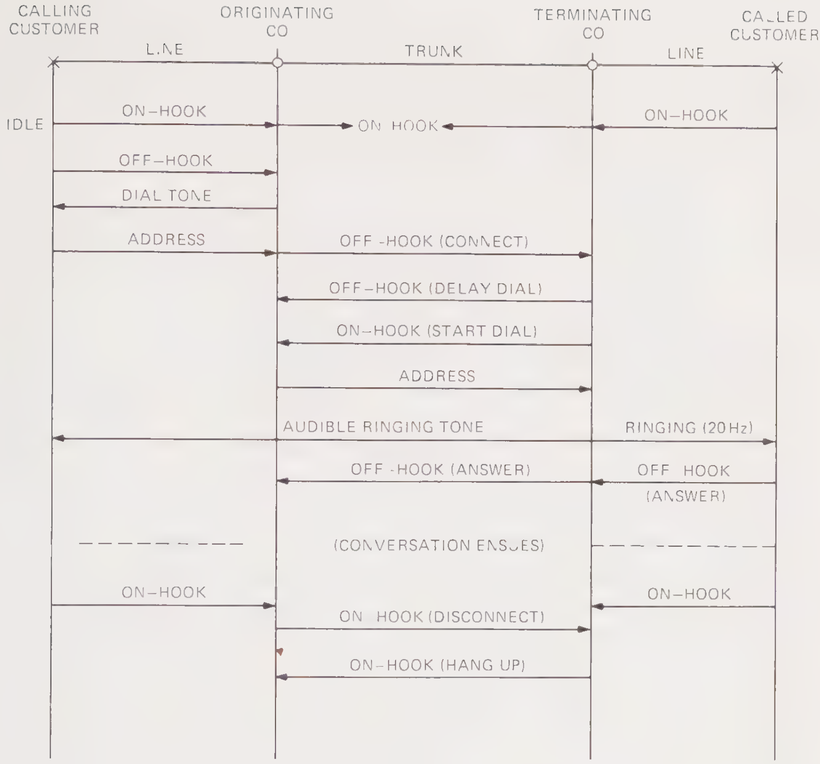


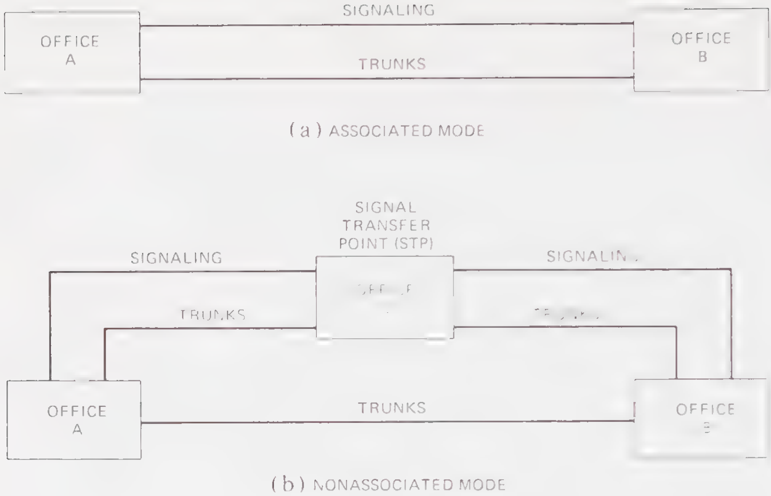
Fig. 7-3. Signaling on a Typical Connection

With CCIS, it is easier to introduce new signals. For example, it is possible to introduce traveling class marks, which can be thought of as unique labels that follow a call no matter how it is routed through the network. It is also possible to modify, automatically and in real time, the characteristics of a communications network if certain prescribed thresholds, such as trunk occupancy, are exceeded. However, many of the advantages offered by CCIS cannot make a significant impact on service until a large proportion of the plant is equipped with CCIS.

The economics of introducing CCIS, particularly on small trunk groups, can be improved by a nonassociated signaling network (see Fig. 7-4). The principle of nonassociated CCIS is that signaling for trunks between offices A and B would be routed through a signal transfer point (STP) located at office C. The STP is essentially a signal message switch, the purpose of which is to reduce the number of CCIS data links required to serve the network.

7.1.5 CHALLENGES

Ensuring intersystem compatibility is a continuing challenge in the signaling area. New switching, transmission, and station systems, as well as new



NOTE: IN THE NONASSOCIATED MODE (b), SIGNALING FOR A B TRUNKS IS BY WAY OF THE SIGNAL TRANSFER POINT (STP) AT C WHICH ALSO HANDLES SIGNALING FOR A C AND C B TRUNKS

Fig. 7-4. CCIS Operating Configurations

features for existing systems, are continually being developed, and the complexities are such that ensuring compatibility of signaling arrangements is a major concern.

Another challenge is post-dialing delay, which is becoming more important because of the new ways in which customers are using the network. For example, many calls involving computers at one or both ends have relatively short messages, and therefore the call setup time represents an appreciable part of the customer's total network time. Call origination, dialing, and answering functions are readily mechanized in these cases, so that these components of delay become small compared with present-day post-dialing delay.

Still another challenge is that existing per-trunk signaling methods are not easily adaptable to certain future needs. Examples of such needs are (1) transfer of network management signals, (2) combining different types of traffic on one trunk group and keeping the types separate at the ends, (3) far-end make-busy of trunks for maintenance purposes, (4) return of busy signal from originating rather than terminating office, so that the intermediate trunk(s) can immediately be made available to other calls, (5) increased transparency for the network (such as removal of constraints imposed on customer data transmissions to prevent deleterious interactions with inband signaling equipment), (6) call tracing, (7) elimination or improved handling of simultaneous seizure of both ends of 2-way trunks (a 2-way trunk allows calls to originate from either end), and (8) reduction of fraud.

7.1.6 SIGNALING TRENDS

The trends in signaling are toward higher speed, increased information-handling capacity, and less coupling between signaling and voice channels.

Increased signaling speed presently is being realized by the gradual shift to pushbutton dialing on customer lines and to MF pulsing on interoffice trunks. This is being accompanied by a corresponding decrease in the amount of dial-pulse signaling on lines and trunks. With the introduction of CCIS in the near future, the door will be opened to ultimate reductions of an order of magnitude in post-dialing delays.

Moderate increases in signaling capacity are now occurring with the conversion from dial pulsing, which has a capacity of 10 unique signals, to TOUCH-TONE calling and MF pulsing, which provide 16 (ultimately) and 15 signals, respectively. With CCIS, the capacity for extra signals virtually will be unlimited.

With regard to separating signaling and voice channels, the trend toward PCM transmission facilities, which eliminates the need for inband signaling, represents a partial step toward complete (physical) separation. Large numbers of PCM systems presently are going into service in short-haul applications, and a start has been made in the medium-haul field.

CCIS, of course, will permit complete physical separation of signal and voice paths on links on which it is installed. This new independence between functions will provide the basis for dealing with the challenges outlined previously. It is envisioned that over the long term a nonassociated CCIS signaling network will evolve, as a separate and distinct entity from the trunk network, to serve the trunk network. The CCIS network, by virtue of its message-switching capability (signal-transfer-point function) will provide the operating companies with a powerful network management tool.

In the area of data transmission, the Switched Digital Data System (see Section 12.4) will be capable of very fast signaling to achieve rapid call setup and will have a new kind of signaling interface with the customer.

7.2 INTERFACES

This section discusses the basic concept of an interface and the role of interfaces in equipment design and plant operation. Several specific interfaces will be described and assessed.

An *interface* can be thought of as the common boundary or set of points where two systems or pieces of equipment are joined. An interface specification is a set of technical requirements for the mating equipments and is intended to ensure proper operation. An interface device is any equipment used on one side of an interface to ensure that the interface specification will be met.

A basic function of an interface is to provide a set of boundary requirements that will, to some degree, separate responsibilities on the two sides of the interface allowing each side the flexibility of rearrangement and evolutionary introduction of new equipment and services. The interface specification should be defined so as not to impede technological progress and to minimize the need for changes in the interface specification itself as new products and services evolve.

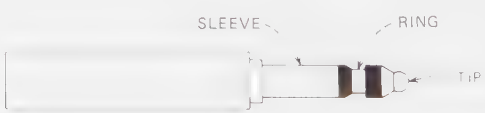
Another very important function of an interface is to provide a demarcation point from which testing can be performed on the individual units being mated. If the interface is well defined, the units can be designed and tested independently, with a good assurance that they will work together as a total system. The interface specification also makes it possible to conduct tests at the interface after the equipment is put into service to locate the sources of service impairment. Ideal interfaces are not always achievable, and, as will become apparent, the term interface sometimes is used in a broader sense than defined above.

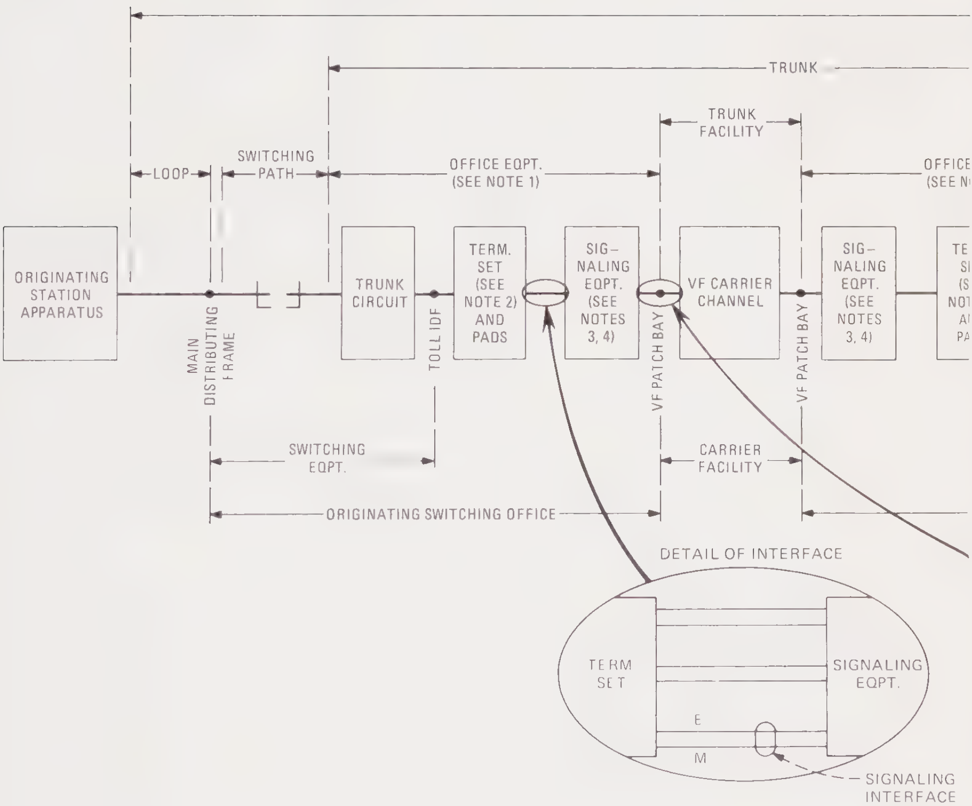
7.2.1 INTERNAL INTERFACES

A good example of an interface is the boundary where the four wires constituting the transmit and receive pairs of a carrier-derived voiceband channel connect to terminating equipment at a channel bank. A specific case can be seen in Fig. 7-5, where the T, R, T1, and R1 leads[1] connect the channel bank to signaling equipment. This 4-wire interface is a common one in the Bell System. It represents an interface that is clean, well-standardized, durable, and very useful. Specifically, the impedance looking in either direction from the interface is a nominal 600 ohms, balanced, and the transmission level point, or TLP, is -16 dB going into the channel bank and +7 dB coming out of the channel bank. Not all interfaces are as clean, simple, easily described, standardized, or durable as this one.

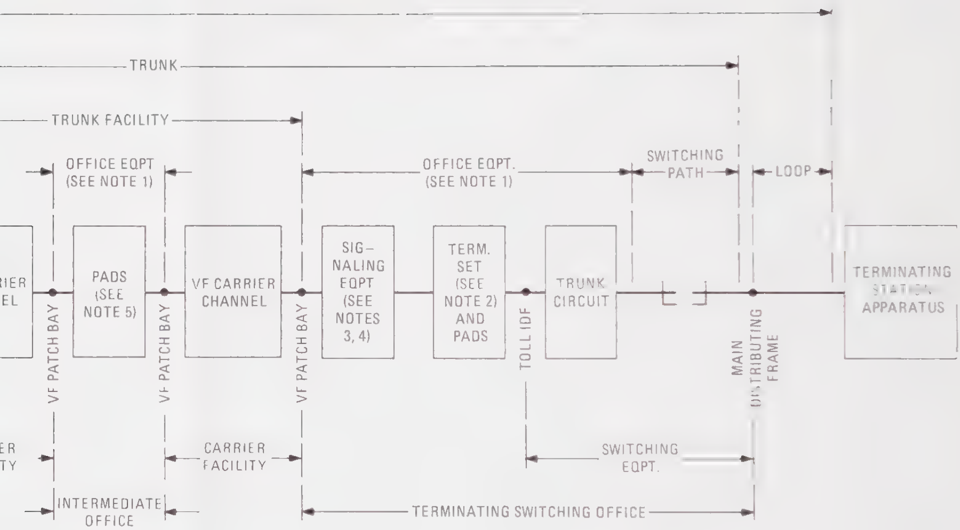
An important aspect of the 4-wire interface described above is the specification of transmission level points. TLPs define levels throughout a telephone connection in relative, but not absolute, terms. For example, the TLP at the demod-out is 23 dB higher than that at the mod-in. The 0-dB TLP at one time was associated with a test access point on a testboard. This access point no longer exists, and 0-dB TLP may not necessarily be associated with any physically accessible point in the system. However, this does not mini-

1. In a 2-wire pair, the two leads are often termed tip (T) and ring (R), after the parts of a standard telephone plug (shown below) to which they connected in the days of manual switchboards. Similarly, a third wire (if present) is termed sleeve. In 4-wire transmission, the four leads are termed T, R, T1, and R1.





TRUNK
TRUNK FACILITY
LOOP
SWITCHING PATH
OFFICE EQPT. (SEE NOTE 1)
ORIGINATING STATION APPARATUS
MAIN DISTRIBUTING FRAME
TRUNK CIRCUIT
TOLL IDF
TERM. SET (SEE NOTE 2) AND PADS
SIG-NALING EQPT. (SEE NOTES 3, 4)
VF PATCH BAY
VF CARRIER CHANNEL
VF PATCH BAY
SIG-NALING EQPT. (SEE NOTES 3, 4)
SWITCHING EQPT.
CARRIER FACILITY
ORIGINATING SWITCHING OFFICE
DETAIL OF INTERFACE
TERM SET
SIGNALING EQPT.
E
M
SIGNALING INTERFACE



NOTES

1. TRUNK LAYOUT IS FOR A CARRIER FACILITY SOME OF THE OFFICE EQUIPMENT MAY BE OMITTED FOR A VOICE FREQUENCY SYSTEM

2. IN A 4-WIRE OFFICE THE TERMINATING SET IS OMITTED.

3. SIGNALING EQUIPMENT MAY BE ASSOCIATED WITH TRUNK EQUIPMENT, TERMINATING SET, OR CARRIER CHANNEL

4. IF THE TRUNK IS EQUIPPED WITH ECHO SUPPRESSORS, THEY ARE PHYSICALLY LOCATED ON THE OFFICE SIDE OF THE SIGNALING EQUIPMENT

5. IF THE FACILITIES ARE CONNECTED AT GROUP OR SUPERGROUP FREQUENCIES INSTEAD OF AT VOICE FREQUENCIES, GROUP OR SUPERGROUP CONNECTORS REPLACE THE OFFICE EQUIPMENT BETWEEN THE HIGH-FREQUENCY PATCH BAYS.

Fig. 7-5. Block Diagram of a Telephone Connection, Showing Details of Interfaces

mize the utility of the concept of relative TLPs. The absolute power that exists at any point depends on the service involved. For example, the present standard power for data transmission is -13 dBm0. This is a shorthand notation for specifying the data signal power as -13 dBm at the 0-dB TLP, which would in turn make it -29 dBm at the -16 dB TLP mod-in.

With the 4-wire transmission interface example in mind, the reader can understand the general role of an interface. A telephone connection is made up of a great many links and pieces of equipment in tandem; Fig. 7-5 is a much simplified diagram of the real situation. Where links or pieces of equipment join, the signal sent by the customer as well as the signals involved in network control must cross the interface successfully; that is, the equipment on the two sides of the interface must be compatible to work together properly. On a very short time scale, as different channels are associated by switching, this compatibility must be maintained. On a longer time scale, as equipment is installed and rearranged, compatibility must still be maintained. And, on an even longer time scale, as innovation results in development of advanced equipment that is gradually introduced into the network, compatibility with older equipment must be maintained. The interface concept greatly facilitates maintaining compatibility. Clearly, there is a great premium on stability in a widely used interface. However, this stability should not unduly constrain innovation in systems adjoining the interface. The 4-wire transmission interface described above is a classic example of success in this respect.

Another important interface is between the signaling equipment in one switching system and the transmission equipment that carries the signals to a distant switching system. One of the most common interfaces in this category is the E&M lead interface shown in Fig. 7-5. It is well standardized and widely used, but by no means universally applicable. This interface is discussed in some detail in Section 11.3; here, its nature and limitations will be considered briefly. In the example in Fig. 7-5, the signaling equipment uses single-frequency (SF) signaling. It sends and receives signals from office to office by means of a tone in the voiceband channel; this tone goes through the 4-wire transmission interface mentioned previously just like any other voiceband signal. Signals across the E&M lead interface are sent by a relay contact and are received by a relay winding. More specifically, on the M lead, a contact in the switching system controls the current in a relay winding in the SF signaling unit. By means of the E lead, a contact in the SF signaling unit controls the current in a relay winding in the switching system. In both cases, ground is used to complete the circuit. Why would this not be a universal interface? First, it does not lend itself to all types of switching systems. For example, it has been found that some electronic systems work more readily with a different interface, and a new interface has therefore been created for this type of system. Second, it does not lend itself to all means of sending the signal to a distant office. For example, when the distance between offices is short and wire transmission (rather than carrier) is used, the E&M lead interface would be much too expensive. Therefore, there are a number of signaling interfaces (discussed in greater depth in Section 11.3), and not all the equipments that could be compatible in principle are actually compatible in practice.

Another situation involving interfaces is the connection of a customer's station to a switching system by means of a loop. The loop is used for both transmission and signaling. People working in the field think of the entire loop and portions of the station as a *signaling interface*, although this does not agree with the interface definition stated previously. Adhering to the definition given at the beginning of this section, one interface might be taken to be where the loop is connected to a switching system and another interface where the customer's station is connected to the loop. In both instances, the physical interface is simple, two wires; however, it has not been practical (or desirable) to define stable interface specifications of the kind described at the beginning of this section for these interfaces. What, then, can be said about the station-loop signaling interface? First, there are certain strong invariant parameters. For example, the ringing signal supplied by the central office must be of at least a specified voltage and current. As a practical matter, this has put constraints upon innovation in switching systems because an electronic switching network does not lend itself to these voltages and currents. On the other hand, there is a pervasive lack of uniformity. For example, loops in the plant have variable length (and thus a wide range of resistance), and it is not economically feasible to bring all loops to a standard value at the interface with the switching system. Accordingly, the switching system encounters loops with a wide range of parameters. In those cases in which the parameters of a particular line are beyond the values with which the switching system is designed to work, standard practice is to add to that line, at the central office, a piece of equipment called a *range extender*. The function of the range extender, as its name implies, is to provide satisfactory operation over longer loops than could otherwise be used. As station equipment has evolved, tradeoffs have been made between the station and the loop. For example, modern telephone instruments can operate properly with loops of higher loss than was possible with earlier instruments.

An example of a relatively new internal interface is the DS-1 digital interconnection interface, where 1.5-megabit-per-second bit streams are interconnected. This interface is used, for example, when streams from a number of T1 Carrier Systems are to be multiplexed onto a digital carrier system of higher capacity. (See Section 6.2, "Transmission Multiplexing".) The standard parameters of this interface are summarized in Table 7-1. Note that this interface requires a great many more parameters to define it than the classic 600-ohm, -16 dB, +7 dB interface.

7.2.2 INTERFACES FOR INTERCONNECTION

As a result of the 1968 Carterfone Decision by the Federal Communications Commission, the Bell System initiated a program allowing the interconnection of customer-provided equipment (CPE) to the public telephone net-

TABLE 7-1
DS-1 DIGITAL INTERCONNECTION INTERFACE

INTERFACE PARAMETER	DESCRIPTION
Location	Digital distribution frame
Bit rate	1544 kilobits/second
Pair(s) in each direction of transmission	One symmetric pair
Code	Bipolar
Test load impedance	100-ohm resistive
Pulse shape	Rectangular (duty ratio ½)
Test method	Direct measurement
Peak voltage	3V ±10%
Ratio of amplitude of positive pulses to amplitude of negative pulses	Output power ratio <0.5 dB
Rise time and decay time between 10% and 90% of the pulse amplitude	≤80 ns
Overshoot relative to pulse amplitude	Trailing edge overshoot 10-30% of pulse amplitude decaying to less than 10% of peak overshoot within 400 ns
Pulse width	324 ±30 ns at half amplitude

work. As part of this program, the Bell System established a set of interconnection criteria and introduced what is known as *connecting-arrangement service.* This service provides for the interconnection of the customer-provided equipment to the public telephone network at specifically defined interfaces and protects the network from possible harm from improperly designed or maintained CPE. Harm is construed to be physical damage to the telephone plant, injury to telephone personnel, or impairment of network performance and usefulness for other users. Connecting-arrangement service does not ensure that CPE users will obtain satisfactory performance.

Providing connecting-arrangement service involves:

(1) Tariff criteria under which interconnection is permitted.

(2) Technical References that define responsibilities and contain the interface specifications.

(3) Interconnecting units that are the interface devices on the telephone company side of the interface.

(4) Surveillance of the installation to ensure continued compliance with requirements.

The requirements for protecting the network from harm are spelled out in the tariffs and in the Technical References provided by AT&T for interconnectors. Enforcement of compliance with these requirements is provided by the *interconnecting unit* (ICU) (also called a *coupler* or *access arrangement*) and any other administrative measures the telephone company may wish to take. The amount of enforcement varies with the motivation for violation, cost of implementation, and effect on service.

An ICU used to implement connecting-arrangement service not only provides some network protection but also serves as an interface device to translate the conditions in the telephone plant to the interface specifications stipulated in the Technical References. Careful design of interconnecting units with thorough attention given to possibilities for harm has led to an interface that is multiwire rather than 2-wire, with signaling and transmission separated. These CPE interfaces represent a new class of interfaces between customers and the telephone network.

Adoption of the registration program proposed by the FCC in 1975 may result in minimal use of this type of interface. See Section 4.2.4 for a brief history of interconnection.

Another type of interface involved in connecting customer-provided equipment to the telephone network is a plug and jack arrangement used where interconnection is authorized by attestation, conformance, or registration. Several types of jacks have been standardized by the Bell System, some of which have been incorporated into registration requirements by the FCC. Standard jacks help to ensure that customers' equipment is properly connected to the telephone network.

7.2.3 DATA SET/BUSINESS MACHINE INTERFACES

Another type of interface associated with station equipment is that provided between data set terminal equipment and the customer's business machine. The interface specifications were developed by the Electronic Industries Association (EIA) and are published as RS-232-C for data sets employing serial binary data exchange.

The RS-232-C interface specification consists of three general parts:

(1) Physical requirements, which specify a particular type of 25-pin connector, pin function identifications, and cable length limitations.

(2) Electrical signal characteristics, such as allowable voltage levels and logic sense.

(3) Control signal formats, such as the function and timing of various control signals.

The interface itself provides a convenient demarcation point for testing to determine if a problem exists in the data set and network or in the customer's business machine. This type of interface is a classic one in terms of the definition given at the beginning of this section.

7.3 OPERATORS

This section covers the functions of Bell System operators, the need for these operator functions, and the strategies employed to meet this need. There are, in addition to operators, PBX attendants who perform related functions. The functions of PBX attendants and the part that the Bell System plays in their training are described in Section 12.3.3.

7.3.1 OPERATOR FUNCTIONS

The operator at a manual switchboard was the first switching system. The operator responded to a customer request by establishing a connection, supervising the connection, and idling the connection after the customers completed their conversation. The connection was made with a cord having plugs at both ends. These plugs were inserted in jacks which were the terminations of customer lines. The number of lines an operator could serve was limited by the number of jacks that could be placed within physical reach. An upper limit was about 10,000. The customer appearances (terminating jacks) were multipled onto more than one operator position so that enough operators could be assigned to serve the number of attempts generated and enough cords could be provided as interconnecting links to accommodate the traffic expected.

This manual switching system performed all of the basic switching functions described in Section 5.1.3. Fig. 7-6 shows an operator's position in such a manual central office.

As the number of customers and consequently the telephone traffic grew, some manual systems were split into an originating half and a terminating half. The originating board was labeled an "A Board", and trunks were used to interconnect these boards with other boards. In large cities, in which the community of interest extended well beyond 10,000 customers, the probability of a call originating and terminating within the same 10,000-number block was small. Therefore, this split was more efficient for metropolitan areas, whereas a combined arrangement was more efficient for rural and small suburban areas.

The above description applies basically to a local manual office. Most of these offices have been replaced by automatic switching systems. Indeed, in 1970, there were only 11 local manual switching systems, serving about 0.02 percent of the total telephones in the Bell System. However, there are still a

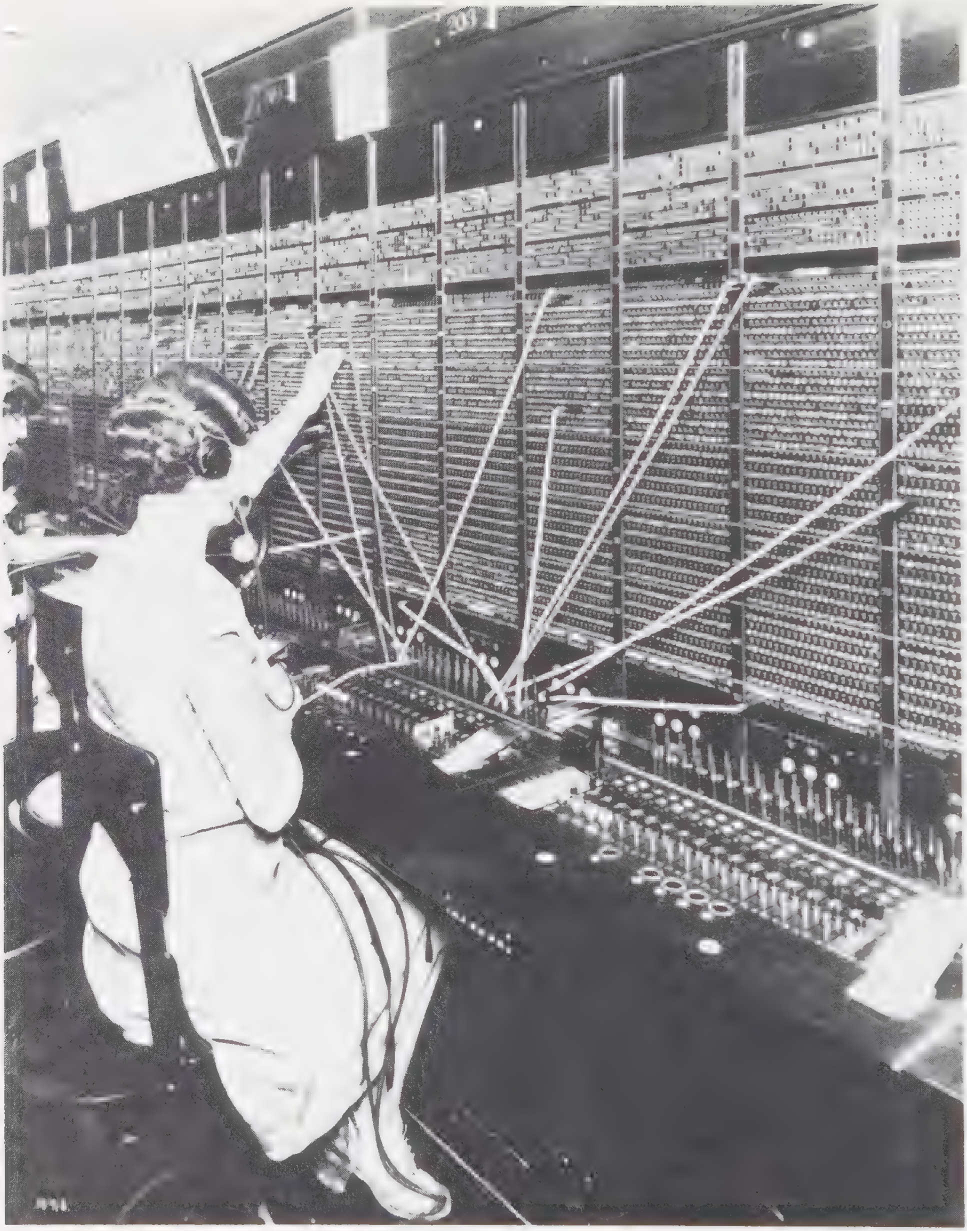


Fig. 7-6. Operator Position in a Manual Central Office

substantial number of manual toll switchboards, with about 30,000[2] operator positions. A toll switchboard operates in essentially the same manner as a local manual office, except that a toll switchboard ordinarily serves only trunks

2. 33,000 as of January 1, 1976

from offices that have been reached by customers and does not connect directly to customer lines.

At the toll switchboard, the operator assists customers in completing toll calls. Since direct distance dialing with automatic message accounting (AMA) is now widespread, the toll calls handled by operators normally are only those involving special handling or special billing (such as person-to-person or collect calls) or those for which the customer requests assistance. The operator records the call details, including the calling and called numbers, the class of call (e.g., collect), and the beginning and ending times for charging purposes.

A toll operator position is shown in Fig. 7-7. The operator responds to an alerting signal (an illuminated lamp) of a calling trunk which appears in the answering multiple (the lower group of rows of jacks on the vertical panel in front of the operator) by inserting a rear cord into the respective jack. Upon insertion of the rear cord, the operator switches the talk/monitor key to the talk position, requests customer information, and inserts the complementary front cord into the appropriate idle outgoing multiple jack. The operator keys the required digits for the called number; then switching systems take over control of the call through the point of alerting the called party by ringing. Upon answer, the operator returns the talk/monitor key to the normal position and supervises the call by observing the corresponding illuminated lamps. When a lamp is extinguished (indicating that a customer has returned to on-hook), the operator "pulls down" the cord pair associated with that call.

Operators perform a number of functions and can be grouped in two major categories:

(1) Toll service operators, who directly assist in the completion of calls.

(2) Number service operators, who provide information necessary for call completion.

Within the toll service category there are three sets of functions: toll switching, assistance, and calling number identification for message accounting. The toll switching function consists of the following:

(1) Providing a manual switching capability as described previously.

(2) Providing billing functions for calls not presently handled by switching systems. Examples of these calls are credit card, collect, and person-to-person calls, and coin calls for which the operator assesses charges and controls the collection and return of coins.

(3) Placing calls to nondialable points such as certain mobile radios and marine stations and most foreign countries.

(4) Providing special services such as conference and call-back calls.

Assistance functions consist of:

(1) Answering customer requests for emergency assistance.

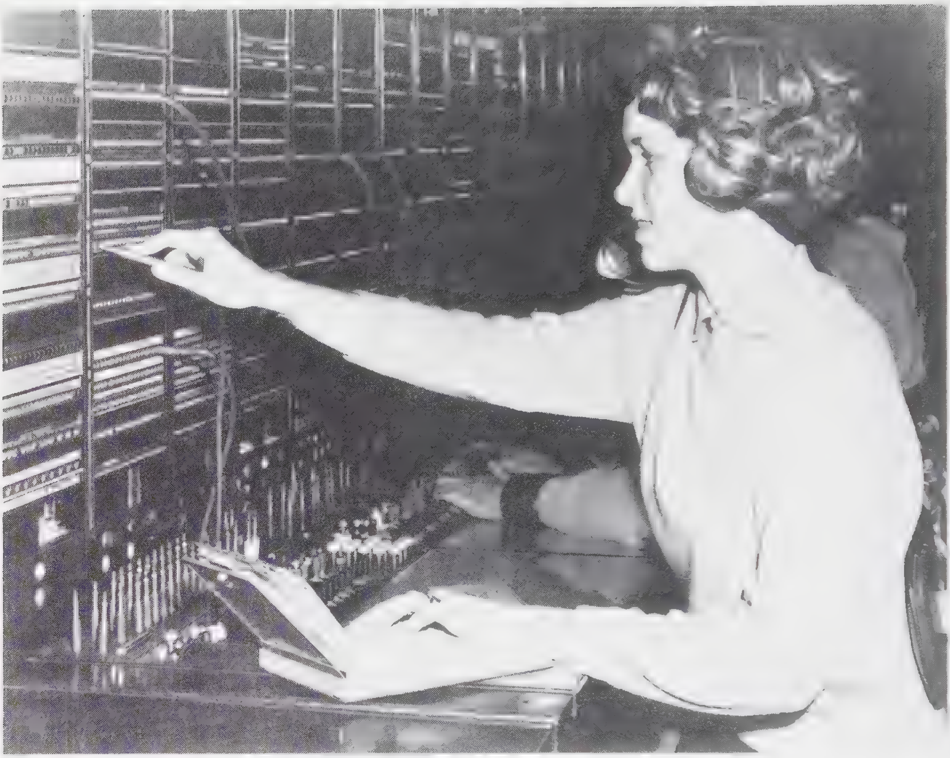


Fig. 7-7. Manual Toll Operator Position

(2) Assisting customers who are having trouble with the network. This includes verifying busy-idle status of lines, accepting requests for credits, providing dialing instructions, and completing local calls when the customer becomes frustrated.

(3) Other functions that have been assigned to operators because they are available on a 24-hour basis. These are referred to as special operator service traffic (SOST) functions and include such items as providing a night answering service for the telephone company business office and repair service, opening doors via remote control, and discharging plant alarms. These functions are all internal to the operating company.

The third toll service function is that of a centralized automatic message accounting-operator number identification (CAMA-ONI) operator. A CAMA-ONI operator is required when a local office cannot identify the originating party on a billable call that would not otherwise need an operator. An operator is called in to request the calling number, which the operator then keys into the switching system for entry on the billing tape. The CAMA-ONI operator is located at either a tandem or toll switching point.

In the number service category, there are three functions also. Directory assistance (DA) operators respond to customer calls to 411 or 555-1212 and also provide assistance to toll operators when required. Intercept operators handle calls to an unassigned or changed number. Finally there are the rate and route operators, who are the toll operators' assistance operators. They provide special operator routing codes, rate information, and lists of numbers that are possible coin lines.

A topological view of operator locations in the network is presented in Fig. 7-8. The Traffic Service Position System, which is described in Section 9.6.1, is not included. Note that when a customer dials 0 for operator, a toll assistance operator responds.[3]

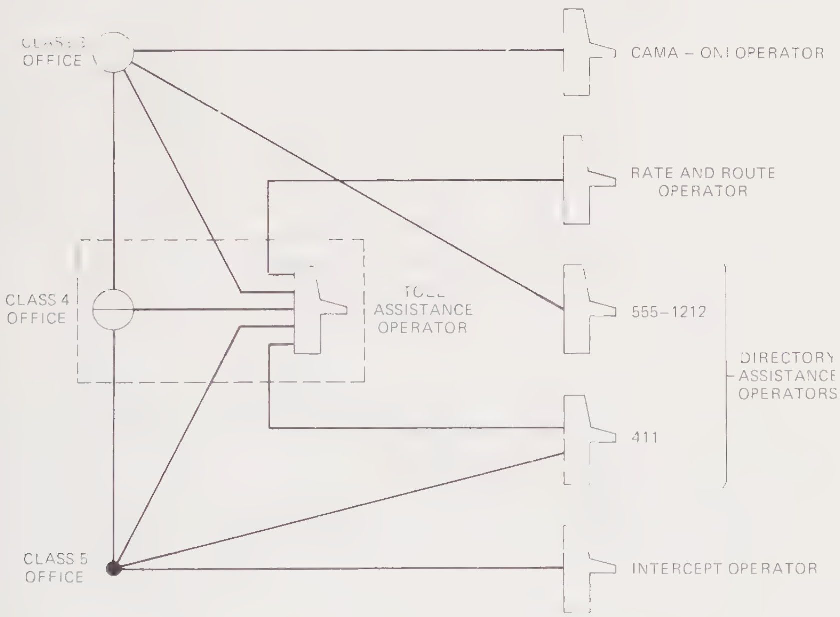


Fig. 7-8. Topology of Operator Systems[3]

7.3.2 THE OPERATING FORCE

In 1974, the operating force numbered about 155,000. These operators received a total of $1.6 billion in wages yearly for handling 35 million calls per average business day. Table 7-2 shows the average-business-day call volumes by type for 1974.

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3. See Fig. 9-35 for Traffic Service Position System.

TABLE 7-2
OPERATOR-HANDLED CALLS PER
AVERAGE BUSINESS DAY, 1974

FUNCTION	CALLS (MILLIONS)
Toll Switching	6
Assistance	5
CAMA-ONI	3
Subtotal for Toll Service	14
Directory Assistance	17
Intercept	3
Rate and Route	1
Subtotal for Number Service	21
TOTAL	35

The number of toll calls handled by operators has been remarkably close to 6 million per average business day since 1947. During this period, total toll traffic has been rising. Direct distance dialing has thus reduced the percentage of toll calls requiring operator service (currently 20 percent), but has not significantly reduced the absolute number of operator-assisted calls. The most recent rate structure includes a higher rate for operator-handled toll calls. This may reduce the number of operator-handled calls by encouraging customers to place directly dialed calls instead.

Assistance traffic is generally about 5 million calls per average business day. This represents slightly more than 1 percent of all calls. Until recently, this figure was almost 1.2 percent, but improvements in the performance of the network have increased the customer's willingness to dial his own calls, thereby decreasing his dependence on the operator.

The CAMA-ONI traffic in 1974 was about 3 million calls per day. Fortunately, all of the Bell System's new switching systems make local automatic message accounting (LAMA) or automatic number identification (ANI) so inexpensive that the need for the CAMA-ONI operator function should be eliminated eventually.

DA operators handle a daily average of just over 17 million calls. This represents almost 3-3/4 percent of all calls originating in the Bell System. The most worrisome aspect of DA traffic is that it has been growing faster than the total originating traffic.

Intercept operators handle an average of 3 million calls per day, representing less than 1 percent of the total traffic. This percentage has been fairly constant, and continued volume growth is therefore expected in this area.

Finally, rate and route traffic is small and is declining as the Bell System provides more sophisticated aids to the toll operator.

Because of the relative complexity of the job, the majority of operators are toll operators, even though most operator-handled calls are number service calls. There were about 98,000 toll service operators and 57,000 number service operators in 1974. Except in the area of toll service, volumes have been increasing steadily. Efforts aimed toward substituting direct distance dialing for operator-handled toll calling have been successful, but attention must now be given to providing the customer with substitutes for the other operator services. Although it may never be desirable to completely eliminate the personal contact that operators provide, lower-cost alternatives should be available for customers who do not require an operator's assistance.

The distribution of operator work time by function in 1974 is shown in Table 7-3.

TABLE 7-3
OPERATOR WORK TIME BY FUNCTION, 1974

FUNCTION	PERCENT OF TOTAL WORK TIME
Toll Switching	52
Assistance	9
CAMA-ONI	2
Subtotal for Toll Service	63
Directory Assistance	33
Intercept	3
Rate and Route	1
Subtotal for Number Service	37
TOTAL	100

Fig. 7-9 shows the historical trend of the operating force. From 1940 to 1950, force levels rose to meet increased demand. Following the introduction of operator dialing and customer direct distance dialing, there was a reduction in the number of operators needed as more calls were processed automatically; however, growth in demand during the 1960s again began to increase the force needed. The dip following 1970 is explained by three factors: a slight business recession, a new rate structure that discouraged toll operator use, and the introduction of new labor-saving systems (which will be mentioned in Section 7.3.3). The force numbered about 155,000 in 1974. Some projections have indicated that it may reach 300,000 by the year 2000. Much effort is being given to prevent this doubling of the operating force because of the costs involved and the difficulties in obtaining, managing, and training such a large working force.

7.3.3 STRATEGY TO MEET OPERATING FORCE NEEDS

Efforts to meet operating force requirements in the future include automation, improved work environment, consolidation, control of demand, and alternate arrangements.

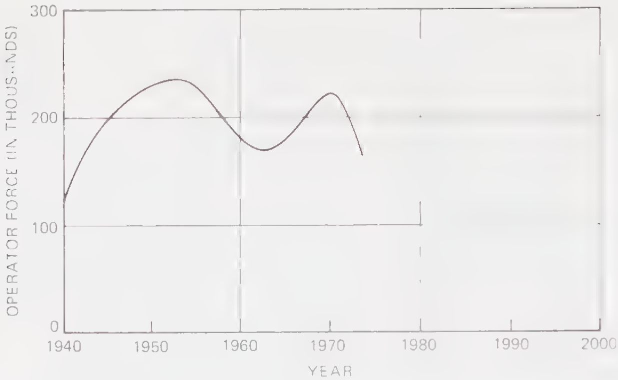

Fig. 7-9. Historical Trend of Operating Force

Alternate methods are being prescribed for some of the SOST services now provided by operators. For example, door-opener circuits may be replaced with suitable mechanical or electrical locks.

An example of automation is the Traffic Service Position System (TSPS), which will be described in more detail in Section 9.6. TSPS is the most modern toll operator system; it has no cords or jacks and uses a processor with stored program control. The operator sits at a console and enters information into a processor, which takes over the functions of outpulsing, timing calls, computing rates, and making records for billing. The operator performs only that minimum set of functions, such as requesting coin deposits, that distinguishes an operator-assisted call from a standard telephone call.

In addition to automating the toll function with TSPS, other areas are being automated. The CAMA-ONI function is being automated by the use of automatic number identification (ANI) equipment and, as previously noted, by the use of LAMA in new local offices. Possible means of automating the directory assistance function are being explored. An Automatic Intercept System (AIS) is in operation. Rating will be done automatically in most cases by the TSPS, and calls working directly into the toll network, including directly dialed international calls, will eliminate much of the need for rate and route operators.

Local coin overtime service can be automated with a circuit that either allows a call to continue or disconnects the call, depending upon whether the customer responds to an announcement by depositing the required coins. Coin toll service via TSPS will be further automated.

Stored program control systems such as TSPS require a substantial investment and a correspondingly large amount of traffic to justify such an investment. A remote trunk arrangement (RTA) has been developed which permits extending the control from a TSPS base unit to small toll centers. The RTA allows consolidation of operator traffic from the small toll centers to a large TSPS operator team. This consolidation provides a 3-fold gain. First, it provides the large traffic volumes needed to justify the high initial cost of computer systems. Second, it raises efficiency by substituting large groups of servers for smaller groups. Therefore, service levels can be maintained while increasing the productivity of the operators. Third, it allows a reduction in the number of operators required to provide night coverage in small operator bureaus by reducing the number of serving locations. The Bell System presently operates 1500 small locations, where small is defined as requiring fewer than 20 operators during the busiest hour of the year. A TSPS/RTA complex will be able to cover more than 100,000 square miles and will allow operators to be located at the sites with the greatest labor markets. Thus, a customer may have his call handled by an operator hundreds of miles away.

Another technique employed is control of demand. The major approach in this area has been to charge higher rates for services requiring operator assistance. This has already been implemented in the toll area. Several companies now have tariffs that include a charge for directory assistance. Another important way to achieve volume reduction is to improve telephone service, since some of the assistance-in-calling traffic is a direct result of customers having trouble placing their calls. Service must be dependable if customers are to dial all of their calls.

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2. W. A. Winckelmann, "Automatic Intercept Service," *Bell Laboratories Record,* Vol 46, No. 5, pp 138-143, May 1968.

Part Three Economic Evaluation

Economic evaluation is an important engineering function in planning and managing the development, manufacture, and deployment of products in the telephone plant. The magnitude of construction expenditures in the Bell System, over $9 billion yearly from 1973 through 1976, emphasizes the importance of economic evaluation. Chapter 8, "Economic Evaluation of New Products", is an introduction to concepts and practices used in the Bell System and is the only chapter in Part Three. The intent is to familiarize the reader with some of the basic principles and terminology currently in use without presenting a comprehensive treatment of present and evolving procedures.

8 Economic Evaluation of New Products

This chapter describes some of the methods and terminology used in the economic evaluation of new products and the projects that produce new products or services. Section 8.1 presents a broad view of the economic evaluation process as it applies to the Bell System. Section 8.2 discusses demand and how it can be estimated. Section 8.3 examines some considerations in evaluating the economics of manufacturing. The final Section, 8.4, focuses on economic evaluation principles and measures. A glossary of economic evaluation terms is included at the end of this chapter.

8.1 OVERALL PROCESS

A conceptual view of the process of bringing out a new product is given in Fig. 8-1. The process is thought of as a "project" and may or may not involve a new service. The steps shown do not occur in strict order of time, but overlap. Moreover, on sizable projects, there are iterations in the evaluations. Each iteration takes place with more detailed information and after more resources have been committed. This enables development to be started with some indication of the economic attractiveness of the undertaking. Later, more refined information is provided to guide product design and decisions affecting completion of development of the product. Economic evaluations are made both jointly and separately by Bell Laboratories, AT&T, and Western Electric and serve as aids in making decisions.

In addition to indicating whether a project will be economically viable, economic evaluation helps to shape fair projects into good ones and good projects into excellent ones. An example of shaping a project is to direct it toward a particular market segment. This may entail, for example, a decision as to what features to include in a station set or key telephone system in order to increase economic attractiveness. Another example is a determination of a proper balance between initial cost and reliability.

Note that there are interactions among AT&T, Bell Laboratories, and Western Electric which may be thought of as part of the evaluation process. These interactions are along the lines described in Sections 1.6 and 1.7. For example, the quality of the product may be improved by including manufac-

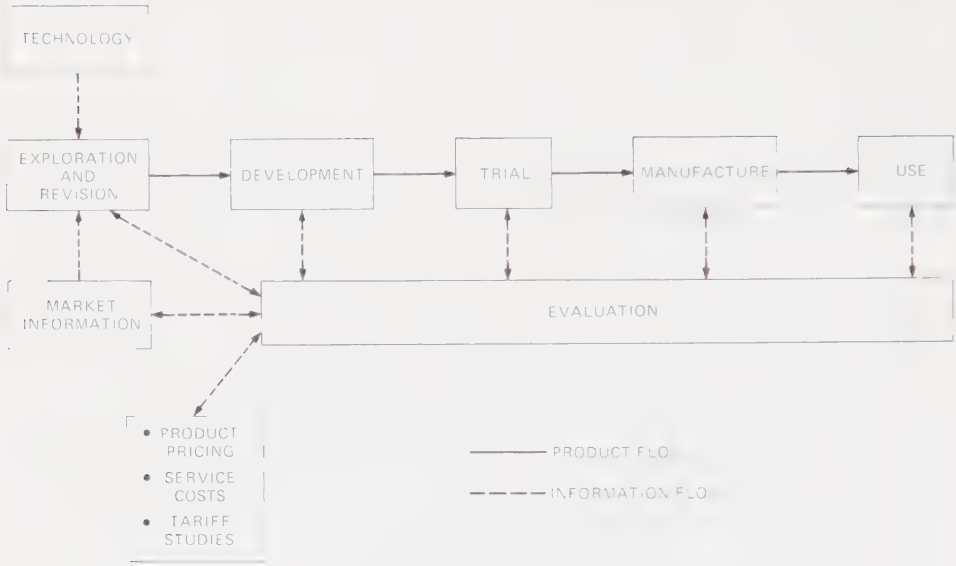

Fig. 8-1. Process of Bringing Out a New Product

turing considerations during development. These interactions play an important role in shaping projects.

To be effective in shaping projects, evaluations must be timely and provide answers to questions concerning sensitivity ("What if...?"). Such evaluations ordinarily involve so many factors that computer models are appropriate. The use of standard models helps to ensure that evaluations are consistent from project to project.

Economic evaluation of an idea or concept requires identification of the following four factors:

Product	What it is; what it will do.
Price	Price of the product and the terms under which it will be offered.
Availability	Where and when the customer can get the product. Some services, such as certain central office services and PhoneCenter service, are available only in certain areas, especially during the introductory period.
Customer Reaction	How will customers view the product and how actively will the product's use be encouraged through promotional activities.

Once the concept is established and there is an initial view of demand, there are two major considerations in evaluation: manufacturing economics (supply of product) and operating company economics (supply of service). The evaluation process, cast in these terms, is shown in Fig. 8-2.

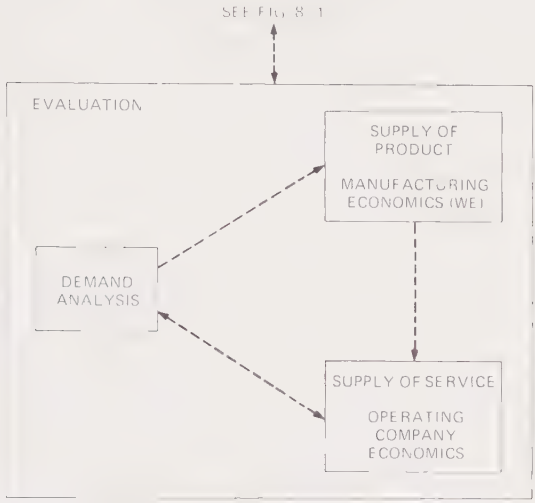

Fig. 8-2. Economic Evaluation Process—Demand and Supply

The interval during which the product is manufactured is called the manufacturer's product life cycle, and the interval from the installation of the first unit until the removal of the last unit by the operating company is called the service life cycle. An objective of both the manufacturer and the operating company is to recover their costs during their respective life cycles.

In operating company economic evaluation there are two kinds of consumers: the operating telephone companies and their customers. Correspondingly, there are telephone-company-use and customer-use products. A transmission system or a switching system for use on telephone company premises is a telephone-company-use product. A PBX or a data set is a customer-use product. The same broad principles of economic evaluation generally apply to both situations, but assessing demand for telephone-company-use and customer-use products may require different techniques.

Another difference in treating these two kinds of products is the way the price of the telephone company service enters the economic analysis. Pricing of services to customers involving telephone-company-use products is not, for the most part, directly related to evaluation of new products. For example, the economic analysis of a proposed long-haul transmission system draws upon traffic forecasts rather than explicitly considering prices for toll calls. However, the pricing of services involving customer-use products is a key element in demand analysis and thus in the economic evaluation of the product. For example, the expected *contribution* (see Section 8.4.2) from the proposed new product may be calculated for several tentative prices of service.

A principle inherent in the economic evaluation process, whether for manufacture or supply of service, is the treatment of a project alternative as the change or increment with respect to some other alternative, which may be (and typically is) to make no change. The rationale for looking at incremental costs and incremental revenues is to determine and understand the effects of a particular project decision.

8.2 DEMAND ANALYSIS

8.2.1 DESCRIBING DEMAND

Demand analysis is the estimation of how many people and organizations will, over a period of time, select and use the product or service under consideration. Included are the effects of the product on the demand for other products in the marketplace, the *cross-elastic effects*. Demand for a product can be stimulated by any of the following factors:

(1) The product provides a new function, not previously available.

(2) The product provides a function similar to existing products, but is superior in some respect, such as lower price, and hence achieves success by capturing some of the potential market for the existing products.

(3) The product is so superior that, in addition to (2), present users of existing products will discard them to buy the new products.

Each of these factors must be considered in estimating potential growth and decline of demand during the service life cycle. The extent to which the potential market is achieved depends, of course, on the relationship between the function performed, the perceived value, and the price.

In evaluating demand, the removal mechanism must be examined in a manner similar to the introduction mechanism. The likelihood of removal of customer-use products may depend in part on the terms under which a customer has purchased service. For example, service arrangements in which the customer bears the cost of early termination should result in fewer early removals than arrangements without such provisions.

Estimates of the number of product purchases and removals can be determined from service life-cycle models. Such models also serve to forecast the number of field and shop repairs and the number of units added, retired, or junked. In addition, life-cycle models help to answer questions regarding the sensitivity to assumptions on location life and equipment life and the relationship between in-service quantities and purchases over the life of the project.

Market demand can be characterized by estimating the number of units of a product or service that buyers would purchase at different price levels during some stated period of time. Demand curves are customarily plotted as shown in Fig. 8-3. Since buyers generally purchase more at lower prices, the resulting demand curves have negative slope; the shape of the curve, of course, depends on a variety of factors.

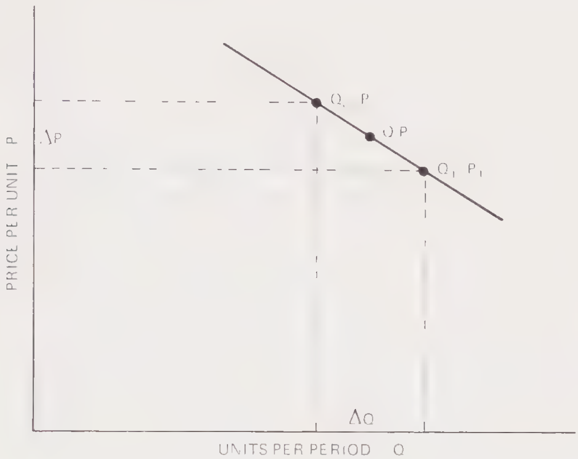

Fig. 8-3. A Demand Curve

The responsiveness of the number of customer purchases to small changes in price level can be described by the coefficient of price elasticity of demand E_p. By definition, E_p is the negative of the fractional change in demand divided by the fractional change in price, i.e.:

$$E_p = -\frac{\Delta Q/Q}{\Delta P/P}. \tag{1}$$

Given E_p for a particular commodity at the existing price level P_0, the effect of price changes on total sales revenue is easily estimated. Fig. 8-3 illustrates that changing from P_0 to P_1 produces the following change in total revenue:

$$\begin{aligned}\text{Revenue Change} &= P_1Q_1 - P_0Q_0. \\ &\approx \Delta P(1 - E_p)Q_0. \end{aligned} \tag{2}$$

If the change in total revenue is in the same direction as the change in price level, the commodity is said to be inelastic. From the above approximation, this is seen to occur if $0 < E_p < 1$. If total revenues move in the opposite direction to changes in price level, the commodity is said to be elastic, i.e., $E_p > 1$.

The total market demand for essential products such as basic telephone service and gasoline tends to be inelastic. Gasoline, for example, is said to have an estimated short-run E_p of 0.2 (at 1976 prices). Thus, at 60¢ per gallon, a 10-percent price increase can be expected to decrease total sales by 2 percent and to increase total revenues by about 8 percent per period. Air travel, on the other hand, is highly elastic.

Cross-elasticity effects are usually expressed in numerical terms giving the effects of one product and its price on the sales or use of another. TRIMLINE sets at present prices are said to be highly cross-elastic with the older PRINCESS sets, because an increase in TRIMLINE demand tends to decrease the demand for PRINCESS telephones. Conversely, a new product may stimulate demand for other products; for example, a new DATASPEED terminal may stimulate demand for data sets to go with it.

In the economic evaluation of a new product, any changes in revenue and cost caused by cross-elastic effects upon existing products must be considered. In addition, the effect of other suppliers should be considered in studying both elastic and cross-elastic effects.

8.2.2 ESTIMATING DEMAND

One important approach to estimating demand is applicable to those products for which the decision to purchase is based largely or entirely on "cost" to the buyer. Most telephone-company-use products are in this class. For this class of product, standard Bell System demand estimation models are available. These models typically simulate future telephone company decisions as to what equipment will best suit forecasted service demands, that is, meet demands while optimizing an economic evaluation measure.

Estimating demand for customer-use products poses different problems. Because customers have a wide choice among the products in the marketplace and may choose none at all, it is difficult, for example, to predict whether they will pay, say, $1 extra per month for a specially housed extension telephone. Introduction of new products by competitors also adds complexity to the estimation process.

For some products, it is useful to construct segmented demand models. A typical model divides the market into a number of segments, ranging from 10 to 1000, each composed of potential customers of similar characteristics. The specific products available to customers are characterized with respect to capabilities, availability, and price. A decision criterion is hypothesized, and the demand for the various products within each segment is estimated. The effectiveness of this market segmentation approach depends on whether more accurate estimates can be made for small segments than for the market considered as a whole. Such models are used for demand estimation of customer switching systems.

Demand for a product can be measured most directly by actual market tests. However, to depend solely on a market test usually would require that the product be fully developed, and hence the information would become available only after substantial financial commitment. Because this is undesirable, another approach, *concept testing*, is often used. In concept testing, a verbal description of the product and price is offered to potential customers, and the responses are tabulated. This has the disadvantage of exposing a firm's product development ideas to a competitor early in the development process, and there is the risk that the customers' actual behavior will not conform to the test results.

In advanced forms of market analysis for new products and services, the market analysts become so familiar with the customer's needs that they can put themselves in the customer's place. This knowledge of the customer's business is combined with the knowledge of potential communications services to shape proposals for attractive new services.

8.3 MANUFACTURING ECONOMICS

Manufactured products used in the Bell System fall into three broad categories: Western Electric manufacture, outside manufacture to Bell System specifications (called KS specifications), and general trade products. For the first two, the design information or specifications come from Bell Laboratories. General trade products may be purchased by an operating company, or Western Electric may serve as purchasing agent. Specifications and prices for general trade products generally are established by the manufacturer; specifications may be assessed against criteria provided by Bell Laboratories.

A long-standing Western Electric policy is to set the lowest prices that provide a reasonable return on the investment involved. Return on investment is computed by principal lines of products, lines that have evolved over the years and reflect homogeneity within each product line. The use of a product-line structure for cost assignment is consistent with the approach generally used by multiproduct companies in industry. Cost control and cost reduction are major activities.

In setting prices, Western Electric develops price factors for each individual product line; included in the factor is a markup to cover overhead costs. The same costing and pricing procedures are used by Western Electric regardless of whether the product is for telephone company use or customer use. The Western Electric price is not influenced by demand except as costs, generally long-term costs, may be influenced by demand. This contrasts with other manufacturing firms, where product price may be adjusted in response to current demand. Costs for Western Electric software are different in nature from equipment costs because development costs, not manufacturing costs, are predominant. As software becomes a larger part of Western Electric sales, pricing practices are being reexamined.

In general, the pricing process spreads development costs and manufacturing overhead costs of products in a product line across the whole line. But, as will be seen, manufacturing economic evaluation for a proposed product includes its estimated specific development cost.

In estimating direct costs of manufacture, one must consider that the cost of production for each unit varies as experience is gained. Empirical evidence indicates that where technology is evolving, the logarithm of Western Electric's direct manufacturing cost for components tends to decrease linearly with the logarithm of the rate of production. The change with time depends on the rate of production buildup. The extent to which the principle applies to systems as well as to components is subject to further study.

One approach to product pricing could be to apply product line price factors to current production costs. For new products, this could make the initial units very expensive, and thus it would unfairly penalize those operating companies taking early deliveries. Furthermore, adjusting prices over a period tends to reduce the ability of the purchaser to plan effectively, another undesirable result. Hence, Western Electric looks ahead to estimate the eventual production cost and considers the whole profile of cost versus time in pricing. For estimating production cost over time, a year-by-year estimate of demand is needed.

In manufacturing economic evaluation, the cash flow method (see Section 8.4.3) generally is used. Manufacturing cash flow analysis takes overhead costs into account. Overhead costs attributable to the project, such as development expense, are estimated, and costs that are not directly attributable, such as Western Electric corporate overhead, are reflected by means of factors applied to known costs. Briefly, the procedure examines all of the cash flows involved in the development and manufacture of the product and estimates if, when, and to what extent the manufacture of the product will return cash to the firm. The principle flows in this type of evaluation are:

INFLOWS	OUTFLOWS
Sales receipts (at the estimated demand and at the price derived by application of pricing principles)	Direct cost of manufacture: labor and materials
	Development costs, Western Electric and Bell Laboratories
Increases in accounts payable	Outlays for new facilities
	Outlays for inventory
	Increases in accounts receivable
	Taxes
	Operating expenses

The difference between inflows and outflows defines Western Electric net cash flow. Calculations are made with and without consideration of the cross-elastic effects between Western Electric products.

Development of a product should take into account the effect of the particular design on cost of manufacture, inventory, repair, and so on. To this end, the designer is expected to consult with Western Electric early in the design process.

8.4 ECONOMIC EVALUATION PRINCIPLES

This section describes some of the basic principles and methods used in economic evaluation. Further discussion can be found in the references listed at the end of this chapter.

Measures for assessing the economic attractiveness of new projects reflect the impact on the *income* and *funds flow* statements used in financial accounting. The income view is expressed in the *contribution* measure, and the funds view is expressed in the *after-tax cash flow* measure.

In an income statement the basic quantities are:

Revenues
Cash Expenses
Depreciation
Income Taxes
Other Taxes
Interest
Net Income (Earnings)

where Net Income = Revenues − [Cash Expenses + Depreciation + Income Taxes + Other Taxes + Interest].

These quantities can be estimated for a prospective project by considering future tariffs, service demands, equipment costs (manufacturer's price and installation expenses) manpower estimates, labor costs, etc. All of the quantities listed above are included in calculating contribution, with target earnings and the income tax resulting from these earnings being considered as costs. Specifically, a prospective project would generate the following incremental[1] annual costs:

Depreciation
Interest (on debt capital)
Target Earnings (on equity capital)
Income Tax (resulting from target earnings)
Cash Expenses
Other Taxes

The first four items in this listing are the *annual capital costs,* accounting for the recovery of investor-supplied capital, as well as for the "rental" cost of capital. When all cost items are subtracted from the incremental annual project revenues, the remainder defines the annual contribution for the project. It can be shown that the incremental net income for a prospective project equals target earnings plus $(1 - \tau)$ times contribution, where τ is the income tax rate.

The funds flow statement presents a summation of the sources and applications of funds from all ongoing projects. The sources of funds are new

1. The word incremental implies the change in a quantity caused by a project, that is, the amount corresponding to a baseline plan plus the project less the amount for the baseline plan alone.

financing and revenues from operations; the applications of funds are flows to investors and purchases of plant. The effect of a prospective project would be to provide additional sources from operations and financing for application to investors and for purchases of plant (investment). To determine the impact of a project on investors, the incremental funds flows for a project can be arranged with investor-related terms on one side and operations-related terms on the other side to give the following equation:

Net Funds Flows to Investors = Revenues − Cash Expenses − Taxes Paid − Investment

Each side represents the net annual funds provided by or required by the project. This relation is used to develop the after-tax cash flow measure.

Contribution and after-tax cash flow are discussed in Sections 8.4.2 and 8.4.3, respectively. Comparison between them is made in Section 8.4.4, and other measures are touched on briefly in Section 8.4.5. All abbreviations and symbols used in this section are listed in Table 8-1 at the end of this chapter.

8.4.1 BASIC CONCEPTS

To understand the economic effect of a project, one needs to account for both short-term and long-term effects. Frequently, a project with good or excellent long-term effects has adverse short-term effects. An example is a project with a heavy initial capital outlay and a slow buildup of revenues. Conversely, a project that saves cash operating expense with small investment may pay off almost immediately. Diverse projects are put on a common basis by applying *discounting*, a procedure in which future dollars receive less weight than today's dollars.

The purpose of the discounting process is to account for the time-value of money. In applying the discounting concept, future worth (FW) is translated to present worth (PW) by:

$$PW = \frac{FW}{(1 + d)^n} \tag{3}$$

where n is the number of periods separating the present and future and d is the discount rate per period. In general, the firm chooses the appropriate numerical value for d based on financial objectives and the conditions in capital markets. Thus, the rental cost of money, such as the cost of debt and equity earnings, is accommodated implicitly through the discount rate. For example, a project that has an outflow of 100 units in the first year and an inflow of 110 units in the second year will show a positive discounted cash flow only if the discount rate (average rental cost of money for debt and equity capital) is less than 10 percent.

When there are multiple future flows, the aggregate present worth is the sum of present worths of these flows. The sequence of aggregate present worths over a period of time is called the *cumulative present worth*. For a sequence $[x_i]$ for periods $i = 1$ to n, aggregate present worth is given by:

$$PW_d^n [x_i] = \sum_{i=1}^{n} \frac{x_i}{(1 + d)^i} \quad (4)$$

where d is the discount rate. In applying the present worth concept to year-by-year contribution or net cash flow, a project is attractive in principle if the total cumulative present worth exceeds a threshold (typically >0) over its life cycle.

The year-by-year attractiveness of a project, from the contribution perspective, depends on both the revenues and annual costs in each year. Since both revenues and annual costs may vary during the project life, the annual contribution may vary. By levelizing revenues and annual costs over the project life with the present worth operation, one defines a levelized contribution measure in each year, thereby imputing an "average" contribution to each period.

When alternatives have different service lives, special steps beyond the scope of this text must be taken. Consider, for example, alternative switching system projects having service lives of 20 and 25 years, respectively. To compare them properly, the same study period, either 20 years or 25 years, should be used for both alternatives. For a 20-year study period, the value of the last 5 years of the longer alternative is taken into account, and for a 25-year study period, a potential successor to the shorter alternative is assumed.

Complete economic evaluation also would include analysis of the effect of uncertainties in the input data such as demand, revenues, costs, and service lives. Hence, calculations should be made to determine the sensitivity of the economic measure(s) to changes in one or more such inputs. This procedure will identify those input parameters that may have a significant effect on decisions as a guide to where data validation efforts are required. Thorough sensitivity analyses and data validations are important elements of economic evaluation studies.

A noteworthy aspect of incremental analysis of operating company effects is that overhead costs, costs not directly assignable to the project, are not included in calculations.

The importance of estimates of telephone company costs in the economic evaluation process is reflected in the activities of the AT&T Service Costs organization. It is responsible for developing procedures and computer programs, sometimes with Bell Laboratories support, to estimate these costs. Both the procedures and the estimates are used in evaluating new products and services and in analyzing the economic impact of changes in prices.

Of particular importance are operating company taxes including income taxes, payroll-related taxes, property taxes, and gross receipts taxes. In general, all of these taxes are influenced by the undertaking of a project. For project evaluation, income taxes are equal to the income tax rate times taxable income. By definition, taxable income is revenues less cash expense (CE), other taxes (OT), tax depreciation allowances (TD), and debt interest (DI). Investment tax credit realized (TCR) reduces taxes to be paid in the year of the investment. Thus, in year j:

$$Income\ Tax_j = \tau[REV_j - (CE_j + OT_j + TD_j + DI_j)] - TCR_j \tag{5}$$

where τ is the income tax rate.

8.4.2 CONTRIBUTION

Contribution is generally used to measure the economic effect of new projects on the telephone company. Manufacturing economics appears primarily through product prices which are reflected in investment or, in some cases, as cash expense. Each of the basic quantities used to calculate contribution is, as stated previously, an increment (including cross-elastic effects) resulting from undertaking the project in contrast with not undertaking the project. For example, revenue or costs may be reduced (or increased) by effects on other products. The entire set of basic quantites in each year j is:

Project Revenue = REV_j

Project Annual Costs

- Cash operating expense = CE_j
- Taxes other than income taxes = OT_j
- Book depreciation (i.e., capital recovery) = BD_j
- Debt interest = DI_j
- Target earnings[2] TE less amortized investment credit TCA for that year = $TE_j - TCA_j$
- Basic income tax liability which would be incurred if target earnings on equity for that year were realized = $\frac{\tau}{1-\tau}(TE_j - TCA_j)$, where τ is the corporate income tax rate.[3]

Thus, contribution in year j is given by:

$$CNTR_j = REV_j - [CE_j + OT_j + BD_j + DI_j + (TE_j - TCA_j) + \frac{\tau}{1-\tau}(TE_j - TCA_j)]. \tag{6}$$

The economic impact of the project as a whole is given by the sequence $CNTR_j$ for $j = 1...n$.

2. As noted previously, target earnings on equity is considered to be a cost. The rationale is that the service cannot be given without the investment, and the investment cannot be made without paying rental cost of money.

3. If $TE_j - TCA_j$ is the after-tax earnings requirement, the corresponding income tax $TXTE_j$ equals

$$\tau(TXTE_j + TE_j - TCA_j) = \frac{\tau}{1-\tau}(TE_j - TCA_j)$$

Each of the six cost elements can be thought of as resulting from the aggregate of all the investment vintages of the project, where investment vintage refers to all the investments made in a specific year.

Calculation of DI_j and TE_j requires determination of net investor capital *INVCAP* in each year j. From the fundamental accounting identity (assets = liabilities + capital), it can be shown that net investor capital equals initial investment minus depreciation reserve minus the reserve for deferred income taxes minus the account for unamortized investment tax credits. Given $INVCAP_j$ as such, one obtains:

$$DI_j = i_d \, \delta \, INVCAP_{j-1} \quad (7)$$

$$TE_j = i_e \, (1 - \delta) \, INVCAP_{j-1} \quad (8)$$

where i_d is the cost of debt, i_e the cost of equity, and δ the debt ratio.

In the absence of accelerated tax depreciation and investment tax credit, net investor capital is simply the difference between all the investments and all accumulated depreciation. Accelerated tax depreciation and investment tax credit effects, providing deferred credits, tend to reduce the net investor capital. To simplify exposition, effects resulting from a single investment INV_0 at time 0 are discussed. Extension to multiple investments is straightforward.

Consider first the effect of accelerated tax depreciation, resulting from the fact that book depreciation BD_j is not typically equal to tax depreciation TD_j, although it is assumed that, overall,

$$\sum_{j=1}^{n} BD_j = \sum_{j=1}^{n} TD_j = INV_0. \quad (9)$$

With $BD_j \neq TD_j$, the tax depreciation deduction assumed for book purposes (BD_j) differs from the deduction used in calculating taxes paid (TD_j). In the early years when $TD_j > BD_j$, taxes paid is less than the amount of taxes incurred. Rather than "flowing-through" these differences to earnings, the differences are "normalized" over the project life through an accounting procedure that keeps track of the cumulative differences in τBD_j and τTD_j; this creates the deferred tax reserve. The value of the reserve in year j is given by:

$$TDRES_j = \sum_{i=1}^{j} \tau(TD_i - BD_i) \quad (10)$$

where $TDRES_0 = TDRES_n = 0$.

Since tax depreciation exceeds book depreciation in the early years of a project life, the reserve increases and then decreases to the final value of 0.

The treatment of investment tax credit is somewhat different. Investment tax credit is a reduction in income taxes during the year of investment. The amount is equal to a given fraction of the investment. However, for accounting purposes, this reduction is not reflected on the firm's income statement during the year of investment, but is amortized over the project lifetime. The tax credit realized in the year of investment, TCR_0, results in an amount amortized in each future year, TCA_j, where $j = 1, 2, \ldots, n$. Accounting procedures ensure that the sum of the amortized amounts TCA_j for all $j = 1, 2, \ldots, n$ is equal to the initial amount realized, TCR_0. The difference between the amount realized and the amount amortized (i.e., the unamortized amount) is recorded in the investment tax credit account ($ITACC$) and is given by:

$$ITACC_j = TCR_0 - \sum_{i=1}^{j} TCA_i \tag{11}$$

for $j \geqslant 1$.

The final value of the account, $ITACC_n$, is equal to 0.

The third and final element in determining the amount of net investor capital each year is book depreciation. The book depreciation reserve is defined as the sum of prior depreciation accruals (ignoring retirements) and is given by:

$$BDRES_j = \sum_{i=1}^{j} BD_i \tag{12}$$

for $j \geqslant 1$.

Thus, the total amount of net investor capital, $INVCAP_j$, in each year, serving as the basis for computing target earnings and interest, is given by:

$$INVCAP_j = INV_0 - BDRES_j - TDRES_j - ITACC_j. \tag{13}$$

If investments are made during several different years, this relation must be applied to each vintage and the results summed.

Recalling equations 7 and 8

$$DI_j = i_d \ \delta \ INVCAP_{j-1}$$

$$TE_j = i_e \ (1 - \delta) \ INVCAP_{j-1}$$

and assuming that the target equity earnings rate (i_e), interest rate on debt (i_d), tax rate (τ), and corporate debt ratio (δ) are constant over the project lifetime, the equation for $CNTR_j$ for $j = 1, 2, \ldots, n$ can be written:

$$CNTR_j = REV_j - [CE_j + OT_j + BD_j - \frac{TCA_j}{1-\tau} + \frac{i_a}{1-\tau} INVCAP_{j-1}] \tag{14}$$

where i_a, the tax-adjusted cost of capital, is given by $i_e(1 - \delta) + i_d(1 - \tau)\delta$. This formulation assumes an end-of-year convention,[4] namely, the first payment of interest, expenses, etc., resulting from an investment at time 0 occurs at the end of the first time period.

The last effect to be mentioned is the deferral of taxes on Western Electric profits, which tends to reduce telephone company costs. For simplicity, however, this effect is not included in the above equation. Western Electric incurs a tax obligation equal to the tax on profit on goods sold to the operating companies. Rather than paying this tax at the time of sale to the operating com-

4. Note that other conventions also are used.

pany, the Internal Revenue Service allows the operating companies to pay this tax over the tax life of the investment by an appropriate reduction in tax depreciation *TD*. This is allowed because Western Electric and the operating companies file a single consolidated Bell System tax return.

In principle, to be economically attractive a project should show a positive present worth of contribution aggregated for all the years of the life of the project. In practice, this present worth should be substantial. If contribution is 0 for a particular year, the effect of the project upon reported earnings is equal to the target return on the equity portion of net investor capital.

An important use of contribution is in testing a price for a service associated with a customer-use product. A price that is too low could depress revenue so much that the present worth of contribution could be negative. Also, a price that is too high could depress the demand (and revenue) and lead to a negative contribution. Optimizing long-run contribution has been a fundamental consideration in choosing prices for vertical and competitive services.

8.4.3 CASH FLOW

Undertaking a project results in changes in cash flows (including cross-elastic effects) for each year of the project, giving a figure for incremental after-tax cash flow for each year. These flows include revenue, funds for purchase of equipment, funds to pay salaries, taxes, etc. The net cash flow, as defined below, is equal to net cash flow to investors. The principal flows used in cash flow analysis are:

Inflows in year j
- Revenues = REV_j

Outflows in year j
- Cash operating expenses = CE_j
- Taxes other than income taxes = OT_j
- Investment = INV_j
- Income taxes = $\tau[REV_j - (CE_j + OT_j + TD_j + DI_j)] - TCR_j$ where various expressions for DI_j, including that used in calculating contribution, are possible.

Taking the difference and collecting terms, after-tax cash flow in year j can be written:

$$ATCF_j = (1 - \tau)(REV_j - CE_j - OT_j) + \tau(TD_j + DI_j) + TCR_j - INV \qquad (15)$$

Cash flow measures are routinely applied to assess the effect of a project on Western Electric as discussed in Section 8.3 and on the telephone companies. Western Electric cash flow can be combined with the cash flows of the telephone companies to provide a composite view.

To interpret cash-flow values for a project, it is useful to plot them in cumulative discounted form as shown in Fig. 8-4. For decision-making, one looks particularly at (1) the time at which the curve becomes positive, (2) the most negative value reached, and (3) the final value.

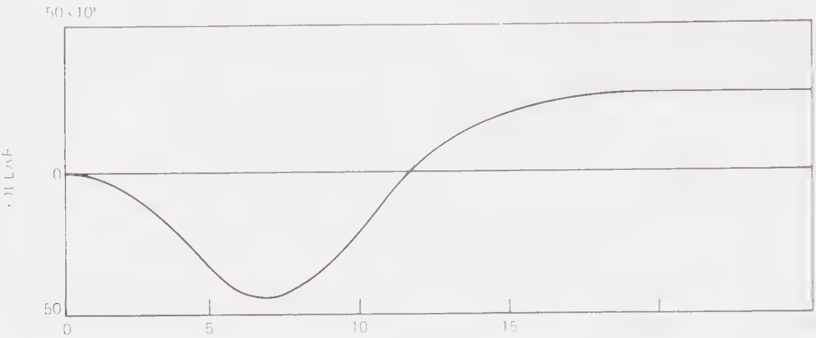

Fig. 8-4. An Example of Cumulative Present Worth of After-Tax Cash Flow

8.4.4 CONTRIBUTION COMPARED WITH CASH FLOW

Because of the wide use of contribution and cash flow measures, it is illuminating to look at some of the differences and similarities. First, book depreciation does not explicitly appear in the cash flow calculation because, while book depreciation is a cost in calculating contribution, it is an accounting cost not requiring disbursement of funds.

Further, recall that in calculating contribution, the effects of investment tax credit and accelerated tax depreciation are reflected primarily as a reduction of the investor capital obligations upon which the project must pay interest and equity earnings. In contrast, these same effects are reflected in cash flow calculations as a reduction in taxes paid.

There is another difference between cash flow and contribution calculations concerning income taxes. The cash flow calculation is based on taxes on revenues while the annual costs used in calculating contribution include only taxes resulting from target earnings. If the revenues are different from the annual cost in any year (non-zero contribution) the total tax, as would be calculated in cash flow analysis, is given by $TXTE_j + \tau(CNTR_j)$.

In spite of these differences between year-by-year contribution and cash flow, these measures have a direct relationship in the cumulative present worth form. Using the composite cost of capital as the discount rate, the present worth of after-tax cash flow equals (1 − tax rate) times present worth of contribution. With the corporate tax rate near 50 percent, contribution is roughly twice the cumulative discounted cash flow for a project as a whole. Similar relationships between cash flow and contribution can be derived for alternative cash flow formulations (e.g., equity-holder cash flow).

8.4.5 OTHER MEASURES

Another set of project measures, not treated here, is expressed in percent rather than in dollars. One of these, for example, is called *project rate of return.* This figure for a project can be thought of as the equivalent rate of return on investment such that an investor would be indifferent to accepting this project or another investment offering the same annual rate of return.

In addition to dollar measures and percent measures, there are certain project "input" quantities that are of themselves useful in the decision-making process. Of particular interest are year-by-year estimates of (1) incremental revenue, (2) incremental cash operating expense, and (3) incremental investment. These three quantities and service life of equipment can be thought of as the variables associated with the project. Not only are these quantities used in calculating contribution and after-tax cash flow, but also they are directly useful when comparing the economic impacts of several alternatives.

TABLE 8-1
ABBREVIATIONS

ATCF	Net after-tax cash flow.
BD	Book depreciation.
BDRES	Book depreciation reserve.
CE	Cash operating expenses. As used here, does not include operating taxes.
CNTR	Contribution.
d	Discount rate.
DI	Debt interest.
δ	Corporate debt ratio, i.e., debt/total investor capital.
FW	Future worth.
i_a	Tax-adjusted cost of capital.
i_d	Cost of debt.
i_e	Cost of equity.
INV	Investment.
INVCAP	Investor-supplied capital remaining after depreciation and tax effects.
ITACC	Investment tax credit account.
OT	Taxes other than income taxes.
PW	Present worth.
REV	Revenue.
TCA	Tax credit amortized.
TCR	Tax credit realized.
TD	Tax depreciation.
TDRES	Tax depreciation reserve.
TE	Target (or required) earnings on equity.
TXTE	Basic income tax liability resulting from meeting the earnings requirement of the project (or target earnings), unmodified by accelerated tax depreciation or investment tax credit except as these tax effects influence the investment remaining.
τ	Income tax rate.

GLOSSARY OF TERMS USED IN ECONOMIC EVALUATION

Accelerated Tax Depreciation

A schedule of depreciation allowances that provides for larger initial depreciation allowances and smaller later allowances than with straight-line depreciation.

After-Tax Cash Flow

A measure of the incremental effect of a product or project on the cash flows of a firm.

Annual Contribution

The difference, for any year, between the incremental revenues recorded for a project and the associated costs (including the cost of money).

Book Depreciation

A portion of the cost of an investment subtracted from revenues in a given year to calculate reported earnings. Book depreciation and accelerated tax depreciation need not be identical, but the permissible variations are limited by tax and regulatory rulings.

Contribution

The present worth of annual contribution summed over the project life. Also used to mean annual contribution.

Cross-Elasticity of Demand

The fractional change in the demand for a product or service divided by the fractional change in the price of a substitutable or complementary product or service.

Discounting

A process by which flows of money in the future are converted to equivalent flows at the present using the time-value of money.

$$PW = \frac{FW}{(1 + d)^n}$$

where PW = present worth, FW = future worth, n = number of periods separating present and future, and d = discount rate per period.

Investment Tax Credit

A tax incentive intended to stimulate investment in buildings and equipment. Taxes are reduced directly by the stipulated percentage of qualifying investment.

Levelize

A process in which a quantity or measure, such as annual contribution which may vary from year to year over project life is characterized by a single "levelized" value for all periods such that the present worth of the quantity is equal to the present worth of the levelized value over the project life.

Present Worth

The result of applying time value of money to cash flows occurring in the future to obtain a present amount having equivalent value. It is used in economic evaluation to compare or combine flows occurring in different years. It also applies to contribution. See *Discounting*.

Price Elasticity of Demand, Coefficient of

The coefficient of price elasticity of demand is the negative of the ratio of the fractional change in quantity demanded to the fractional change in price of a product.

Product Life Cycle

The interval from introduction to last sale of a product.

Revenue

Payment obtained from provision of a service or product.

Service Life Cycle

The interval from the installation of the first unit until the removal of the last unit by an operating company. Alternatively, the period from introduction of a service to cessation of revenue.

Target Earnings

The earnings that correspond to the target rate of return times equity capital. The target rate of return is established in regulatory proceedings.

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Part Four

Systems—The Network Elements

Chapters 9 through 12 describe the variety of systems that are elements in the facilities network. Switching, transmission, associated systems (including power, distributing frames, and signaling), and customer-premises systems are considered. The treatment is broad, with the objective of giving the reader an understanding of the systems now in extensive use and an indication of trends in evolution. Lists of references are provided for those interested in more detail on specific systems.

Several system considerations not treated elsewhere are mentioned in Chapter 13. These include safety, problems associated with evolution, and quality assurance.

9 Switching Systems

This chapter introduces several basic concepts common to all switching systems. It then presents a reasonably complete summary of the switching systems used in the Bell System, including some history of their evolution. Additional material on switching systems is contained in Section 12.3, "Customer Switching Systems". A list of references is provided at the end of this chapter for supplementary reading.

9.1 SWITCHING CONCEPTS

The basic function of any switching system is to interconnect communication paths. The achievement of the function can be understood by considering the two essential parts of a switching system:

(1) A switching network made up of individual switching devices and used to connect paths together.

(2) A control section to operate the right switching devices at the proper time.

9.1.1 SWITCHING NETWORKS

The most common kind of switching network is a space-division network, in which the talking paths are physically or spatially separated. Both progressively controlled and coordinate space-division networks will be considered. Time-division networks, in which more than one conversation may share the same physical path, also will be explained.

To begin, consider a 4-point rotary switch as shown in Fig. 9-1. By directing the wiper to the proper position, any of the four telephones can be connected to the rest of the network. While one of the telephones is in use, however, the others are blocked. More paths and less blocking can be provided by connecting or *multipling* the same four customers on two switches as shown in Fig. 9-2. Now there can be two simultaneous conversations, but at the cost of an extra switch and its interconnection to the rest of the network. Notice that with four inlets and two outlets, the net effect is one of concentration, with a concentration ratio of 2:1. Because customer lines are being concentrated, the output links are in use, on the average, twice as much as the individual lines. In general, the more a facility is in use, the greater the efficiency and the lower the cost per unit of traffic.

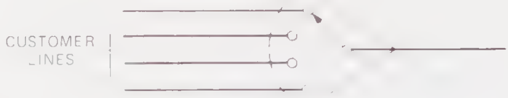


Fig. 9-1. Four-Point Rotary Switch

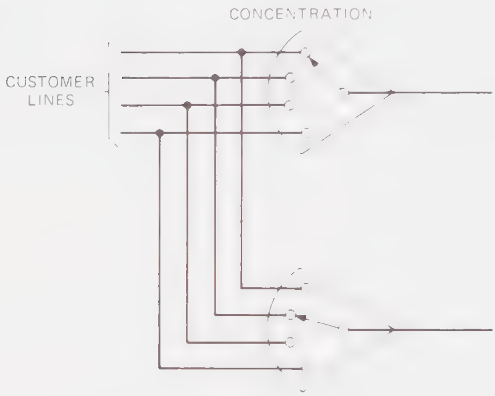


Fig. 9-2. Concentration Stage

After the usage or load has been built up in the early stages of a switching network by concentration, the ability to connect to many places is needed. This may be done as shown in Fig. 9-3, where each input has access to each output. This technique is known as *distribution*, and a network (or portion of one) that provides this function is known as a *distribution network*. In contrast to concentration networks, in which the ratio of inputs to outputs is greater than one, distribution networks have a ratio exactly equal to one.

The ratio of inputs to outputs may also be less than one, as shown in Fig. 9-4. This gives the ability to reach a number of potential outputs of the network. Some of these outputs may go to other switching offices over trunks, whereas the rest may be connected to customers on this network. This effect is the opposite of concentration and is known as *expansion*.

Most switching networks have stages for concentration, distribution, and expansion.[1] The result is the capability to make the required interconnections, while holding down the number of switches in the network.

Consider how a path may be set up through the switching network of Fig. 9-4. First, the wiper of an idle switch in the concentration stage must be moved to the input of the calling customer. Then, the connecting switch in

1. The No. 4 ESS network has no concentration stage.

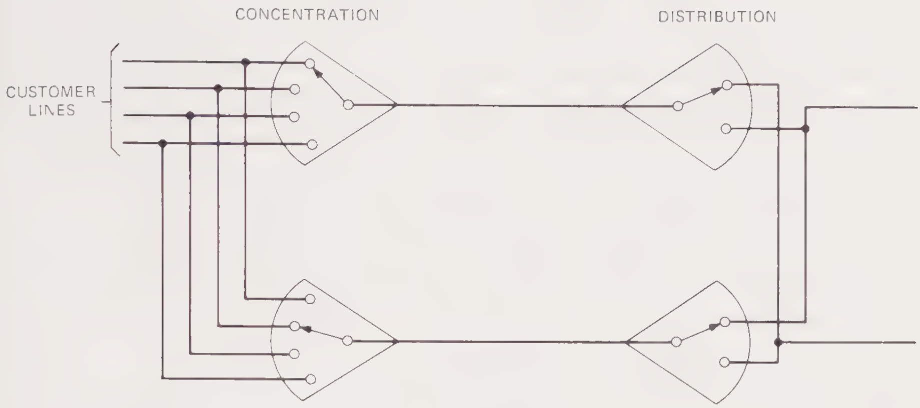


Fig. 9-3. Concentration and Distribution Stages

the distribution stage must be moved to select the proper path to the expansion stage, where again a one-out-of-four choice must be made. Such a switching network, in which the paths are established one stage at a time, is known as a *progressively controlled network.* Control of such a network is treated in Section 9.1.2.

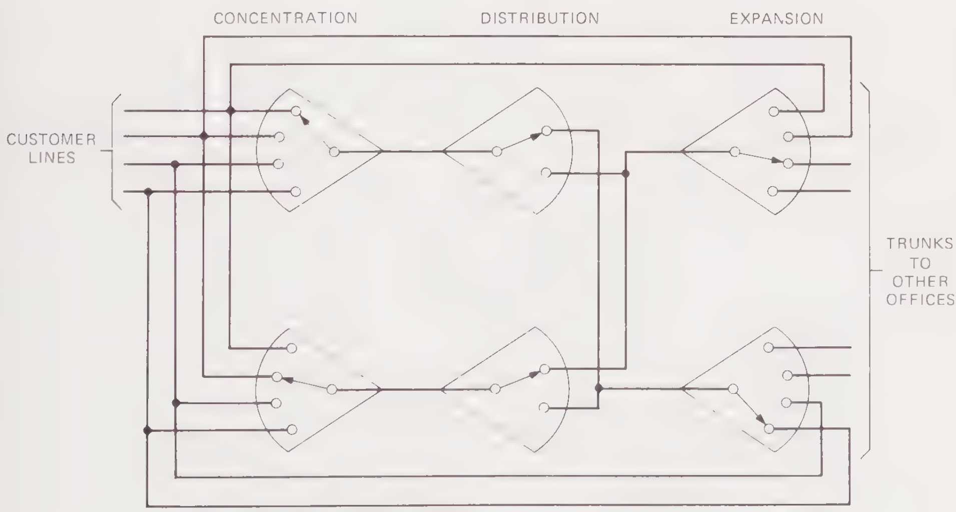


Fig. 9-4. Concentration, Distribution, and Expansion Stages

Although rotary switches are not the only type used in a progressively controlled switching network, all types of progressively controlled network switches, like rotary switches, tend to be large, gross-motion traveling switches. These switches have several disadvantages:

(1) They are slow.

(2) They can be used to set up paths in one direction only.

(3) They experience considerable wear on the contacts because of the large motion; maintenance costs are therefore high.

In contrast to the large gross-motion switches of progressively controlled networks, coordinate switches (used in coordinate networks) are fine-motioned, thus reducing wear and maintenance expense. As their name implies, these switches have a coordinate or grid-like structure consisting of an array of contacts or crosspoints where several inputs can be connected independently to several outputs. (Recall that rotary-type switches are one-to-several or several-to-one devices.)

If coordinate switches are substituted into the progressively controlled switching network of Fig. 9-4, the result is an equivalent coordinate network, shown in Fig. 9-5. Here the switch motion is smaller and faster; this means less holding time and more sharing. Several conversations can be set up through a single switch. Connections can be made both ways through the switches, and thus it is possible to loop back or "fold" the network on itself to complete a call between customers with line appearances on the same side of the network.

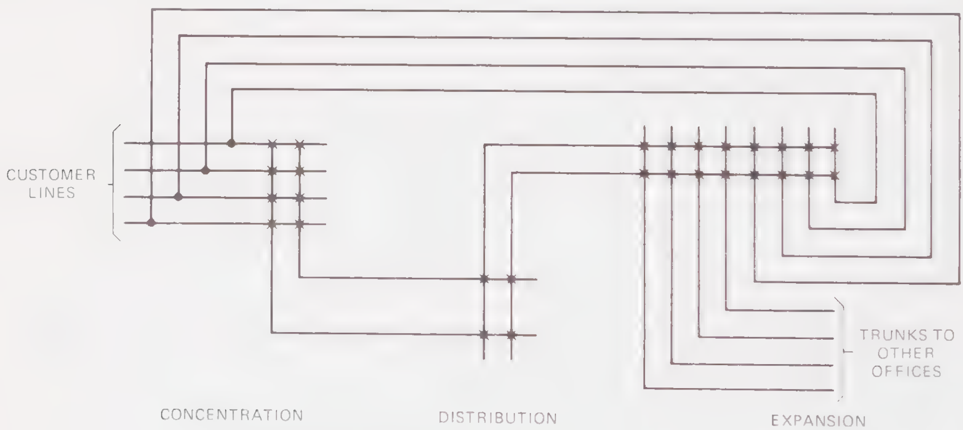


Fig. 9-5. Coordinate Switching Network

Progressively controlled and coordinate switching networks have in common the fact that each call has its own physical path through the network. This is the concept of space division. By contrast, in time-division networks, the paths for simultaneous conversations are separated by time. To elaborate, consider two telephones connected by an electronic switch or gate. If the gate is operated for only 1 microsecond 8000 times per second, voice signals (if filtered) can pass between the two telephones, even though the telephones are actually connected for only a very short time. A time-division switch consists of gates for a number of telephones connected together to a common bus. By selecting two telephones and operating their gates simultaneously 8000 times per second, a conversation can take place between these two telephones. In practice, pulse code modulation (PCM), in which amplitudes of signals are encoded as binary pulses, may be used for transmission of the voice signals between the two telephones.

Besides space-division and time-division switching networks, it is also possible to build frequency-division networks, which are similar in principle to frequency-division carrier transmission systems (see Section 6.2.1). However, no Bell System switching systems currently use frequency division.

9.1.2 CONTROL

The most straightforward way to control a switch is by using pulses from the customer's dial to directly drive the switch to the right contacts. Consider a system with rotary switches as shown in Fig. 9-6. Each switch has a controlling mechanism associated with it. When a customer goes off-hook, a relay on his line is actuated. This causes a line-finder switch to hunt until it finds the customer's line.

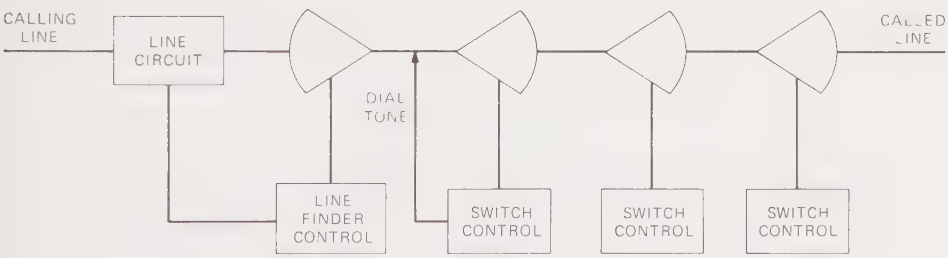


Fig. 9-6. Direct Progressive Control System

The customer is now connected through to the next switch and receives a dial tone. The first digit the customer dials causes that switch to step to the proper position (e.g., 2 if the customer dialed "2"). As the customer dials, each stage of switching responds to the dial pulses representing a dialed digit, thus selecting a path progressively through the switching network until the called customer's line appearance is reached. This is direct control of a progressively controlled switching network, or simply direct progressive control.

Direct progressive control systems have a major advantage in that the integration of switching network and control makes for economy in small- or medium-size offices. On the other hand, there are major drawbacks:

(1) Customer lines must be connected to switch terminals in strict correspondence with directory numbers.

(2) Alternate routing is not possible since dialed digits are "used up" by the system.

(3) The switching network needs considerable spare capacity because it sets up a path blindly; that is, it cannot look ahead to see if it will be blocked along the way.

Switching designers have alleviated these problems by interposing a register between the customer's dial and the switching network, as shown in Fig. 9-7. In this register (or indirect) progressive system, the dialed digits are collected in the register; logic associated with the register then causes digits to be pulsed out to the rest of the network to make the proper connection. These digits, however, need not be the same as those dialed, because some equipment is usually present to translate the directory number into an equipment-appearance number for the called party. If blocking occurs, the register still has the dialed digits, so a retrial is possible.

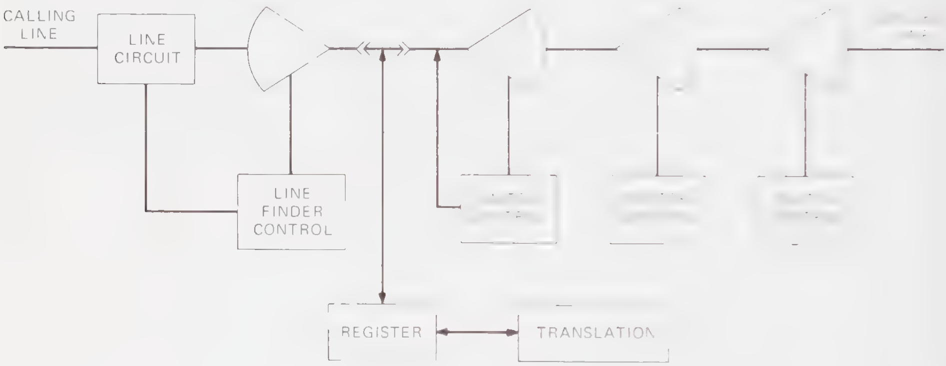


Fig. 9-7. Register Progressive Control System

Notice that the registers are not dedicated to each customer on a per-line basis, but instead are connected after the concentration stage and thus are common to many customers. This sharing of control registers is a rather limited form of the common-control principle. A more extensive form is exhibited by systems that concentrate the path selection and switch control functions into a wired logic unit called a marker, which gives its name to this kind of system.

Markers are used to control coordinate networks. With this arrangement (see Fig. 9-8), separate registers still exist, but instead of driving the switches directly, the digits are passed to a marker. The marker makes translations, tests many possible paths simultaneously to select one, and causes the proper switches to operate.

The functions of a marker can be performed by a computer-like electronic processor with suitable hardware interfaces. With such a processor, translation changes, new service additions, and other modifications can be implemented as changes in the program, rather than as complex hardware changes. These possibilities, as well as the advance of computer technology, have led to the most modern form of control, known as *stored program control.*

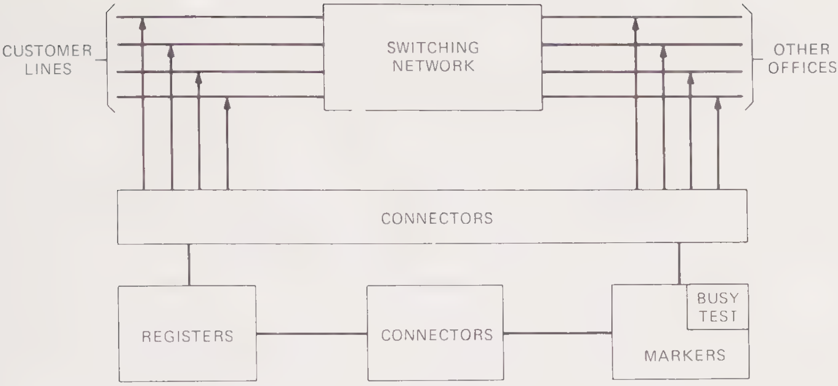


Fig. 9-8. Marker-Type Common-Control System

In a stored program system, the control circuitry is designed to execute a number of basic instructions that constitute the machine language of the system. The organization of a stored program control system is shown in Fig. 9-9. Besides the switching network, there are these other main elements:

(1) A high-speed central control that, one-by-one, interprets and executes the instructions of the program.

(2) A memory that stores the program.

(3) A memory that is used as an erasable scratch pad to record and accumulate data during call processing.

(4) Input signal devices (scanners) through which the central control receives information such as customer on-hook, off-hook, dialed digits, etc.

(5) Output signal devices (signal distributors) through which the central control causes network switches to operate.

An important concept used in stored program control systems is the time-sharing of control: many calls in various stages of completion are handled simultaneously by the central processor, which executes one function per call in a very short time interval and then progresses to the same function on a different call or to another function on the same or a different call.

9.1.3 RELATIVE PROPORTIONS OF COST IN SWITCHING SYSTEMS

In this discussion of switching concepts, a switching system has been viewed as consisting of a switching network and control elements. In fact, to be complete, auxiliary circuits can be considered as a third element.

Auxiliary circuits are added to the basic switching system to provide customer service and operational functions. Examples of customer service functions are TOUCH-TONE dialing, centrex, coin dial-tone-first, and 911

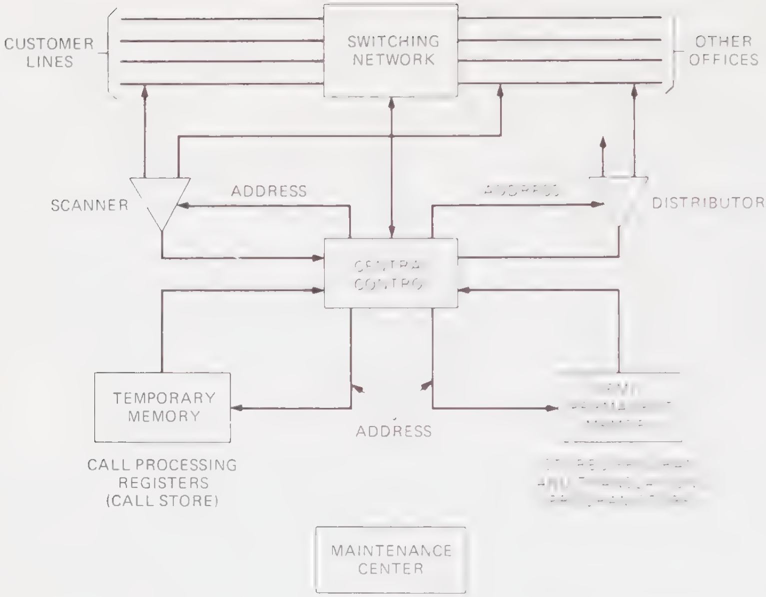


Fig. 9-9. Stored Program Control System

emergency services. Operational functions include traffic measurement, automatic message accounting, and network management controls.

The cost of the three elements varies with the type and size of switching system. In the design of small systems (50 to 3000 lines), an attempt is made to reduce the fixed components of cost required for "getting started". In a direct progressive control system, this is done by integrating the control with the switching network, so all of the investment is in the network, which can thus be bought piecemeal as the office grows. If auxiliary functions are required, they are added via relatively expensive auxiliary circuits.

At the other extreme are stored program control systems, usually designed to grow quite large. Here, to save on the cost of growth, a large getting-started investment can be tolerated. The control element therefore represents a larger percentage of the investment in these systems. This percentage decreases with larger offices of this type because the cost of the control is largely a fixed cost. However, the fixed cost for these offices still exceeds that associated with smaller, progressive systems. Auxiliary circuits typically make up a small portion of the total stored program system cost, because auxiliary functions can often be added by programming changes.

When considering the choice of a switching system for a particular central office application, an operating company compares the characteristics of available systems (getting-started costs, growth costs, auxiliary function availability and costs) with the needs of the application (starting size, forecasted growth, features required). The choice also may depend on factors other than the equipment costs of the systems themselves. Examples include lower maintenance costs on newer systems and the preference for a larger-capacity system to defer multioffice trunking penalties. In metropolitan situations, it is desirable to route toll traffic through a single, high-capacity switching system or a very small number of switching systems. The rationale is to avoid the use of additional trunk groups that would otherwise be necessary and would lead to inefficient loading of trunks and more difficult administration.

9.2 SWITCHING SYSTEM TYPES

Now that switching systems have been examined from a conceptual viewpoint, the principal types of switching systems currently in use in the Bell System will be surveyed. These systems (both local and toll) are listed in chronological order of introduction in Table 9-1. Sections 9.3, 9.4, and 9.5 contain a more detailed description of each system type.

The following considers briefly how these switching systems have evolved. Step-by-Step, a direct progressive control system, was the earliest of the automatic switching systems. Although Step-by-Step was actually invented in 1889, the Bell System did not begin using it until 1919, and even then the equipment was installed by the Automatic Electric Company. One reason for the delay in applying Step-by-Step was the high percentage of Bell System customers who were located in large cities, where Step-by-Step was not economically attractive. However, by 1921, Western Electric did begin installing Step-by-Step in the smaller cities. Today one finds Step-by-Step in rural and suburban areas and even in some metropolitan areas that began as relatively small areas but grew extensively.

In the early 1900s, the Bell System began working on an automatic system to provide efficient service in large cities. The result was the Panel System, which used a register called a *sender* to store dialed digits and then to control progressive originating and terminating switching networks made up of large-access switches.

Although the Panel System was generally a better alternative for the cities than Step-by-Step, it had room for improvement in several areas: transmission characteristics (its contacts were not made of precious metal), call completion times, and maintenance expense. Following the invention of the crossbar switch and advances in relay technology, the Bell System was able to introduce another metropolitan switching system, No. 1 Crossbar, in 1938. No. 1 Crossbar uses markers to control both an originating and terminating coordinate switching network. This system was an improvement over the Panel System in the areas listed above, but was not used to replace it. Instead, No. 1 Crossbar was used primarily to meet the substantial growth in demand for telephone service in the cities.

Ten years after the introduction of No. 1 Crossbar, conditions were right for another new switching system; relay technology had advanced further and Step-by-Step was becoming somewhat antiquated for meeting growth in the smaller cities and suburbs. No. 5 Crossbar met this need by using the

TABLE 9-1
SWITCHING SYSTEM CHARACTERISTICS — LOCAL

TYPE	INTRO YEAR	SWITCH	NETWORK	CONTROL	CAPABILITIES AND SERVICES: RETRIAL[1]	ALT ROUTING	CHARGING: HAS LAMA	CHARGING: PROVIDES CAMA	TRAFFIC MEAS	MAINTENANCE	COIN	CUSTOM CALLING	TOLL TRANSABILITY	CENTREX CO	PRIMARY APPLICATION	SIZE RANGE: LINES (x1000)	SIZE RANGE: CSS (x1000)	IN SERVICE (1/1/76): SYSTEMS	IN SERVICE: LINES ($x10^6$)	IN SERVICE: CCS ($x10^6$)
ELECTRO/MECH Step-by-Step[2]	1919	Step	Prog	Direct	No	No	No[3]	—	Wired Scan	Manual	Yes	No	—	No	Rural/ Suburban	Up to 40	—	6060	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	Common-[illegible]	No	No	No	—	Wired Scan	Trouble Indicators	Yes	No	—	No	Metro	10-40	—	55	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Wired Scan	Trouble Indicators	[illegible]	[illegible]	[illegible]	[illegible]	Metro	[illegible]	[illegible]	[illegible]	[illegible]	
No 5 [illegible]	1948	Crossbar	Coord	Common-[illegible]	Yes	Yes	Yes	—	Wired Scan	Trouble Recorder	Yes	No	—	Yes	Rural/ Suburban	1-35	—	2700	[illegible]	
No 3 Crossbar	[illegible]	[illegible]	[illegible]	Marker	[illegible]	[illegible]	[illegible]		[illegible] nal [illegible] access	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—			
ELECTRONIC No 1 ESS[5]	1965	Ferreed	Coord	Common-[illegible]	Yes	Yes	Yes	—	Data Channel	Diagnostic Programs	Yes	Yes	—	Yes	Metro	10-65	—	637	[illegible]	
No 2 ESS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
No [illegible] ESS	[illegible]	[illegible]	[illegible]	[illegible] Program	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	Rural	0.6-4.5	—	[illegible]	[illegible]	
No 2[illegible] ESS	[illegible]	Ferreed	Coord	Common-[illegible]	Yes	Yes	Yes	—	Data [illegible]	Diagnostic [illegible]	Yes	Yes	—	Yes	Suburban	4-24	—	—		
No 1A ESS	1976	Remreed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]		Yes	Metro	10-128				

TABLE 9-1 (Cont)
SWITCHING SYSTEM CHARACTERISTICS — TOLL

TYPE	INTRO. YEAR	SWITCH	NETWORK	CONTROL	CAPABILITIES AND SERVICES										PRIMARY APPLICATION	SIZE RANGE		IN SERVICE (1/1/76)		
					RETRIAL[1]	ALT ROUTING	CHARGING		TRAFFIC MEAS	MAINTENANCE	COIN	CUSTOM CALLING	TOLL TRANS ABILITY	CENTREX CO		LINES (x1000)	CSS (x1000)	SYSTEMS	LINES ($x10^6$)	CCS ($x10^6$)
							HAS LAMA	PROVIDES CAMA												
ELECTRO MECH																				
Step-by-Step	1926	Step	Prog	Direct	No	No	—	Yes	Wired Scan	Manual	—	—	No	—	Terminating Toll	—	Average 4	* 361		2.7
Crossbar Tandem	1941	Crossbar	Coord	Common-Marker	Yes	Yes	—	Yes	Wired Scan	Trouble Recorder	—	—	Yes	—	Local Tandem Class 3 4 Toll	—	Up to 50	210		6.1
No. 4 Crossbar	1943	Crossbar	Coord	Common-Marker	Yes	Yes	—	Yes	Wired Scan	Trouble Recorder			Yes		All Toll Classes	—	Up to 224	22		†
No. 5 Crossbar	1953	Crossbar	Coord	Common-Marker	Yes	Yes	—	Yes	Wired Scan	Trouble Recorder	—	—	Yes	—	Sparse Areas	—	Up to 40	341	—	2.5
No. 4 Crossbar (ETS)	1969	Crossbar	Coord	Common-Marker	Yes	Yes	—	Yes	Wired[6] Scan	Trouble[6] Recorder	—		Yes	—	All Toll Classes		Up to 224	155	—	†
ELECTRONIC																				
No. 1 ESS	1970	Ferreed	Coord	Common-Stored Program	Yes	Yes	—	Yes	Data Channel	Diagnostic Programs	—	—	Yes	—	Sparse Areas	—	Up to 180	23	—	0.2
No. 4 ESS	1976	Solid State	Time Division	Common-Stored Program	Yes	Yes	—	Yes	Data Channel	Diagnostic Programs	—	—	Yes	—	Gen Toll Succeeds 4A	—	Up to 1700	—	—	

1 Retrial is a means of circumventing, during call setup, certain call-abortive conditions (e.g., failure to match)

2 There are about 350 step by step offices with common control providing controlled outpulsing and alternate routing

3 Step-by-step offices in the Los Angeles area are arranged for a form of AMA recording referred to as SAMA

4 Except in 10 percent of the cases

5 4-wire versions of No. 5 crossbar and No. 1 ESS have been developed for special applications, their characteristics are not listed

6 Trouble analysis and traffic data available through peripheral bus computer

* Local tandems not included

† Together No. 4 crossbar and No. 4 Crossbar (ETS) served about 14.4M CCS on January 1, 1976

common-control principle to the greatest degree yet, with new markers controlling a single coordinate switching network instead of separate originating and terminating networks. The flexibility of this arrangement made it possible to provide functions like local automatic message accounting (LAMA) and centrex service. In fact, this flexible system has found economical applications in both small rural and large city central offices, in toll offices, and, as a special version, in the AUTOVON network.

The era of local Electronic Switching Systems (ESS) began in 1965 and brought even greater flexibility than No. 5 Crossbar. ESS can provide custom calling services (e.g., call waiting, call forwarding) and a sophisticated maintenance system with trouble messages printed by a teletypewriter. A complete ESS product line for local offices (No. 1, 2, and 3 ESS) permits telephone companies to use stored program machines economically at all line sizes.

Toll switching systems have evolved following, to a large degree, the same technological advances as local systems. In the early years, Step-by-Step was used primarily to assist the operator force in completing toll calls. As the volume of toll traffic increased and as the nation converted to direct distance dialing, Crossbar Systems were introduced into the toll network. No. 4 Crossbar became the workhorse, with modified versions of No. 5 Crossbar and Crossbar Tandem (originally designed as a local tandem) also being used. In the electronic era, an Electronic Translator System (ETS) was added to most No. 4 Crossbar Systems to increase the translation capability and to simplify administration. Today, tremendous growth in toll traffic is foreseen over the next two decades. A new electronic toll switching system, No. 4 ESS, uses stored program control, a high-speed processor, and a time-division solid-state switching network in order to achieve the high capacity required to meet this demand economically.

Additional general information concerning switching systems may be found in References 1 and 2.

9.3 LOCAL ELECTROMECHANICAL SYSTEMS

9.3.1 STEP-BY-STEP

The name "Step-by-Step" describes both the manner in which the switching network path is established and the way in which the switches operate. As mentioned in Section 9.1, the basic Step-by-Step System is classified as a direct progressive control system because the dial pulses generated by the customer's telephone directly control the stepping switches of the networks.

The switches used are functionally described as line finders, selectors, and connectors. Each of these switches combines vertical stepping and horizontal rotary stepping motions in a 2-stage selection process symbolized in Fig. 9-10. An actual switch is shown in Fig. 9-11. A set of wiper brush contact fingers is moved, first in a vertical direction to select one of ten level positions, then in a horizontal direction until the selected position of ten positions is reached.

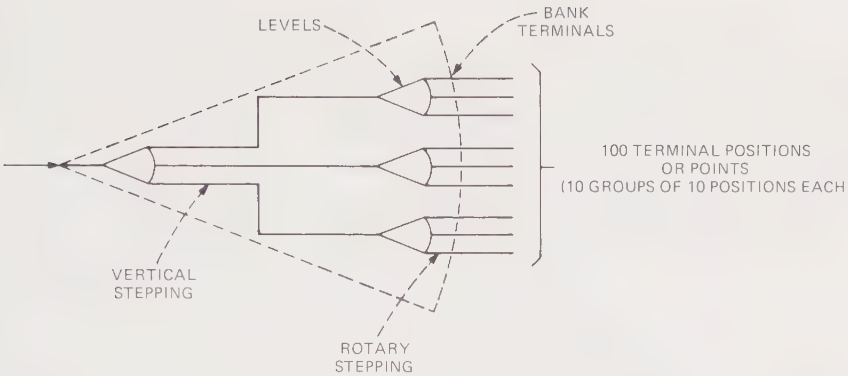


Fig. 9-10. Equivalent Diagram of a Step-by-Step Switch

A 1000-line Step-by-Step System is shown in very simple form in Fig. 9-12. When the customer goes off-hook, an idle line finder locates the line requesting service through a vertical and horizontal hunt. The line finder is wired to a selector switch that returns dial tone to the caller. The selector switch moves upward in accordance with the first digit dialed. Next, the switch moves horizontally across the contacts in the selected row, hunting for a circuit to an idle connector switch in the called customer's hundreds group. (For a 1000-line system, customers would be numbered from 000 to 999.)

When the second digit is dialed, the connector switch is stepped vertically to the level corresponding to the digit, thereby selecting a particular row of ten lines in that hundreds group. When the third digit is dialed, the connec-

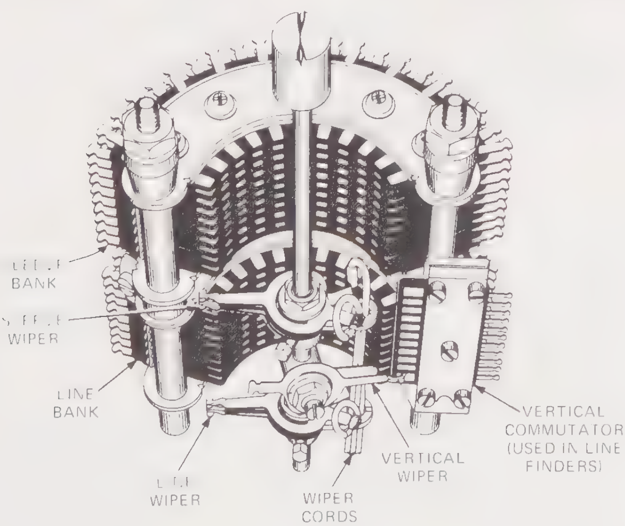


Fig. 9-11. Terminal Bank of 100 Customer Lines

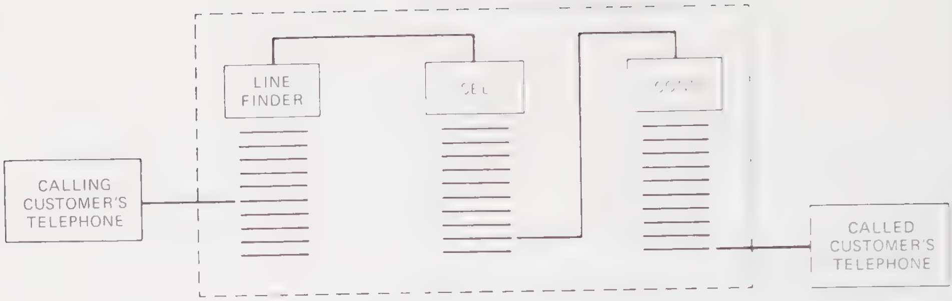


Fig. 9-12. A 1000-Line Switching System Requiring 3-Digit Selections

tor switch moves horizontally across the row of terminals to the line dialed. If the line is idle, the called customer's telephone rings. If the line is busy, a busy signal is returned to the calling customer.

The number of line finders, selectors, and connectors required in an office is determined by a number of factors, including the amount of simultaneous traffic to be accommodated, the numbering plan, routing patterns, and growth predictions. The number of switches in a system is thus highly variable; for a 1000-line system, it is in the order of a few hundred. If the system is larger than the 1000-line system just described, more stages of selector switches are required to reach the called line connector terminal.

The Step-by-Step System has proven to be a popular system in the past because it is economical for basic functions and can be readily expanded as the need develops. At present, about 34 percent of all Bell System lines are served by this equipment. However, the progressive control nature of the system precludes the addition of new functions, such as alternate routing and TOUCH-TONE calling, without adding costly equipment to the office. For this reason, operating companies are replacing Step-by-Step equipment with highly flexible Electronic Switching Systems. Some of the replaced Step-by-Step equipment is being reused in other locations.

9.3.2 PANEL

The Panel Switching System was developed to solve the telephone switching problem that existed in the early 1900s in large metropolitan cities. In these areas, the demand for telephone service was constantly increasing, and large complex manual systems had evolved.

The Panel System derives its name from the fact that the contact terminals of lines or trunks on the network switches are arranged in large flat panels or banks, rather than in arcs as in the step-by-step switch (see Fig. 9-13). Selector rods with attached contact brushes are moved vertically to select terminals in the flat panels by means of mechanical coupling to constantly rotating power shafts driven by electric motors. With this arrangement, each panel switch has access to 500 terminals.

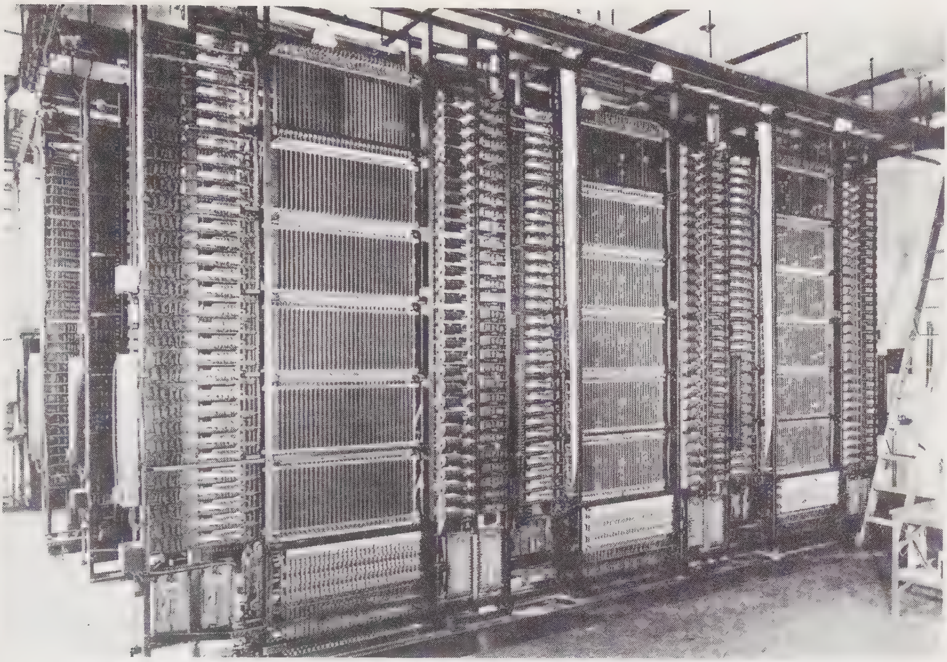


Fig. 9-13. Panel-Type Switching Equipment

The general plan of the Panel Switching System is shown in block diagram form in Fig. 9-14. A line finder is used to locate a line requesting service. Simultaneously, a sender is connected to the line to provide dial tone and, in turn, to receive the dialed digits. The decoder translates the called office code digits and returns to the sender information regarding the appropriate group

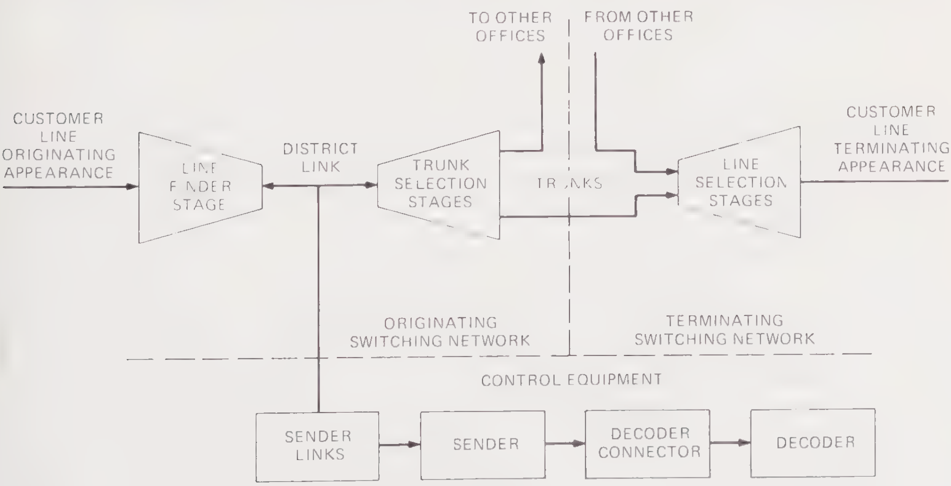


Fig. 9-14. Panel System Block Diagram

of trunks that will reach the terminating office. The sender now dismisses the decoder and progressively directs the switches of the trunk-selection stage to connect to an idle trunk in the desired trunk group. Signals under control of the sender are then sent over the trunk to cause the switches of the terminating office to connect to the called line. The sender is then released from this connection and is available for other calls.

Panel offices require a high level of maintenance because of the age and mechanical nature of the equipment. For these same reasons it is both difficult and costly to add new features to Panel offices. Therefore, Panel offices are presently being replaced by No. 1 ESS.

9.3.3 NO. 1 CROSSBAR

The No. 1 Crossbar Switching System was developed for use in large metropolitan areas. The Panel System had previously been developed for this application, but constant growth created a need for a system having improved electromechanical devices and more common control in call processing. The switching apparatus and the method of setting up calls in a No. 1 Crossbar office differ from those of either the Step-by-Step or Panel System. The latter two systems use devices that cause selector brushes to wipe over contacts in either rotary or linear motions to progressively establish the network path. In contrast, the No. 1 Crossbar System finds a path through the switching network and establishes it by direct orders to each switch.

The No. 1 Crossbar System derives its name from and is built around the crossbar switch shown in Fig. 9-15. The name "Crossbar" is derived from the use of horizontal and vertical bars to select the contacts. There are five selecting bars mounted horizontally across the front of each crossbar switch. Each selecting bar can choose either of two horizontal rows of contacts. A selecting bar has flexible wire-like selecting fingers attached to it, one finger for each vertical path. The bars can be rotated slightly to cause the selecting fingers to go either up or down, depending on which of two magnet coils is energized to tilt the armature and selecting bar. The five horizontal selecting bars can therefore select ten horizontal rows of contacts. Ten or 20 vertical units are mounted on the switch, and each vertical unit forms one vertical path. Each unit operates under control of a hold magnet and has ten groups of contacts (one for each horizontal path) associated with it.

When a horizontal select magnet operates, the selecting bar is rotated up or down, and one of the two horizontal paths available to this selecting bar is chosen by moving the selecting fingers either up or down to a position adjacent to that set of contacts. When rotated by a magnet and armature at one end, the vertical or holding bar along each column of contacts moves a vertical bar inward to press against all of the selecting fingers in that column. If a horizontal selection has been made previously, the vertical bar presses against the selecting finger, using it as a wedge to cause the group of contacts beside the selecting finger to close, thus connecting the horizontal and vertical paths.

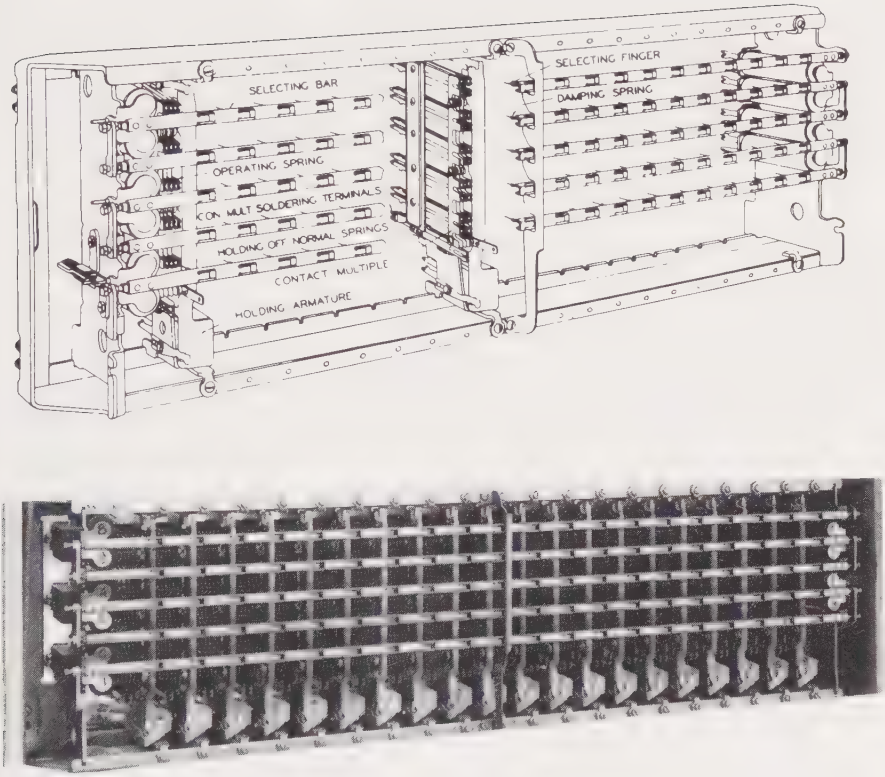


Fig. 9-15. A Typical 200-Point Crossbar Switch

After the operation of the hold magnet, the select magnet releases. This restores the horizontal bar and all of the selecting fingers to normal, except those actively held by the operated hold magnet. Thus, in 20 separate operations, up to 20 different crosspoints can be closed, independently of each other, in the crossbar switch. This allows several conversations to pass through simultaneously, as opposed to only one in a stepping or panel switch.

A simplified block diagram of a No. 1 Crossbar office is shown in Fig. 9-16. The establishment of a call proceeds as follows. On requesting service, the calling customer is connected to a district junctor and subscriber sender. The sender provides dial tone and then receives the called number as it is dialed by the customer. The subscriber sender is then connected to an originating marker, which selects the switch frames for establishing the originating-end connection from the district junctor to an outgoing trunk, a path to the terminating portion of the network. The terminating portion may be in the same

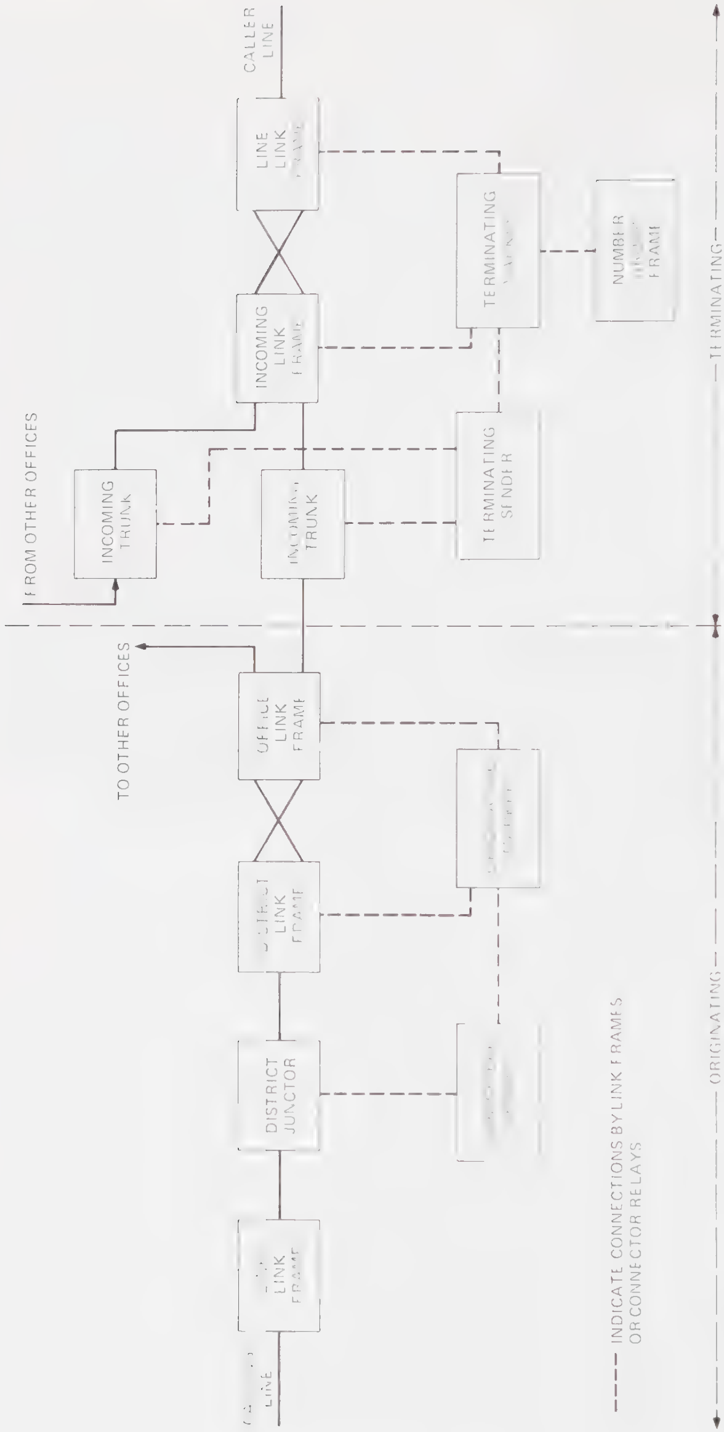


Fig. 9-16. No. 1 Crossbar Block Diagram

office or in another office. The outgoing trunk circuit is connected to a sender at the terminating end; this sender registers the called number when it is sent by the subscriber sender. The terminating sender is connected to a terminating marker, which selects the switch frames for establishing the terminating-end connection of the trunk to the called customer's telephone.

Although no new No. 1 Crossbar offices are being installed, about seven million lines are currently served by this system. For this reason, substantial effort is still devoted to improving maintenance techniques and adding essential switching features.

9.3.4 NO. 5 CROSSBAR

No. 5 Crossbar was originally developed to fill a need for a switching system especially suitable for suburban residential areas and for smaller cities not requiring large multioffice telephone complexes of the Panel or No. 1 Crossbar type. For these areas, it was expected that a high percentage of calls would be completed to customers in the same office, and this consideration influenced the design of the system. Another design consideration was the then new concept of direct distance dialing by customers, requiring automatic recording of call details for billing purposes. The resulting system design has proven to be suitable for applications and features that go well beyond what was planned at the outset.

A simplified block diagram of the main No. 5 Crossbar equipment units is shown in Fig. 9-17. The equipment may be divided into two broad categories: the switching network through which all talking paths are established and the common-control equipment that sets up the talking paths.

Customer lines appear on the line link frames, and trunks and originating registers on the trunk link frames. Each of these frames consists of a number of factory-wired crossbar switches; upon installation, a number of these frames are wired together to form the switching network. Connections are established from lines to trunks or from lines to lines through the crossbar switches on the line link and trunk link frames. The common-control equipment used to establish the various connections includes the registers, markers, senders, number groups, and connectors. The originating register provides dial tone and receives the digits dialed by the customer. At the completion of dialing, a marker is used to select an appropriate idle trunk to complete the call. On calls leaving the office, the marker connects a sender to the selected trunk so that the necessary signaling between offices can take place. On incoming calls, an incoming register is used to receive the directory number of the called party from the distant office. A marker is required to obtain the line link frame location of the called customer from the number group. Once the connection is established, the common-control equipment is released and only the line link, trunk link, and trunk circuits (that form the transmission path) remain in the connection.

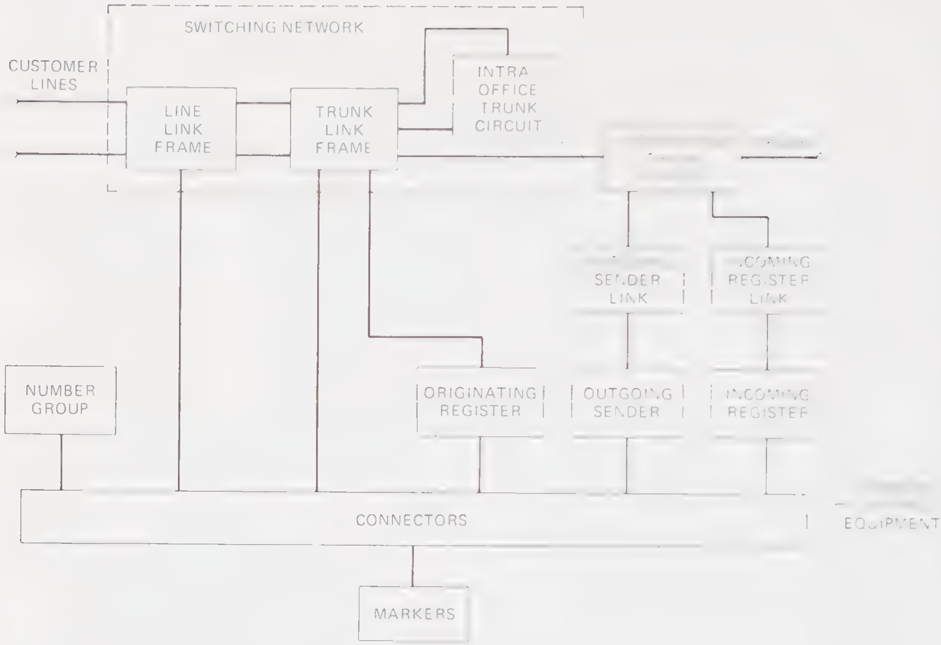


Fig. 9-17. No. 5 Crossbar Block Diagram

The box labeled "trunk circuit" deserves attention because trunk circuits represent a substantial amount of investment and play a large part in the administration of the plant. Furthermore, the purpose and nature of the trunk circuit are not as intuitively clear as are, for example, the purpose and nature of an originating register. Broadly, the purpose of a trunk circuit is to handle certain aspects of signaling while a call is in progress or is being terminated and to work with the sender or register for signaling during call setup. There are many varieties of trunk circuits because of the variety of switching systems to which the trunks connect and the variety of signaling systems used. A typical trunk circuit in an electromechanical system consists of a substantial number of relays. As will be seen later, trunk circuits in electronic systems have been simplified, but not eliminated.

During the 30-year history of the No. 5 Crossbar System, important improvements and functions have been added. These include:

(1) Centralized automatic message accounting (CAMA), making No. 5 Crossbar more attractive as a small toll office.

(2) Line link pulsing to facilitate direct in-dialing to stations served by dial PBXs.

(3) International direct distance dialing (IDDD), allowing customers to dial up to 12-digit overseas calls.

(4) Centrex service, including station-controlled dial transfer.

(5) A large automatic call distributor (ACD) for directory assistance and intercept service. In this capacity, a No. 5 Crossbar System is used only as an ACD; it does not perform central office functions.

Only a few of the No. 5 Crossbar offices operating today have reached their maximum size. Although very few new installations are taking place because of the availability of Electronic Switching Systems, growth in existing offices will substantially increase the amount of equipment now in the field.

9.3.5 NO. 3 CROSSBAR

A recent addition to the Crossbar family of switching systems, No. 3 Crossbar, is designed for very small wire centers, primarily in rural areas. It can be expanded in 100-line blocks from 200 to 800 lines and uses small crossbar switches in the switching network.

9.3.6 REFERENCES

Additional information concerning electromechanical systems may be found in References 3 through 8.

9.4 LOCAL ELECTRONIC SYSTEMS

9.4.1 NO. 1 ESS

During the late 1950s and early 1960s, Bell Laboratories developed a new general-purpose switching system to economically meet the growing demand for telephone services. The system was designed to be far more flexible than any preceding system, to anticipate the need for new services, and to avoid the high costs associated with modifying existing systems. As a result of this work, the first No. 1 ESS was put into service in May 1965.

No. 1 ESS applied the basic concept of a central control or processor operating under the direction of a stored program to control a switching network, as described in Section 9.1.2 and illustrated in Fig. 9-9.

References 9 and 10 contain descriptions of No. 1 ESS.

9.4.1.1 Stored Program

In No. 1 ESS, the logic procedures for making telephone connections are in the form of a stored program. Therein lies the system's great flexibility to meet present and future service needs. This is in contrast to electromechanical systems, in which the logic is designed into the hardware and each circuit performs one specific function. To change the operation of an electromechanical system to provide a new service, it was often necessary to redesign circuits and rewire them extensively in the field. In No. 1 ESS, it is usually only necessary to change the stored program on the semipermanent memory cards (see Fig. 9-18) of the system. New services can be made available almost immediately after the program for them has been developed.

The sequencing of operations required to set up a call to another office, including timing the duration of signals, is controlled by the program. Program control thus reduces system cost by minimizing the types of circuits associated with trunk and line terminations and the number of manufacturing wiring options needed.

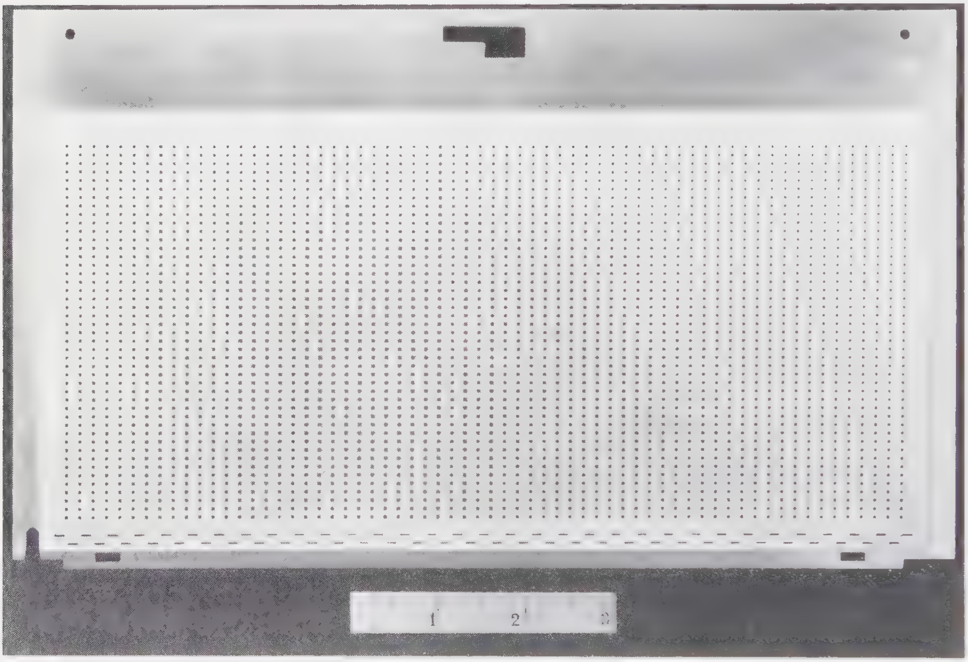


Fig. 9-18. Twistor Memory Card

9.4.1.2 Time-Sharing—Central Control

In No. 1 ESS, the central processor (central control, call store, and program store) is time-shared by all calls served by the system. The central control (see Fig. 9-19) consists of wired logic for performing information processing operations. The central control interacts with peripheral units (scanners and distributors) in a synchronous mode and, using instructions in the program store, continually updates the call store, which contains information such as:

(1) Busy/idle status of lines and trunks.

(2) Digits being received.

(3) Digits to be transmitted.

(4) Billing information.

(5) Results of diagnostic tests.

A typical operation is the comparison of the results of a scan of all lines with the previous scan to determine if any lines have changed state (off-hook or on-hook). It is important to realize that the wired logic in the central control is largely independent of the type of telephone service provided and the services offered to the customers. The telephone switching logic and specific services are contained in the stored program.

There is only one active central control (duplicated for reliability) in No. 1 ESS. Whereas No. 5 Crossbar offices can have 6 dial tone and 12 completing markers, each simultaneously processing different calls, the electronic speed of an ESS (3 or 4 orders of magnitude above the speed of electromechanical components) allows one central control to handle all calls.

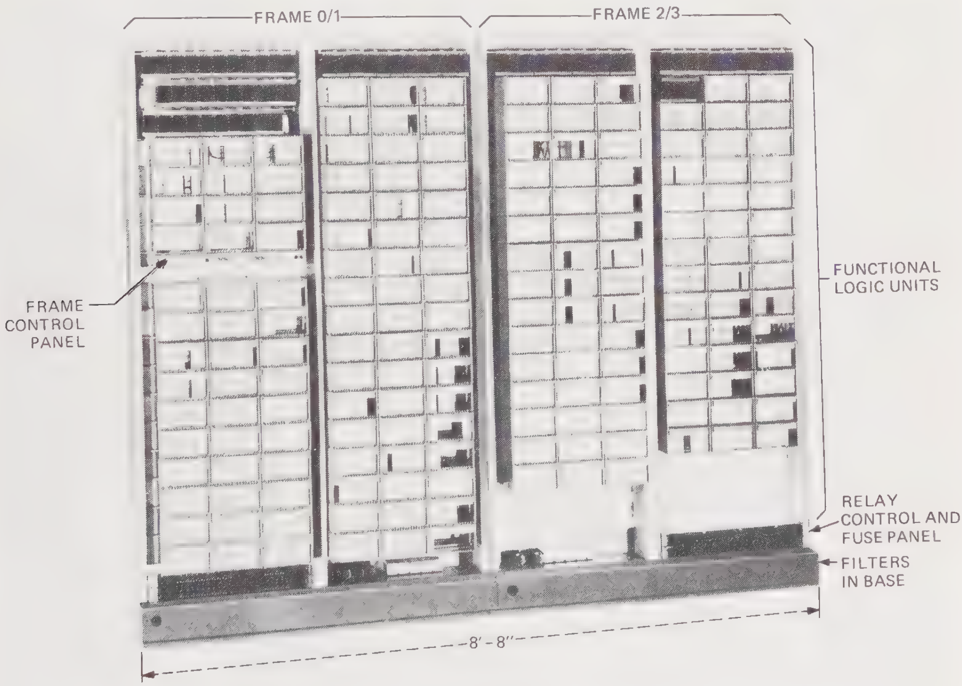


Fig. 9-19. Central Control

9.4.1.3 General Approach to Program Organization—Typical Call

The program analyzes a call in discrete steps. Just as in the No. 5 Crossbar call described in Chapter 2, these steps start when a calling customer lifts the receiver. The program then proceeds through a chain of control actions to ultimately establish a talking connection. To the customer, the connection seems to be made instantaneously; actually, the system deals with each step in turn. A simplified description of how No. 1 ESS handles a call follows.

Every 200 milliseconds, the system checks, or scans, each customer's line and records its state: on-hook, off-hook, dialing, busy, in a talking connection, etc. The state detected at each scan is compared with the state recorded at the previous one. No action is taken if there is no change. When the system encounters a change of state, from on-hook to off-hook for example, it consults the program to find out what action to take. In this case, the off-hook state indicates that the customer wishes to place a call. The program therefore directs that dial tone be sent to the customer's line. While the customer dials, the program directs that the line be scanned at regular intervals and that each digit be recorded in turn. No further action is taken until the customer completes dialing.

After the system registers all the dialed digits, it again consults the program for the next step. For a regular station-to-station call, this step is to make connections through the switching network to the called telephone. That telephone may be busy or idle, and the program is prepared for either eventuality. If the telephone is busy, it directs that a busy tone be sent to the calling party. If idle, the called telephone is rung and an audible ringing tone is sent to the calling party.

When the call is answered, this state is registered, and again the line is scanned at regular intervals. No action is taken until one of the parties hangs up, at which time the program directs that the connection be taken down. The whole process is characterized by continuous interplay between the programmed logic and the temporary memory which acts as an electronic slate. This memory records the instantaneous state of the line and registers dialed digits and other transitory information needed during the progress of a call. When a call is completed, the slate is wiped clean of information pertaining to that call.

The organization of the No. 1 ESS program is strongly influenced by the fact that it must operate in real time. That is, the program must respond promptly to signals and data submitted to it by customers and other switching systems. It must also respond to trouble detection circuits designed into the hardware to ensure dependable operation. For the program to meet all these demands, it is necessary to establish a hierarchy of program tasks. Some tasks must be performed on a strict schedule; others may be delayed without significant adverse effects.

The central processor incorporates an interrupt mechanism which momentarily seizes control of the system when a manual interrupt, clock interrupt, or trouble detector signal is received. The interrupt circuit causes the system to stop its present program task, to store the program address at which it was interrupted, and then to transfer to the appropriate fault recognition program or clock-controlled input-output program. When the interrupt programs are completed, control is returned to the program that was interrupted except in cases where it is not possible.

The interrupt sources and their associated programs are arranged in a hierarchy of nine interrupt levels; from highest to lowest, these levels are designated A, B, C, D, E, F, G, H, and J. An interrupt source assigned to a particular level can interrupt programs of lower levels only. The majority of programs are subject to interruption by any of the nine levels and are therefore called base-level programs.

The highest interrupt source is the A level, initiated from the master control center, which allows manual selection of operating modes. Interrupt levels B through G are activated by system trouble detectors. Every 5 milliseconds a system clock activates interrupt level J, which in turn gives control to input-output programs. Level H is used to interrupt the level J input-output program when the input-output tasks performed exceed 5 milliseconds.

9.4.1.4 Characterization of the Program—Generic Program Concept

In the first No. 1 ESS offices, approximately 90 programs totaling about 100,000 words were used to control the operations required for telephone service and maintenance of the system. Several approaches to providing programs for a large number of different offices could be used. The approach for No. 1 ESS uses a generic program that is the same for all offices; the detailed differences for each individual office are listed in a parameter table. The generic program includes all functions necessary to cover office sizes from 2000 to 65,000 lines and also includes means for handling growth and changing traffic conditions. This approach simplifies record keeping because only the parameter tables that specify the present office size and operating conditions are unique to each office. Additional data that characterize a particular office are found in translation tables in the program store. Typically, 18 different sets of translations are required in each office. These translations include directory number to equipment number for both lines and trunks, classes of service, and special treatments for lines and trunks. Because of the growth in the number of functions and services, recent No. 1 ESS programs have contained over 250,000 words.

9.4.1.5 Hardware

Program Store

With over 250,000 program words, No. 1 ESS is under the control of a very large program. The complete program may require a storage capacity in excess of 10 million bits. In addition, the office must store a considerable amount of data about each line and trunk. The storage needs for this data vary with the office size and range from 1 to 14 million bits. To ensure service continuity, this information must be protected from accidental destruction by either equipment malfunction or operator error.

To meet the need for an economical, high-capacity, random-access memory, No. 1 ESS uses permanent magnet twistor modules as basic storage elements (see Fig. 9-20). These provide a memory that is fundamentally "read

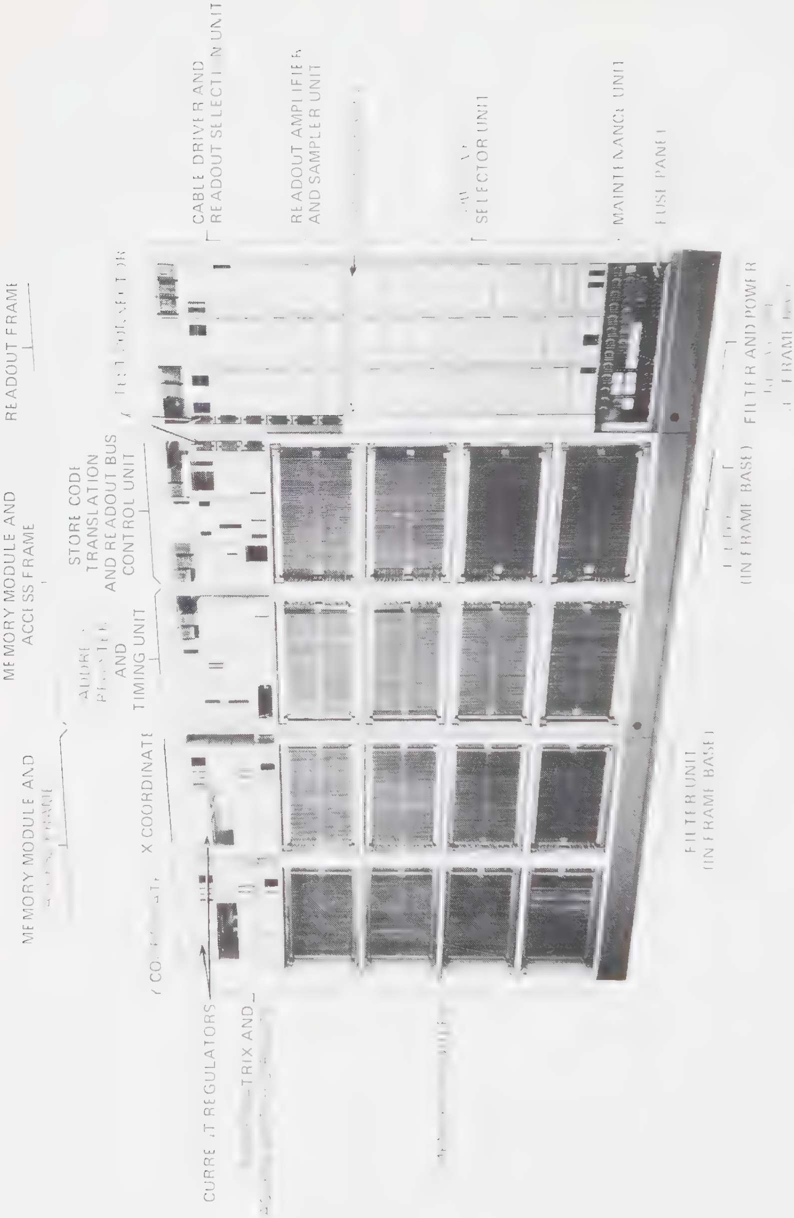


Fig. 9-20. Program Store

only''; thus no electrical malfunction can alter the information content. Program stores contain 131,000 words, each 44 bits long (37 bits of information and 7 bits of redundant encoding). The coding used includes a single error-correcting Hamming code plus an overall parity, taken over both the data and its storage address. The program store has a cycle time of 5.5 microseconds. An office may contain up to 12 program stores; in addition to program and data storage, this allows room for potential growth.

Call Store

A temporary or ''scratch-pad'' memory is required to store transient data needed to set up calls, record the network paths in use for each call, and keep many other short-term operational and maintenance data.

The original No. 1 ESS temporary memory (the call store) employed a batch-fabricated form of cores known as the *ferrite sheet*. Each ferrite sheet (see Fig. 9-21) contained 256 memory elements in a 16-by-16 array of holes. A wiring pattern plated directly on the sheet provided the equivalent of a current access lead threading all of the holes on the sheet. Memory modules

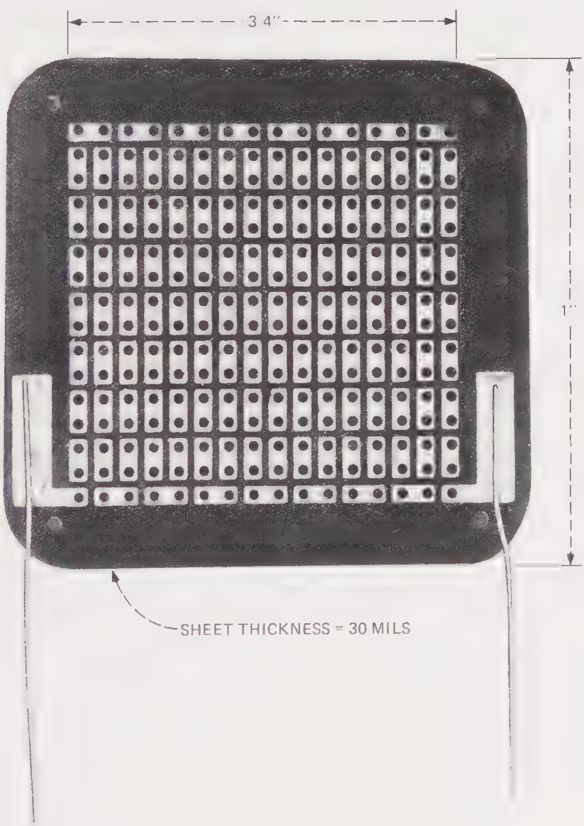


Fig. 9-21. Ferrite Sheet

were then constructed by arranging the sheets into stacks, and the remaining access wires were simply threaded through in-line arrays of holes in the stacks. These modules formed the basis of memory units of 8192 (8K) words of 24 bits each and which operated with a cycle time of 5.5 microseconds.

Advances in materials and fabrication and assembly techniques have led to the replacement of the ferrite sheet memory by a core memory that employs smaller individual cores (23-mil outside diameter), which can be very closely packed because only two access wires are threaded through each core, as opposed to the three or four previously required. (See Fig. 9-22.) A substantial reduction in floor space and power required for the No. 1 ESS call stores has resulted, as indicated in Fig. 9-23.

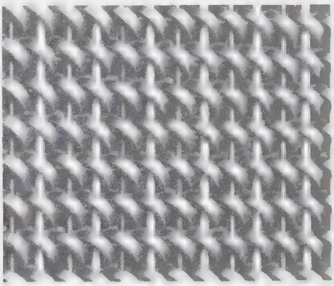


Fig. 9-22. Core Memory Plane

Switching Network

The field of application for No. 1 ESS encompasses offices with from thousands to many tens of thousands of lines, with line occupancies and ratios of intraoffice to interoffice traffic highly variable from one office to the next. Consideration of access and blocking (see Section 9.1) in the largest switching network size led to the adoption of a network with eight stages of switching (see Fig. 9-24). The binary nature of the ESS control language led to use of switch and grid sizes with numbers of terminals that are powers of 2 to realize translation and control economies.

The No. 1 ESS switching network crosspoint element is the ferreed switch (see Fig. 9-25). The ferreed switch is compatible with both existing outside plant and the high-speed electronic central control. In addition, because ferreed switches can be packaged in units of almost any size without undue equipment or electrical circuit restrictions, the sizes of the network building blocks can be determined directly by traffic and office growth considerations.

An improved version of the ferreed crosspoint element, the remreed switch, is more compact and is operated with an electronic controller instead of a relay controller. The combination of the smaller switch for the network crosspoints with new device and packaging technologies for the control circuitry has effected a significant reduction in size of switching network com-

Fig. 9-23. Call Store Frames

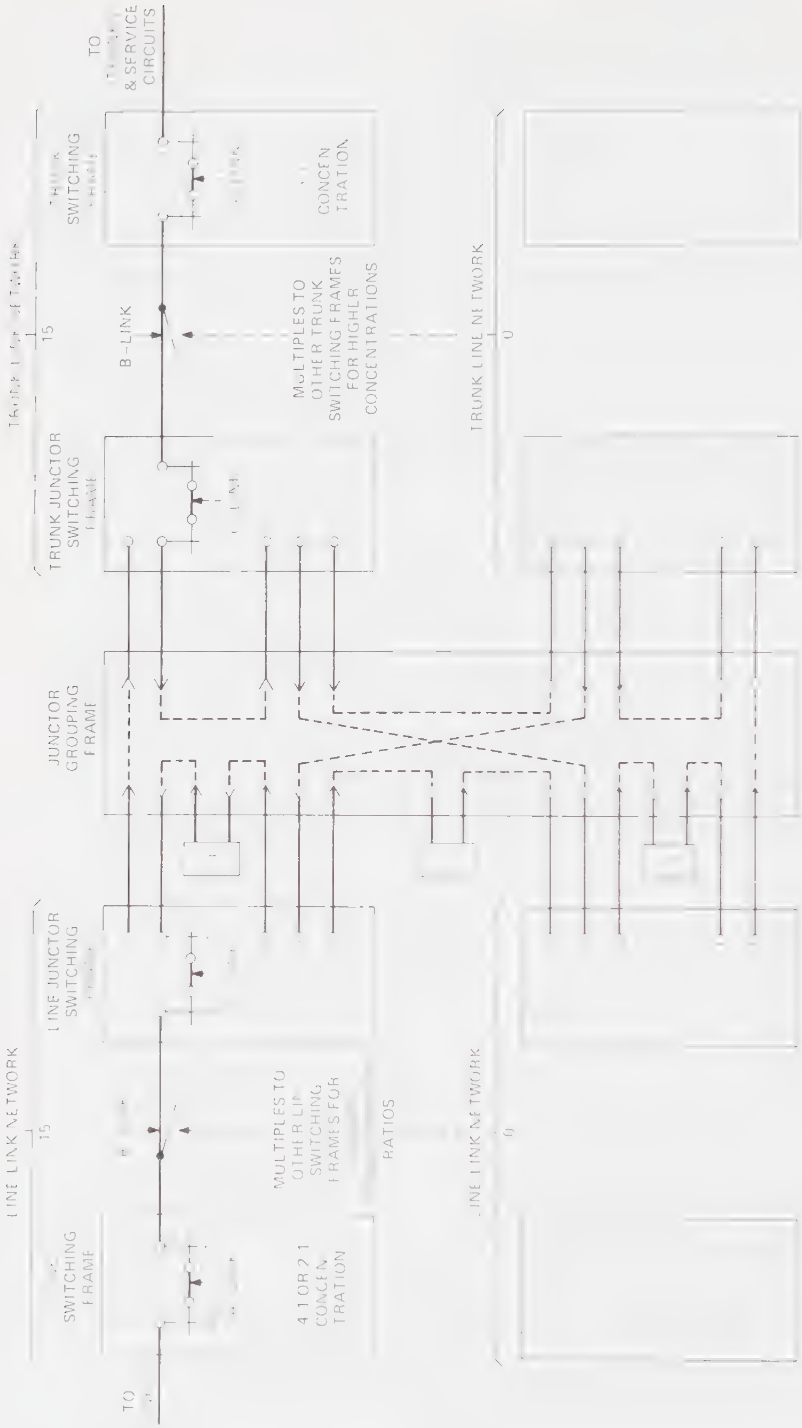


Fig. 9-24. Typical Connections for Line Link Network and Trunk Link Network

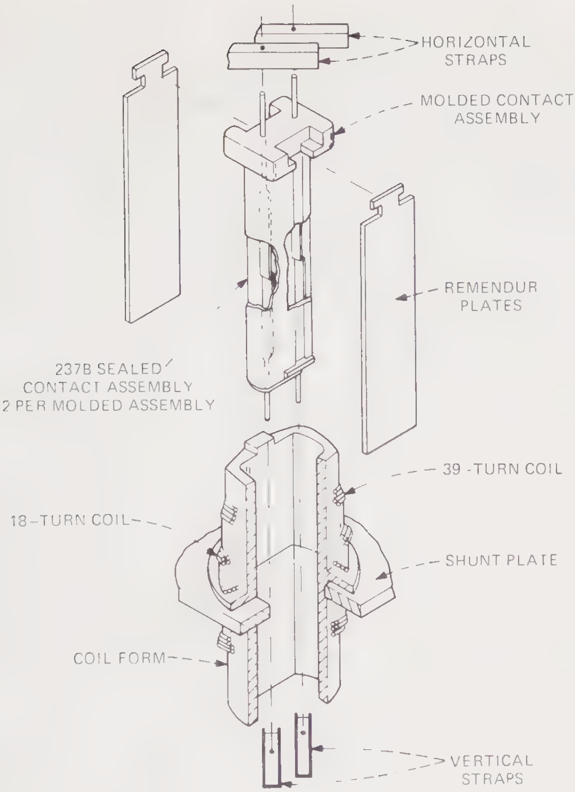


Fig. 9-25. Two-Wire Ferreed Assembly

ponents relative to the ferreed networks. As shown in Fig. 9-26, the remreed switching network is mounted on a single frame as compared with the multiple frames required for the ferreed switching network. This permits the entire network to be wired and tested as a unit at the factory.

Scanner, Signal Distributor, and Central Pulse Distributor

No. 1 ESS includes peripheral units that serve as buffers between the central control and the outside world of lines, trunks, automatic message accounting centers, and maintenance personnel.

Scanners—Every telephone switching system embodies some mechanism for detecting service requests and for supervising calls in progress. Input information of this nature is furnished to No. 1 ESS by the operation of scanners that sample or scan lines, trunks, and various diagnostic points at discrete intervals of time as directed by the system. The sensing element used in all scanners is the ferrod sensor (see Fig. 9-27), a current-sensing device operating on electromagnetic principles. It consists of a ferrite rod around which is wound a pair of solenoidal control windings. In addition, single-turn interrogate and readout windings are threaded through two holes in the center of the ferrite rod.

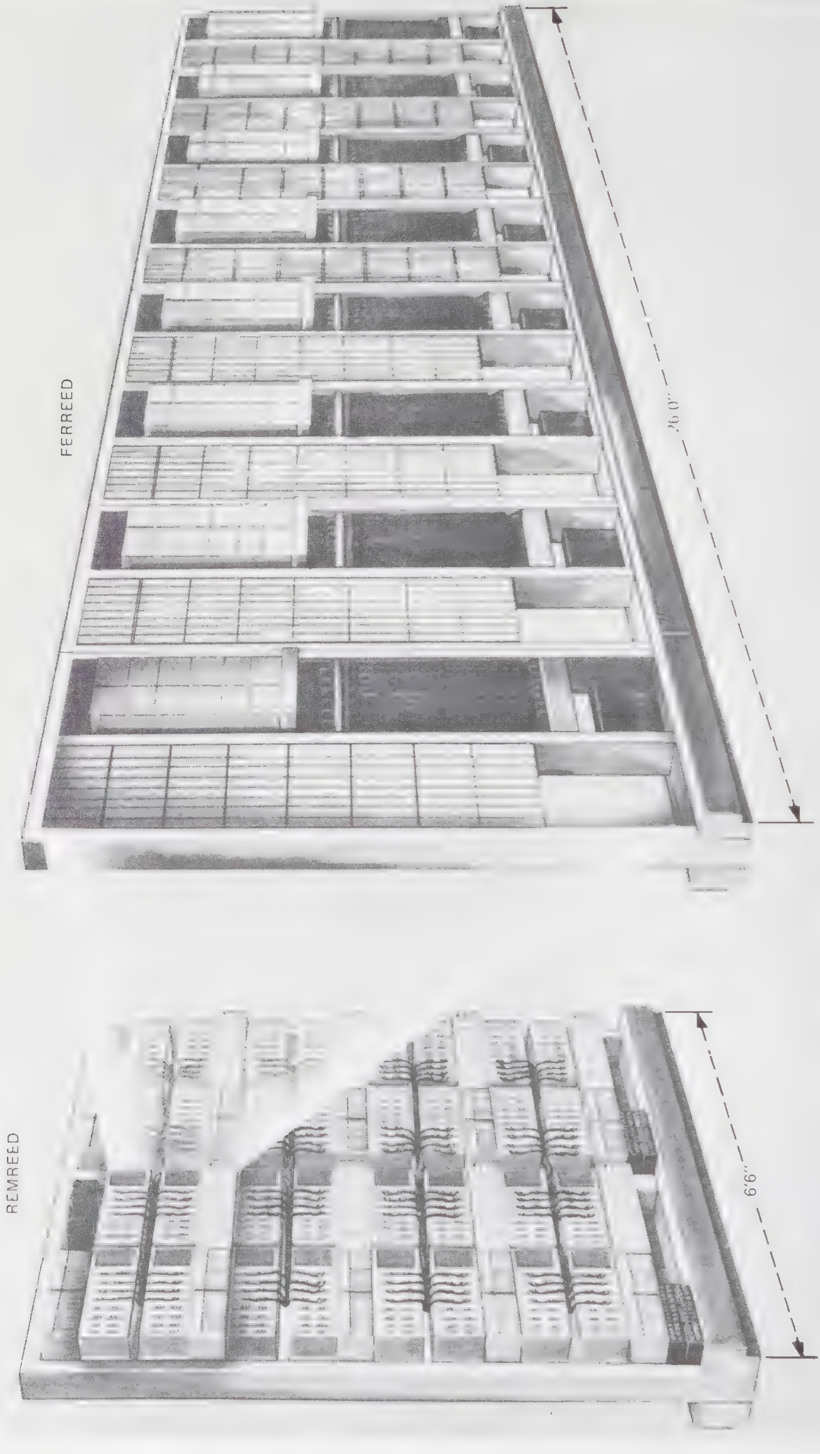


Fig. 9-26. Switching Network

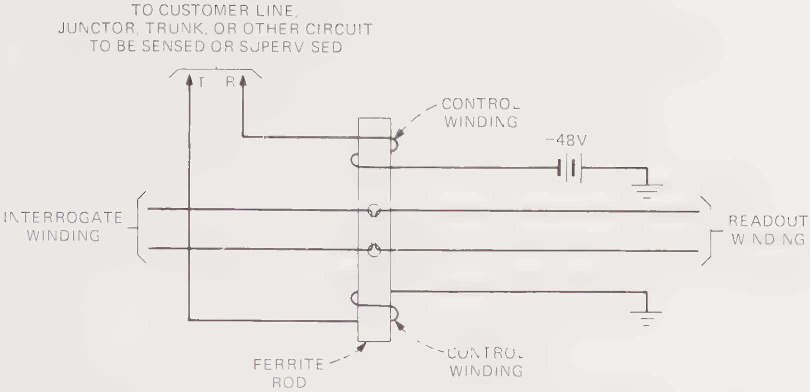


Fig. 9-27. Ferrod Schematic

Signal Distributors—Signal distributors translate orders received from central control into high-power, long-duration pulses which are distributed to the appropriate relays in trunk, service, and power control circuits in No. 1 ESS. These relays are controlled by polarized signals and are magnetically latched (held operated), thus providing a memory function in the end device. The signal distributor has either 512 or 1024 outputs. The decoding to provide access to one of these outputs is performed by relay contacts. Relay contacts were selected because, at the time of design, no electronic device could economically compete with a contact on a large relay for such a decoding function when the required access cycle was about 20 milliseconds. Such is the case for most of the relays in No. 1 ESS trunk circuits as well. New, fully electronic signal distributors have been designed which Western Electric began to manufacture in 1975.

Central Pulse Distributor—Some control functions, such as outpulsing in trunks, must be carried out at electronic speeds or at speeds exceeding the capability of the magnetic latching relays controlled by the signal distributors. These control functions are provided by a central pulse distributor. In No. 1 ESS, a diode-transformer gate was chosen as the decoding element in the central pulse distributor. The transformer provides a balanced output, so a pulse from such an output point can be transmitted over a twisted pair to remote locations without interference. In addition, bipolar pulses can be easily generated and transmitted. These pulses can control the operation and release of a relay over a single pair of wires by using a receiving device (called a *bipolar flip-flop*) that can recognize the two polarities.

Line and Trunk Circuits

Individual circuits are required on a per-call and even per-line basis to match the widely variable outside world to the standardized "inside world" of the central processor. These individual circuits are the line, junctor, trunk, and service circuits. A line circuit is connected to each line (loop); it provides initial battery voltage to the line, senses the on-hook or off-hook state, and isolates the reed contacts in the switching network during switching intervals. A trunk circuit is connected to each trunk; it provides battery voltage to the associated line after connection is established, provides trunk supervision signaling, senses the on-hook or off-hook state, and isolates the reed contacts during switching intervals. A junctor circuit performs the same functions as a trunk circuit for intraoffice calls. Service circuits include circuits for receiving dial pulses or TOUCH-TONE signals, circuits for ringing the called line and for providing an audible ringing indication to the calling line, circuits for providing busy tone, and circuits for transmitting and receiving MF pulses.

In No. 1 ESS, these circuits have been reduced to simple configurations (see Fig. 9-28); each circuit performs only a few functions under program control, and different circuits are connected to the communication path as needed via the switching network. Both flexibility and economy result. These circuits contain input-output arrangements for the central processor; that is, points to which scanners and signal distributors can be connected. Additional circuitry is needed in the line and trunk circuits to match them to the customer lines and trunks.

Fig. 9-28. Plug-In Trunk Units

The plug-in trunk units have been redesigned and repackaged with newer and smaller electronic components yielding a significant reduction in required floor space. Fig. 9-29 shows the 3:1 reduction in size for an array of 512 trunk circuits and associated scanner and signal distributor controls. The newer equipment became available in 1976.

Automatic Message Accounting (AMA)

AMA is provided in No. 1 ESS by magnetic tape recorders that record the necessary call details for billing purposes.

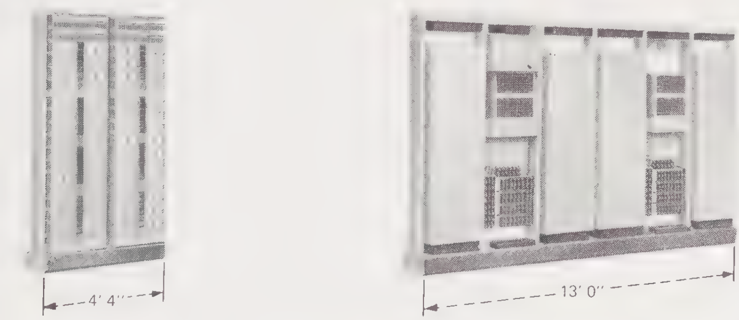


Fig. 9-29. Plug-In Trunk Unit Frames

9.4.1.6 Maintenance

The No. 1 ESS reliability objective specifies that major outages should total no more than 2 hours in 40 years. Because some failures of individual components are bound to occur over decades of system service, duplication is essential to meet this objective. Every system unit required to maintain service must be provided in duplicate, and troubles must be found and corrected quickly in order to minimize the possibility of system failure caused by multiple troubles.

Somewhat less than half of the stored program instructions are used for maintenance. Some of these programs, in conjunction with logic wired into the hardware, detect and report faults and troubles. Other programs control routine tests, diagnose troubles, and control emergency actions to ensure a satisfactorily operating system, either by eliminating faulty subsystems or by reorganizing usable subsystems into a new operating combination. When a trouble occurs, telephone switching actions are interrupted as briefly as possible to reestablish an operational system. Then, on a less urgent basis, the defective unit is diagnosed by the system itself, and the results are printed on the maintenance teletypewriter.

9.4.1.7 Services Provided

The initial No. 1 ESS generic program provided basic local service for medium-size metropolitan offices. In addition, the initial program provided new custom calling services: speed calling, 3-way calling, and call forwarding. Since that time, several new generic programs have been developed to add centrex, toll, international direct distance dialing, dial-tone-first coin, call waiting, and many other services. A signal processor was added to increase the No. 1 ESS call-handling capacity for large metropolitan offices. The signal processor is an adjunct computer added to the system to do some of the input-output work for the central control.

The stored program and single control concepts are the outstanding advantages of ESS over electromechanical designs. These concepts have enabled the newer Electronic Switching Systems to provide custom calling services and special services associated with centrex service (such as selecting the most economical route for a customer who has a private-line network). Many of these services require unique memory for an individual customer. In No. 1 ESS, this can be provided in the program store, where it is easily accessible by the call processing programs. Also, services such as 3-way calling require repeating some call-originating functions (connection to dial tone and digit recognition) while a call is in progress. This is easily accomplished in No. 1 ESS, because a single control follows the call from beginning to end.

9.4.1.8 Lessons From No. 1 ESS

No. 1 ESS demonstrated the success of the stored program and electronic digital processor concepts, and all subsequent electronic central office designs have adopted these ideas. The administrative programming effort and size of each new generic program continue to grow, and work is under way to develop a technique to allow functions to be added to individual offices on a more modular basis. Such a technique will permit services to be made available more quickly, as the operating companies will not have to wait for the issue of a complete generic program to obtain new services.

No. 1 ESS has served as the pioneer electronic system in many ways, not the least being in the area of growth. Techniques have been developed to change generic programs and to add equipment to a working office with essentially no interruption of service.

9.4.1.9 Trends

Development effort continues on cost and space reductions as well as on capacity improvements. New processors with greater call-handling capacity are being developed to meet the needs of future services. A new high-speed, integrated circuit processor, named the 1A Processor, increases call-handling capacity about 2-1/2 times and requires only one-half the floor space of the No. 1 ESS processor. When used with the No. 1 ESS periphery, the system is known as No. 1A ESS.

A very important feature of the 1A Processor is that it has been designed to operate with the No. 1 ESS operational and peripheral maintenance programs. A support program translates the No. 1 ESS machine instructions into equivalent instructions executable on the 1A Processor. In this manner, the programming and debugging effort has been reduced. In addition, as new features are added to the No. 1 ESS programs, they are translated for application to the No. 1A ESS.

The design of the 1A Processor includes the capability to replace a No. 1 ESS processor in a working No. 1 ESS office without disrupting service. This capability will extend the growth capability of the many No. 1 ESSs that are already in service.

Increases in the maximum network size will be provided with the No. 1A ESS. The new network configurations will accommodate up to 128,000 lines and 32,000 trunks and will provide a total traffic capacity of 10,000 Erlangs.

New arrangements are being considered to provide business customers with services that would be tailored to their individual needs. This will require both additional memory and call-handling capacity.

Centralization of maintenance and administration functions, using data channels to transmit information to a switching control center (SCC), has been developed to reduce No. 1 ESS operating expenses. (See Section 16.5.)

9.4.2 NO. 2 ESS

Because No. 1 ESS was designed primarily for the large metropolitan office, it has a high start-up cost and a low cost for growth. No. 2 ESS has been designed to have a much smaller start-up cost than No. 1 ESS and is intended for smaller offices with a low growth rate. No. 2 ESS is therefore expected to have an application in suburban and small metropolitan areas. It provides essentially the same functions as No. 1 ESS.

A lower start-up cost is achieved by using the extra call-handling capacity or processor time resulting from the office's smaller size to do more processing per call, thus reducing program store and call store requirements. Also, the use of a simpler processing hierarchy than No. 1 ESS, three program levels instead of many interrupt levels, leads to additional memory savings at some expense in system efficiency.

Reference 11 contains a technical description of No. 2 ESS.

9.4.3 NO. 3 ESS

No. 3 ESS is designed to provide modern telephone service in the rural community dial office (CDO) switching environment, economically serving offices up to a few thousand lines. The set of functions and services for No. 3 ESS includes basic telephone service plus custom calling services.

The No. 3 ESS processor uses high-speed integrated circuits. It has a semiconductor main store memory which serves as a combined program, translation, and call information store. A tape cartridge memory is associated with each of the two processors in a system; it contains a duplicate copy of the program and translations, as well as infrequently used administrative and diagnostic routines.

In the size range where No. 3 ESS is to be competitive (up to a maximum of 4500 lines at an average of 3 CCS per line), the start-up cost is of even more importance than for No. 2 ESS. Because the processor had a greater speed than was required, it was possible to employ a design strategy that minimized the autonomy of peripheral hardware at the expense of processor real time. The engineering effort and cost for No. 3 ESS is minimized by reducing the number of choices available to the operating companies and by modular design of growth equipment.

9.4.4 NO. 2B ESS

The No. 2B ESS combines the 3A Processor with the existing No. 2 ESS network and periphery. The 3A Processor includes a microprogrammed control, and it can directly execute the No. 2 ESS operational programs. With its faster logic, the No. 2B ESS handles twice as many calls as the No. 2 ESS, and, with its newer processor, is less expensive than the No. 2 ESS. As in the case of the No. 1A ESS, this evolutionary technique has allowed a continued return on the investment in software development of the earlier vintage local switching system.

9.5 TOLL SWITCHING SYSTEMS

9.5.1 STEP-BY-STEP TOLL

In the early 1920s, toll dialing was introduced in Los Angeles, using Step-by-Step as the switching medium. As a result of the success of this equipment, Step-by-Step toll offices were installed in other cities around the country, including Albany, Denver, and San Diego. All of these, however, were used for short-haul toll business and not for long-haul intertoll dialing. By the early 1940s, cities were being tied together by Step-by-Step Systems in long-haul dialing networks. All Step-by-Step Toll Systems are 2-wire, and most are directly controlled systems (no senders, decoders, translators, etc.). About 60 have been modified for centralized automatic message accounting (CAMA), and these use common-control features for the routing and charging features associated with customer-dialed traffic. Nearly all Step-by-Step Switching Systems that do toll switching are in class 4 offices.

9.5.2 NO. 4A TOLL CROSSBAR

9.5.2.1 Design Objectives

The No. 4A Crossbar Toll System, which first went into service in 1953 in Scranton, was designed to meet all of the nationwide toll dialing requirements: foreign area translation (the ability to translate 6-digit area and office codes to derive trunk group choices), automatic alternate routing (the ability to route the call to other trunk groups if the first route is busy), and code digit manipulation (converting the incoming address to a different address for transmission, skipping digits in the transmission, and prefixing new digits if needed). Earlier Crossbar Toll Systems (No. 4 and No. A4A) existed, but these did not have foreign area translation and/or the digit manipulation capability of the No. 4A.

The No. 4A System was designed to interface with all types of local offices and with other types of toll offices (Manual and Step-by-Step). It was intended for metropolitan areas, and was the largest of the Bell System's toll systems until No. 4 ESS became available. It is a 4-wire switching system; that is, it uses separate paths for each direction of transmission. The 4-wire design was chosen after studies of both intertoll and toll-connecting plant predicted more and more carrier (4-wire) operation in the future.

9.5.2.2 Evolution of the Design

The No. 4A Crossbar Toll System is an electromechanical marker system with crossbar switches making up its switching network (see Fig. 9-30). Trunk circuits provide supervisory and transmission paths. Incoming and outgoing trunk link frames, consisting almost entirely of crossbar switches, provide paths for connecting incoming trunks to outgoing trunks. Senders register destination codes pulsed from preceding offices and transmit the necessary information to the decoders. Decoders and translators determine the proper trunk group to the called office. Markers find an idle path through the switch frames, after which they operate the crossbar switches to establish the connection from the incoming to the outgoing trunk. Although markers are common-control equipment, they are associated with specific trains as shown in Fig. 9-30. Decoders also furnish senders with detailed information (such as type of outpulsing and number of digits) required to forward the call to the next office. Sender link and controller frames provide means of connecting incoming trunks to senders. Connectors consist mainly of multicontact relays that are used for connecting large numbers of information-carrying wires between major functional equipments.

The equipment units shown in Fig. 9-30 that make up the common-control part of the No. 4A System are dedicated to a particular call only during the call setup interval. This is in contrast to portions of the crossbar switches, which are engaged for the duration of the call. The length of time a common-control unit is engaged is the principal factor in determining the number of units needed. For example, senders have a long holding time (while they receive digits, wait for a connection to be established, and then outpulse digits), and therefore as many as 300 may be needed. Translators have a relatively short holding time; therefore, only about 24 are required.

The translation function was originally handled by a card translator, a type of equipment very unlike the conventional relay "tree" used in earlier

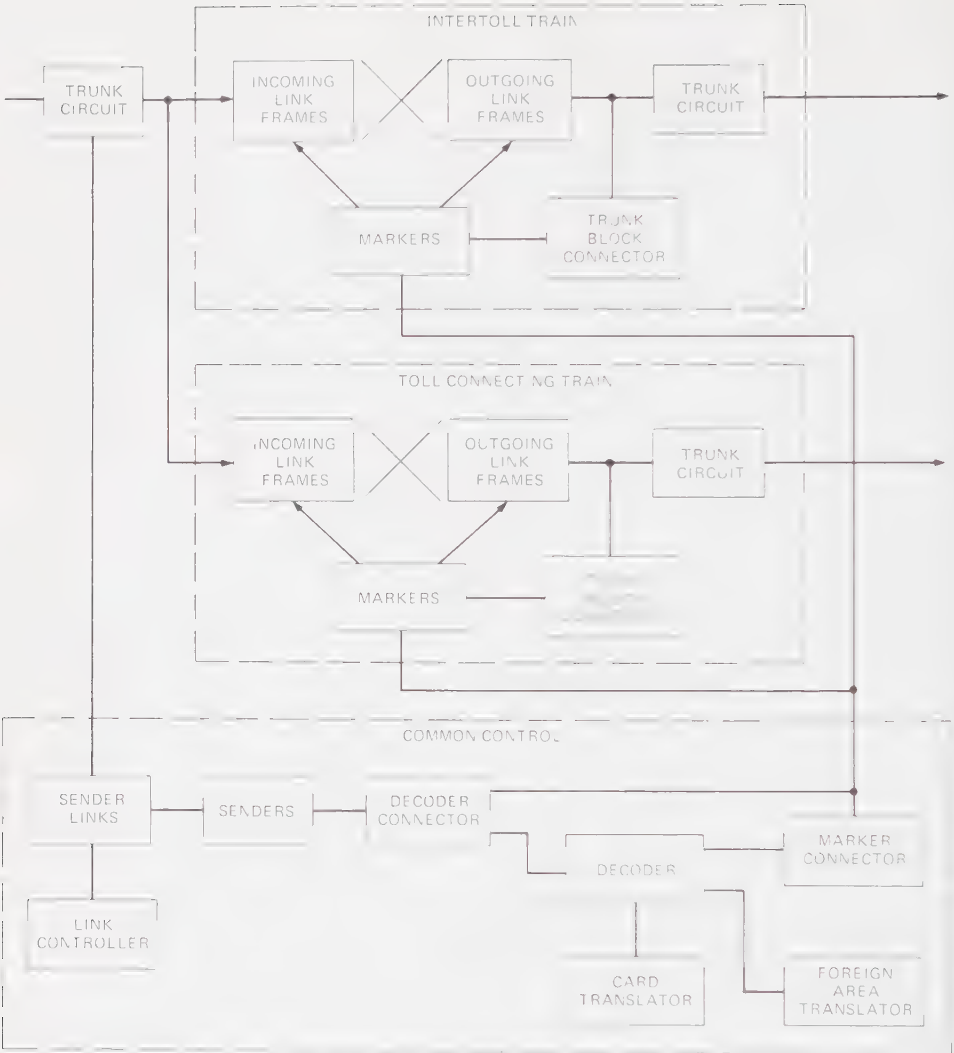


Fig. 9-30. No. 4A Toll Switching System

Crossbar toll and local offices. The card translator contains a number of metal cards, each with tabs on the bottom to allow selection of a card corresponding to the address. The cards contain punched holes, coded to give all the information needed by the other common-control equipment to route the call, such as the trunk group to try first, second, third, etc., the digits to outpulse, the type of outpulsing, etc. In the translator, the cards are stacked between a light source and a bank of phototransistors, one phototransistor for each of the coded holes. Detector circuits associated with the phototransistors read the coded light channels when the selected card is presented. (Incidentally, this was the first use of transistors in Bell System equipment.)

9.5.2.3 Modifications

Centralized Automatic Message Accounting

The No. 4A Crossbar Toll System was modified by the addition of centralized automatic message accounting (CAMA) equipment to record billing information automatically for local and toll calls at a centralized point. CAMA (which went into service in April 1960) permits dialing of these calls by customers served from Panel offices in which no AMA facilities are available, as well as from No. 1 and No. 5 Crossbar and Step-by-Step offices not equipped for AMA, and by party-line customers served from any of these types of offices. These calls are routed through a No. 4A office equipped for CAMA, and the billing record is made at the No. 4A office.

Where local offices are arranged for automatic number identification (ANI), they automatically pulse the calling party's number to the toll office, and the CAMA function is performed automatically. When ANI is not available in the local office (and in party-line situations), the services of a special CAMA operator at the No. 4A toll office are required momentarily to obtain and record the calling line number in the toll recording equipment.

Electronic Translator

The electronic translator, introduced in the No. 4A System in Grand Rapids, Michigan in 1969, consists of Stored Program Control No. 1A (commonly referred to as the SPC processor) and peripheral circuits which are interfaces between the SPC and existing electromechanical equipment (see Fig. 9-31). The SPC consists of the processor, signal distributor, store, master scanner, central pulse distributor, control and display, program tape, and teletypewriter. An electrically alterable memory provides the mechanism to change translation information readily on a day-to-day basis. A system so equipped is known as a No. 4A/ETS to distinguish it from No. 4A Systems equipped with card translators, which are known as No. 4A/CT Systems.

Peripheral Bus Computer

An arrangement has been developed to interface a commercial minicomputer with the No. 4A/ETS Crossbar System. This arrangement, known as the Peripheral Bus Computer (PBC), provides for the acquisition, processing, storage, and output of both traffic and equipment performance data. The PBC takes over the functions of earlier recording equipment as well as some functions presently performed by the ETS. A modest improvement in ETS real-time utilization has been realized, and ETS stores have been freed for use in connection with common channel interoffice signaling.

Common Channel Interoffice Signaling

The No. 4A/ETS System has been modified for common channel interoffice signaling (CCIS) for signaling between processor-equipped switching systems

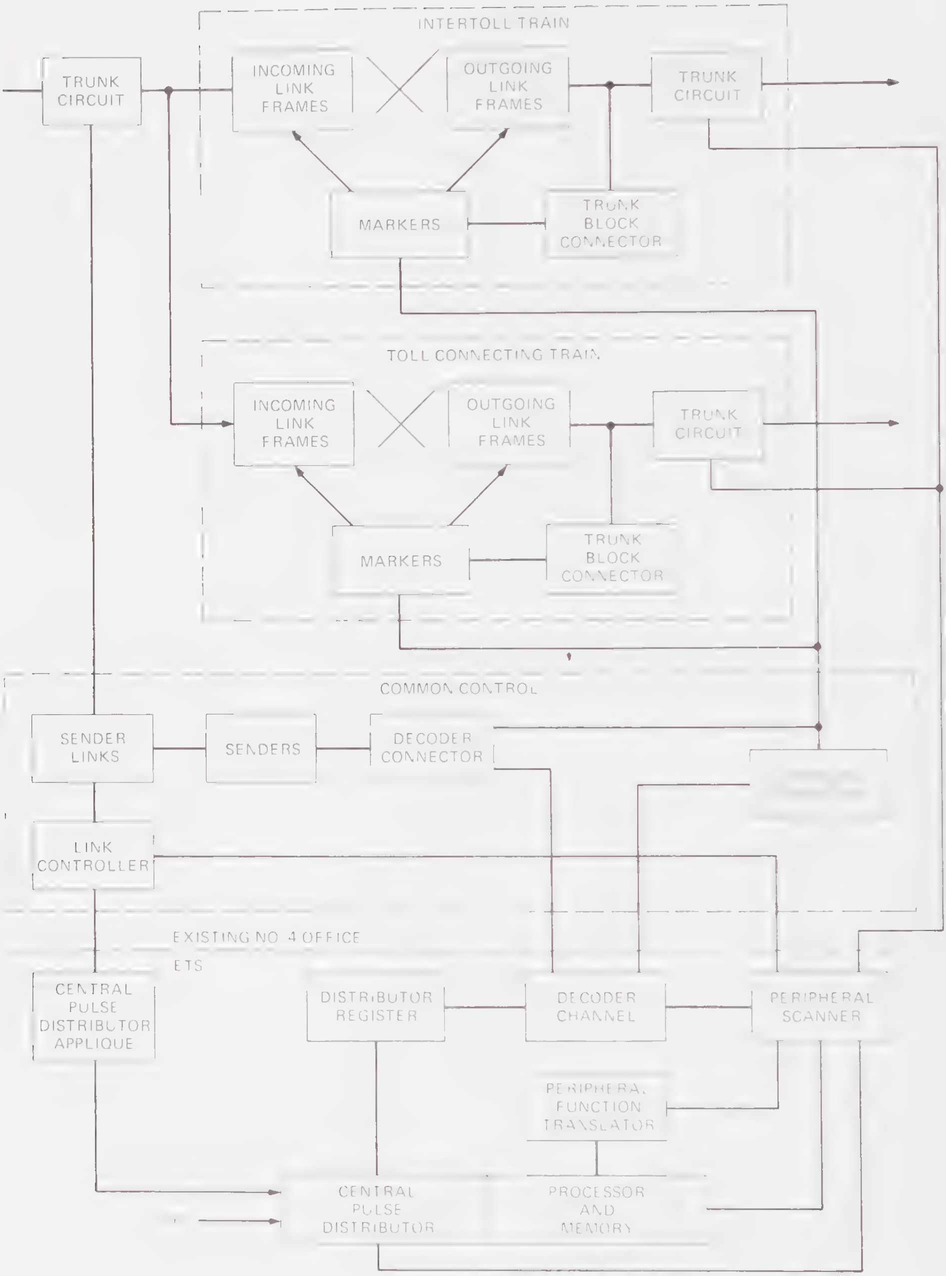


Fig. 9-31. No. 4A Toll Switching System With ETS

(see Section 7.1.4). This involved designing terminal access circuitry to interface No. 4A/ETS with a CCIS terminal. Other new circuits are required to permit No. 4A/ETS to switch calls arriving on a trunk with CCIS signaling to an outgoing trunk with per-trunk signaling, or vice versa.

9.5.3 CROSSBAR TANDEM

9.5.3.1 Evolution of the Design

Crossbar Tandem in its original version (1941) was a replacement for certain Panel equipment being used as local tandems in Panel and No. 1 Crossbar areas. With the original Crossbar Tandem, calls could be completed to Manual, Panel, No. 1 Crossbar, and Step-by-Step offices. Subsequently, features were added to permit receiving dial pulses from Step-by-Step offices and dial switchboards, thus making Crossbar Tandem suitable for use in Step-by-Step cities such as Los Angeles. Where a local Crossbar Tandem office had access to all the local offices in an area, it was attractive for completing toll calls to that area. In order to permit this type of completion, other functions were added in 1948. These functions included the ability to receive seven digits on a multifrequency basis.

In a later version (1951), Crossbar Tandem began handling outgoing toll traffic. This was accomplished by adding multifrequency outpulsing functions and expanding multifrequency inpulsing and outpulsing to 11 digits.

The introduction in 1955 of Crossbar Tandem (a 2-wire system) as a through toll (class 3, 2, or 1) switching system was made possible by improved transmission techniques. Foreign area translation was added to Crossbar Tandem in 1958.

In addition to its function as a switching facility, Crossbar Tandem was arranged to record billing information automatically on a centralized basis for local and toll calls through the application of CAMA equipment. Crossbar Tandem also was arranged for integrated traffic service position (TSP) operation (see Section 9.6.1). This provides a means for extending customer direct distance dialing (DDD) to include customer dialing of special toll calls and long distance coin calls. The services of a TSP operator are required on these calls to perform such functions as requesting the deposit on a coin call and interrogating the person answering a person-to-person call.

9.5.3.2 Description of Design

The Crossbar Tandem System, like No. 4A/ETS, is an electromechanical sender-marker system with crossbar switches making up its switching network. However, the Crossbar Tandem marker includes the decoder-translator and the marking function when only 3-digit translation is required. Foreign area translation is handled by separate equipment.

Although there are no plans to replace the marker and foreign area translator with an electronic processor, Crossbar Tandem is being modified to use minicomputers for AMA recording functions and for processing, storage, and output of equipment performance data.

9.5.4 NO. 5 CROSSBAR

The need to consolidate small quantities of toll traffic in sparsely populated areas led to the development of toll functions on No. 5 Crossbar. By putting toll traffic on an existing local system, the start-up expenses of a new toll system are postponed for many years. A disadvantage is that only 2-wire switching is provided, because toll connections are intermixed on the same switching frames with local connections. If two 4-wire trunks are connected through the system, two otherwise unnecessary hybrids are introduced into the path.

The primary toll functions provided are centralized automatic message accounting, toll operator service, and toll trunk testing.

The descriptions given for the other Crossbar Systems provide a basic understanding of the main features of the No. 5 Crossbar toll design.

9.5.5 NO. 4 ESS

9.5.5.1 Design Objectives

The motivation for designing an electronic toll switching system is basically the same as that for a local ESS: to lower first-cost and operating expenses relative to an electromechanical design and to provide a flexible system that can be adapted to changing needs. An obvious approach to this challenge would be to use the basic No. 1 ESS control system with the substitution of 4-wire switching frames and appropriate trunk circuits. This approach was studied and abandoned for the following reasons:

(1) Rapid growth of toll traffic and the penalties associated with multiple toll systems in a metropolitan area pointed to the long-range need for a system of very large capacity. The No. 1 ESS approach was deficient in both processing and network capacities.

(2) Since digital (PCM) transmission will probably become dominant in the toll network, it appears economically attractive to have a digital switching network in the toll machine.

Other important objectives for an electronic toll switching system arose from considerations of the installation costs of present systems and the cost of trunk rearrangements. One factor in both of these costs in electromechanical systems is the extensive hand wiring needed to connect each frame to many other functional units. With a new electronic system, it is expected that these costs will be minimized by integrated modular design of toll terminal and switching equipment, by multiplexing to reduce the number of interframe conductors in the switching area, and by frame interconnection using precut connectorized cables.

Table 9-2 is a list of the main functions and characteristics needed in a new electronic toll system. Not all of these will be available initially.

TABLE 9-2
PRINCIPAL FUNCTIONS AND CHARACTERISTICS OF A NEW ELECTRONIC TOLL SYSTEM

- Four-wire trunk-to-trunk interconnection
- Interface with toll operators
- Numbering plan functions
  - Six-digit translation
  - Code conversion
  - INWATS screening
  - Access to toll directory assistance
- Signaling compatibility
  - Multifrequency
  - Dial pulsing
  - Common channel interoffice signaling
- Large capacity
- Access for alignment and maintenance of long-haul carrier transmission facilities
- Switching machine maintenance functions
- Multi-alternate routing
- Traffic measurements (with an output format consistent with downstream processing)
- Centralized automatic message accounting
  - CAMA operators
  - Magnetic tape output
- Compatibility with fixed-loss transmission plan
- Network management controls
- Service observing
- International gateway functions
- Local tandem functions
- Private switched network functions
- Automated record keeping
- Humanized man-machine communications

9.5.5.2 No. 4 ESS Design

Capacity

Rapid growth in toll traffic created situations in metropolitan areas in which two or more of the available toll switching systems were needed to provide adequate capacity. As pointed out in Section 9.1.3, trunking penalties result when multiple toll offices serve the same area. In view of these situations and the projected continuing growth of toll traffic, an important objective in the development of No. 4 ESS has been to achieve a substantial increase in capacity.

The design of No. 4 ESS grew out of the No. 1 ESS concept in that it uses a single high-speed processor to handle the most complex aspects of call completion. Signal processors are provided to do preprocessing of the more elementary tasks, thus decreasing the per-call usage of the main processor. The No. 4 ESS main processor, the 1A Processor, through its use of higher-speed logic and core memories, is about five times faster than the No. 1 ESS processor. The No. 4 ESS has a call-carrying capacity of 550,000 peak busy-hour calls. A large-scale integrated circuit semiconductor memory is being developed to replace the 1A Processor core memories. It will provide a 3:1 size reduction, a 6:1 reduction in power consumption, and is expected to be easier to maintain.

Administration and Maintenance

Based on experience with No. 1 ESS, greater emphasis has been given to easing the operation and administration of the No. 4 ESS. For example, cathode ray tube input-output terminals are used to permit an interactive mode of communication between man and machine.

The use of low-cost disc memory (disc file controller in Fig. 9-32) permits storage within the system of data that formerly were kept as paper records. This permits activities such as assigning a trunk to a terminal to be done by the system rather than manually. Furthermore, because the chosen network design can maintain low blocking even with undistributed loads, the physical wiring changes traditionally associated with the periodic redistribution of trunks over terminals required to intermix lightly and heavily loaded trunks have been eliminated.

Magnetic tapes, controlled by the auxiliary data system (ADS), provide for the output of traffic and performance data and billing records and for the input of new program and translation information.

Time-Division Switching

Because new transmission systems are expected to turn increasingly to pulse code modulation (PCM) as a means of exploiting solid-state technology, the switching network in No. 4 ESS has been designed specifically to pass PCM signals without conversion. In early installations, it is expected that this

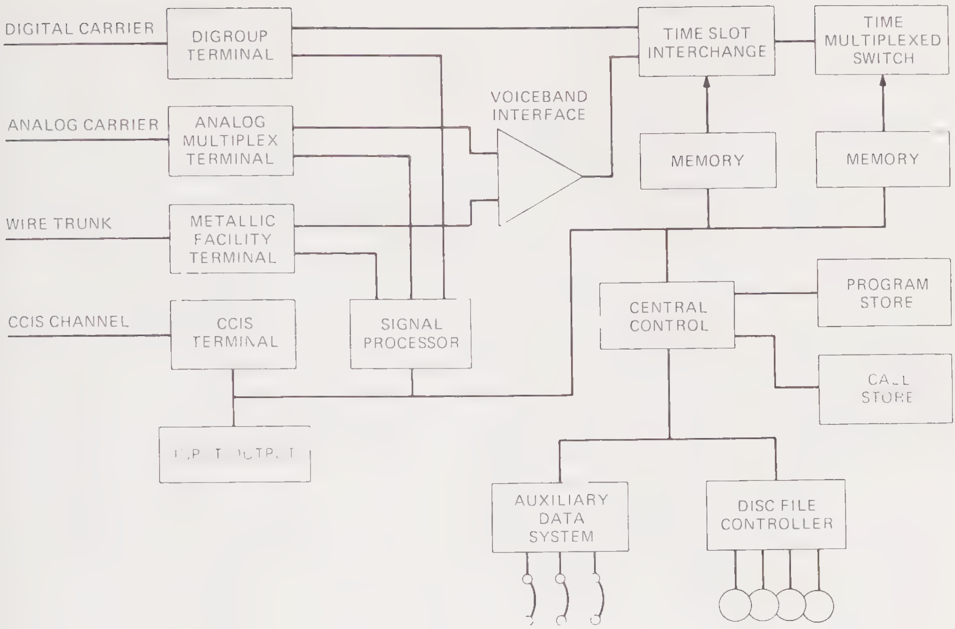
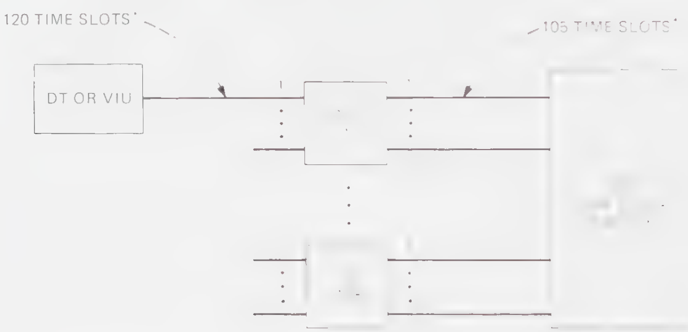


Fig. 9-32. No. 4 ESS Block Diagram

will pay off when interfacing with the toll-connecting plant, where short-haul (up to 50-mile) PCM systems are already in extensive use. Short-haul intertoll trunks (up to 500 miles) using PCM are also in service and are expected to grow rapidly. Long-haul intertoll trunks will be predominantly analog until long-haul digital transmission systems are developed and extensively used. For these analog systems, the design provides for conversion of analog signals to digital form. These arrangements are shown in Fig. 9-32. The triangular shape of the converter, known as a voiceband interface unit (VIU), is intended to signify the multiplexing of 120 voice channels onto one conductor. Connections to trunks on PCM facilities do not need conversion and therefore use a much simpler interface, the digroup terminal. (Digroup is a contraction of *digital group,* which in present systems consists of 24 voice channels.) The digroup terminal (DT) multiplexes digital groups to put 120 voice channels onto one conductor and separates out supervisory signaling information. Trunks derived directly from cable pairs interface via the metallic facility terminal frame before conversion to PCM. Beyond these interface units, all signals are in PCM format and can be switched as required in the time slot interchange (TSI)—time-multiplexed switch (TMS) complex, under control of circulating solid-state memories.

Fig. 9-33 shows the TSI-TMS complex in more detail. The TSI associated with an incoming trunk stores the incoming coded PCM sample until the time slot selected for cross-office transmission of this call comes up. When it does, the TMS is configured by the circulating memory to provide a path to the TSI associated with the appropriate outgoing VIU (or DT). The coded PCM sample is thus sent through TSIs from the incoming VIU (or DT) to a storage register in the outgoing VIU (or DT), where it is held until the time slot corresponding to the appropriate outgoing trunk comes up. A coded PCM sample is, of course, transferred from the outgoing trunk to the incoming trunk in the same way at the same time. Notice that the cross-office time slot is selected independently of the time slots corresponding to the incoming and outgoing trunks. Notice also that the space-division portion of the switch (the TMS) is reconfigured for each time slot (about 10^6 times per second), in contrast to a conventional space-division switch which is reconfigured only in response to the arrival and departure of calls.



* ACTUALLY 128 TIME SLOTS: 8 RESERVED FOR MAINTENANCE LEAVING 120 FOR TELEPHONE CONNECTIONS

† ACTUALLY 128 TIME SLOTS. ON THE AVERAGE ONLY 105 CAN BE OCCUPIED BECAUSE OF THE 7:8 EXPANSION IN THE TS

Fig. 9-33. Diagram of TSI-TMS Complex

Each TSI has eight input and eight output coaxial leads connecting to the TMS. On the average, each of these leads accommodates time slots for $7/8 \times 120 = 105$ voice channels. The 1024 input leads, 8 from each of 128 TSIs, and 1024 output leads are interconnected by the TMS, which is a 1024-by-1024 crosspoint matrix. Since each telephone connection is made up of two paths through the TMS, one for each direction of transmission, the maximum number of simultaneous telephone connections that can be accommodated is given by the number of time slots on each TSI lead times the number of possible connections through the TMS divided by 2:

$$105 \times \frac{1024}{2} = 53{,}760 \text{ connections}$$

Descriptions of No. 4 ESS are contained in References 12 and 13.

Floor Space Savings

An important part of an operating company's initial cost for switching is the building to house the equipment. No. 4 ESS will be very compact compared with No. 4 Crossbar, occupying about one-third the floor space for equivalent systems serving 10 to 20 thousand trunks. This comparison includes all equipment and work space and assumes small crossbar switches in the No. 4 Crossbar System.

9.5.6 NO. 1 ESS

In more sparsely populated areas, the toll capability is often derived from a local common-control machine, because initial demand and annual growth are small. Therefore, toll functions including centralized automatic message accounting, toll operator connections, toll trunk testing, common channel interoffice signaling, and 4-wire switching have been developed for No. 1 ESS.

9.6 OPERATOR SYSTEMS

As mentioned in Section 7.3, a great deal of effort is being devoted to modernizing operator services equipment. This modernization is intended to automate many operator functions and to utilize the operators more efficiently. One example of a new system in each operator category will be described. Additional information may be found in References 14 through 18.

9.6.1 TOLL SERVICE

Most toll operators are at 3CL switchboard positions. A picture of a 3CL toll switchboard position lineup is shown in Fig. 9-34. Call-handling at such a manual system is described in Section 7.3.

Toll operators at manual cord switchboards perform the switching function when they connect circuits through the cords. Also, they perform the functions of recording billing details and of timing the calls. The object of mechanization of the operator's function is to use a machine to perform both the switching function and the recording of billing details and time. The operator is then left to perform those unique functions of speaking with the customers to gather needed information and of entering the information into the system by depressing keys.

The first major mechanization of the toll operator's function was the development of the traffic service position (TSP) to work as part of the Crossbar Tandem switching system. The operator's position was a cordless console with a numerical display and pushbuttons. If this method of providing modernized operator services had been continued, it would have been necessary to provide system modifications in other toll switching systems such as No. 4A Crossbar and No. 5 Crossbar.

Fig. 9-34. Manual Toll Switchboards

In order to minimize continued development effort and to capitalize upon electronic switching technology, the Traffic Service Position System (TSPS) was developed. The TSPS is an autonomous system that stands apart from both toll and local switching systems. Functionally, it is placed between the local office and the toll office as shown in Fig. 9-35. Because the signaling and transmission interfaces for TSPS are standard, it functions with all the different designs of local and toll switching systems.

The system provides for the types of calls shown in Table 9-3. As well as handling these calls from coin and noncoin telephone lines, the system can handle guest-originated calls from hotels and can provide the hotel with an automatic, immediate teletypewriter printout of the charges.

International calls are also handled through TSPS. For customer-dialed station-to-station calls, TSPS serves as a CAMA point to record billing details without operator intervention. TSPS operators also provide assistance on customer-dialed international calls. When local offices are not modified for international dialing, customers can place calls through TSPS on a dial-0 basis, and the TSPS operator keys the overseas number.

The TSPS uses both the basic hardware components and the system structure of the No. 1 ESS. The TSPS has the real-time capacity to process approximately 16,000 initial position seizures in the busy hour. The maximum numbers of major system elements are:

(1) 3000 trunks.

(2) 310 positions, accessible as a single team.

(3) 62 positions per chief operator group.

(4) 8 chief operator groups, local, remote, or both.

Since the basic function of TSPS is to automate the routine aspects of the operator's work, the system description begins from the operator's viewpoint: the way calls appear on the console, the operator's responses, and the arrangement of the console. Against this background, descriptions of the rest of the system should be more meaningful.

Fig. 9-36 shows a typical operating room. Each console contains two positions in a desk-like arrangement. A closer view of the console keyshelf with its lamps and keys is given in Fig. 9-37. Except for the digital display in the uppermost portion of the console, all the lamps are on the main panel. Some keys are equipped with lamps as indicated in the legend at the lower left.

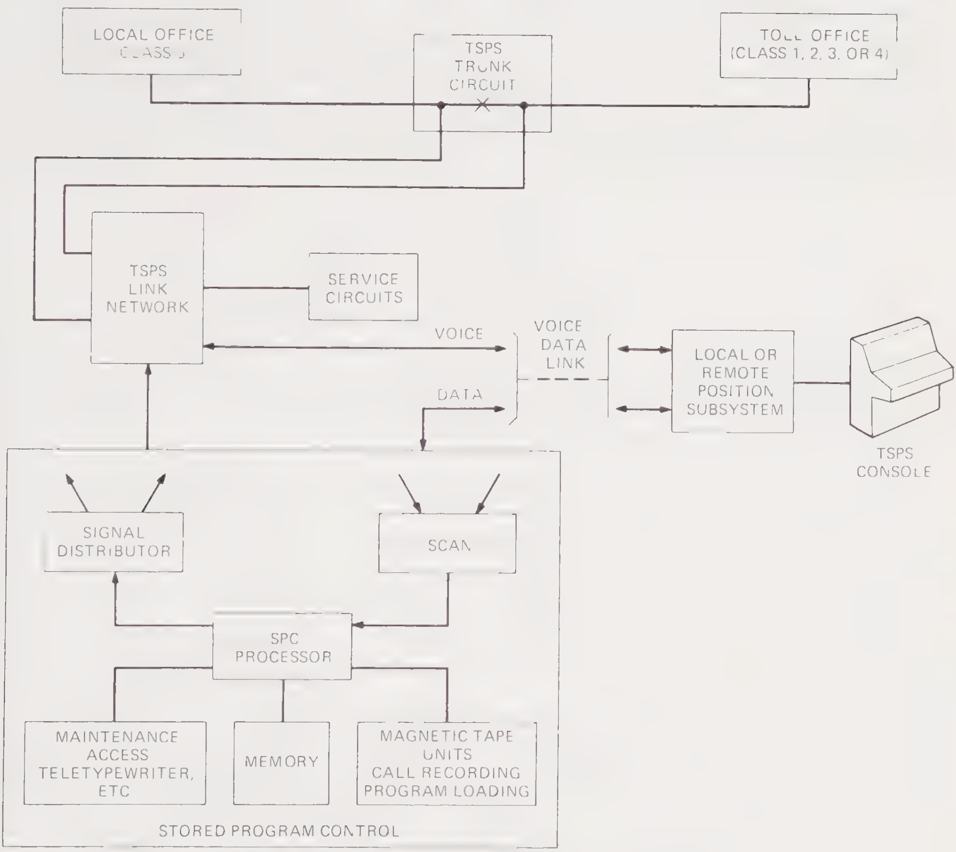


Fig. 9-35. Traffic Service Position System

A position becomes available to the system for service when an operator inserts the headset plug into its jack. Calls are automatically distributed to all attended positions in such a way that all operators receive an equal share of the traffic load. When a position is given a call, the operator hears a distinctive tone and is given a lamp display. A lamp indicates the type of the originating station, coin or noncoin, and whether the customer dialed 0 followed by 7 or 10 digits (0+), dialed 0 only (0-), or dialed a station-to-station call (1+). (The use of a "1" prefix for station calls is not universal, but for purposes of description, station-to-station calls are often referred to as "1+".)

With these indications, the operator is able to respond appropriately. On calls received from coin stations, the deposit for the initial period and the duration of the initial period are indicated in the numerical display when the operator takes the call.

On 0+ calls, the operator first determines the type of assistance the caller wants. The operator then depresses a key to indicate the class of charge. If it is necessary to enter a credit card number or the number of a third station for billing purposes or to provide the called number or calling number, the operator uses a keyset in the lower right corner; it is conditioned by operation of an appropriate keypulse key to indicate the type of number the operator is entering into the system.

TABLE 9-3
TSPS OPERATOR FUNCTIONS

TSPS OPERATOR FUNCTIONS	TYPE OF CALL	
	FROM COIN STATIONS	FROM NONCOIN STATIONS
Obtaining billing information for credit card or third-number calls	1+, 0+	0+
Identifying called customer on person-to-person calls	0+	0+
Obtaining acceptance of charges on collect calls	0+	0+
Identifying calling number*	1+, 0+	1+, 0+
Monitoring coin deposits	1+, 0+	
Handling operator assistance calls	0-	0-
Type of call (as it appears on TSPS console)	1+ = Customer-dialed station-to-station calls 0+ = Customer-dialed special calls 0- = Operator assistance calls	

* Needed only when calling number is not automatically identified and forwarded from the local office.

Fig. 9-36. A Typical TSPS Operating Room

In the lower center part of the keyshelf are three columns of keys which are referred to as "loops". When a call is connected to the position, it is associated with one of these loops. When the operator is in voice contact with the customer, the bottom keylamp, designated ACS (access), is lighted. If the operator desires to keep this call associated with the position while handling other calls, the HOLD keylamp is pushed. The upper two lamps of each loop indicate the switchhook condition of the originating and terminating stations when a call is in either the ACS or HOLD condition. The call is released from the position when both the ST TMG (start timing) key to the immediate left of the three loops and the POS RLS (position release) key in the lower left corner are operated.

Whenever a call is connected to a TSPS position, all call details are available from the system memory. These call details are directly equivalent to those that would be written on a ticket if the call were processed at a cord switchboard. Under key control, the calling number, the number that is being called, a credit card number if keyed into the system, the number of a third telephone if one is being billed, or the charging rate on coin calls can be displayed. Also, the operator can get the exact time of day being used by the system by depressing the TIME key.

Other operator controls include the ability to release connections forward or backward, to ring the stations forward or backward, to collect or return coin deposits, and to connect to special service operators over outgoing trunks.

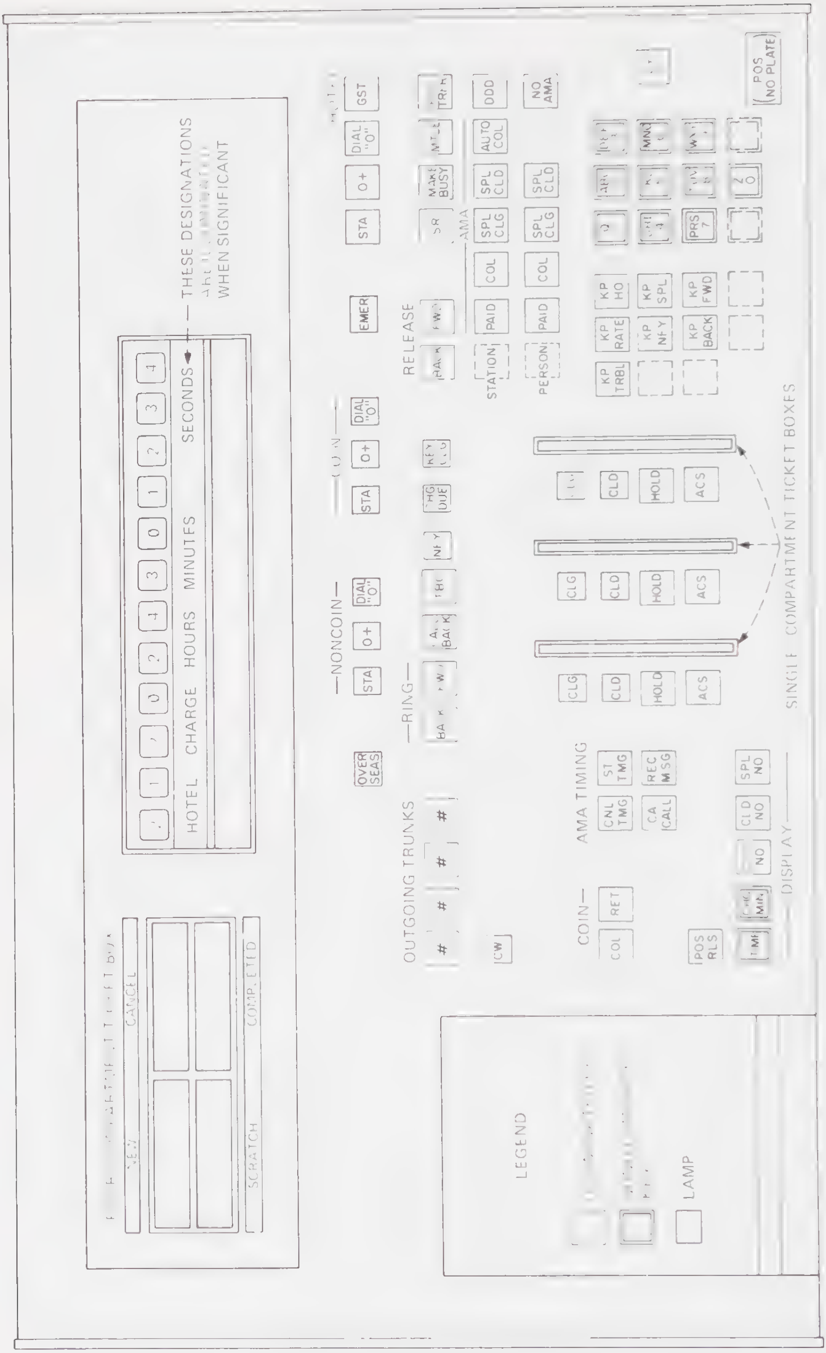


Fig. 9-37. Keyshelf of the 100B Traffic Service Position

Although the operator has some freedom in handling calls, many of the key actions are automatically checked, and flashing lamps indicate errors. If, for instance, the operator depresses the ST TMG key before a class of charge has been recorded, the ST TMG lamp will flash. The operator must then determine what information is missing. Similarly, keying 11 digits on a 0- call will cause the KP FWD (key pulse forward) lamp to flash.

As shown in Fig. 9-35, all trunks have two 2-wire appearances on the link network. The network connects the trunk to various service circuits: digit receivers, outpulsers, coin control circuits, tone circuits, and operator positions. The basic logic instructions for handling calls are in the memory and are executed by a processor. Changes of the supervisory state of trunk, service, and other peripheral circuits, including the positions themselves, are detected by scanners together with programs and memory indicating previous states. Output instructions via signal distributors and central pulse distributors control these circuits and the position lamps.

During the conversation period of a call, the customers are connected only to each other; there are no connections to operators or service circuits. It can be seen in Fig. 9-35 that the TSPS trunk circuit is a dedicated facility connecting the local office to the toll office. No switching capability nor concentration exists for this trunk circuit at the TSPS. Thus, TSPS is a unique type of switching system because all the elements of a switching system are present only for the purpose of temporarily connecting equipment units and operators to the trunk circuit.

The processor-memory complex, including such supporting units as the control and display panel, a signal distributor, a central pulse distributor, a master scanner, the maintenance teletypewriter, and the program tape unit for loading and unloading memory, constitutes a subsystem called the Stored Program Control (SPC) No. 1A. SPC equipment is covered by a separate set of engineering documents and has well-defined interfaces so that it can be used in other applications. For example, it is used with the Electronic Translator System for No. 4A Crossbar toll systems as well as for TSPS No. 1. The switching network used in TSPS No. 1 to connect the trunks to the service circuits and positions is a 4-stage, 2-wire, space-division network using ferreeds.

Many of the peripheral units of TSPS No. 1 are similar in function and appearance to those of No. 1 ESS. The plug-in circuit packs, the framework, and the terminal strips are virtually identical.

The plug-in trunk units and the universal trunk frames look like No. 1 ESS units, but are in fact quite different in function; this is reflected in the internal design. Because TSPS works with any type of local office, it must be able to receive both multifrequency pulsing and dial pulsing over both loop and carrier facilities. Since the serving toll office may have either a 4-wire or a 2-wire switching system, both 2-wire and 4-wire trunk circuits are provided. The 4-wire trunk circuits are used when the toll office has 4-wire switching and the incoming trunk facilities are 4-wire.

When the positions are remotely located, the orders to control the position lamps and the data words for key operations are sent via a digital channel on a T1 Carrier System. The T1 Carrier System also provides the voice circuits for the operators.

A Position Subsystem (PSS No. 2) uses a new peripheral control link for transmitting data between the processor and the positions. The new subsystem allows remote location of positions by using other than T1 carrier, thereby extending the remote location range and application.

The remote trunk arrangement (RTA), referred to in Section 7.3.3, also makes use of the same new peripheral control link. The ability to use a variety of transmission facilities adds to the flexibility and economy of the remote trunk arrangement.

The program structure for TSPS closely follows that for No. 1 ESS. An executive control program, interrupt levels, priority work lists, fault recognition programs, and diagnostic programs are employed to provide the real-time, time-shared characteristics of the system.

9.6.2 NUMBER SERVICE

9.6.2.1 Treatment of Intercepted Calls

Three kinds of calls to nonworking numbers must be intercepted. The first is calls to a recently changed or disconnected number. When a telephone is disconnected, the number obviously cannot be reassigned to another customer immediately, as the new customer would get calls intended for the previous one. Incoming calls to discontinued numbers are therefore intercepted in the terminating central office. The caller must be told why the number is no longer assigned and, if possible, given the new number for the called party. Reassignment of a discontinued number is delayed long enough to ensure that very few calls intended for a previous customer will be routed to the number.

The second kind of call that must be intercepted is calls to a "vacant" number, a number for which there is no terminating equipment in the central office. The third type is calls to a number for which there is equipment, but which has not recently been assigned to any customer. The latter two kinds of calls are presently routed to a recorded announcement that tells the customer he has reached a nonworking number and invites him to stay on the line if he needs an operator's help. Calls to changed or disconnected numbers are routed directly to an intercept operator, along with calls from customers who did not hang up after hearing the recorded announcement. The intercept operator asks the caller what number he is calling, consults a printed record of nonassigned numbers which is updated daily, tells the customer the status of the called number, and gives him a new number if one is available.

9.6.2.2 Automatic Intercept System

The Automatic Intercept System (AIS) is designed to improve the processing of calls to nonworking numbers by automating and centralizing intercept service for large geographical areas. This is accomplished by connecting incoming intercept trunks from local offices to equipment that provides recorded announcements specifically tailored to each intercept case and by improving the method of operator handling for the relatively few nonroutine cases requiring operator assistance.

AIS employs stored program control, high-speed switching, and magnetic storage devices to give economic and service advantages over existing manual or semiautomatic systems. It provides the services that are available with existing systems and has additional capabilities required to provide new services and functions.

The various types of calls that may be routed to AIS include:

(1) Calls to vacant or unassigned numbers.

(2) Calls to changed numbers.

(3) Calls to disconnected numbers.

(4) Trouble intercepts.

A simplified block diagram of AIS is shown in Fig. 9-38. Typically, an AIS serves a metropolitan area (New York City has several) or an entire state, such as North Carolina.

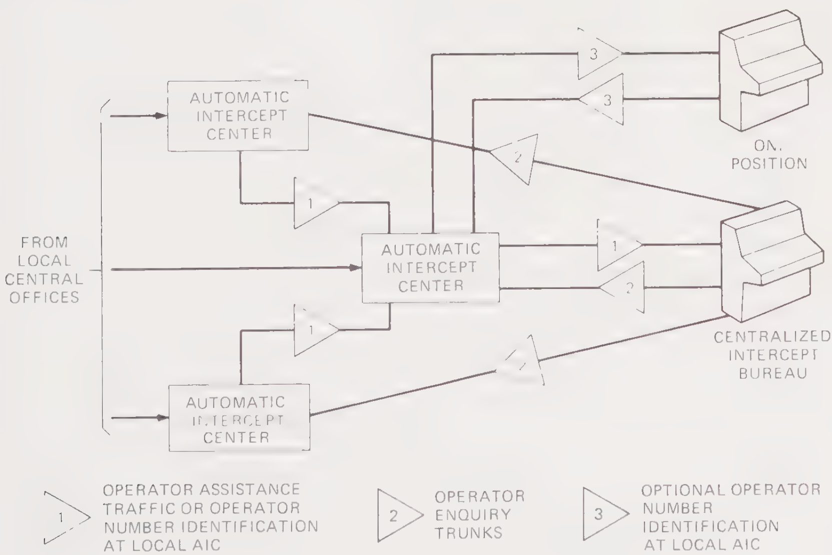


Fig. 9-38. Automatic Intercept System

Under automatic intercept service, calls in local offices are routed to a central automatic intercept center (AIC). The files are searched for the called number, and a recorded announcement is connected to the customer's telephone. The announcement contains all the information available, including the number the customer dialed and a new number if one is available. If the customer still needs help, the call is transferred to a centralized intercept bureau (CIB), where specially trained operators handle the call.

When a call to a nonworking number is intercepted in an office using common-control switching equipment, the called number is already recorded in 4-digit or 5-digit form in the common-control equipment. For the interception equipment, the number is reconstructed as the seven digits dialed by the customer and is placed in an outpulser. The outpulser is connected to a trunk to the intercept center and sends the number to the AIC. In non-common-control offices that are equipped for automatic number identification (ANI), the intercept circuits are modified to use the ANI equipment for identifying the number.

Fig. 9-39 is a block diagram of the AIC. The AIC contains a time-division switching network and a stored program processor. The network connects to a maximum of 512 trunks or equipment terminations and can accommodate as many as 64 connections simultaneously.

When a call comes into the AIC from a local office, it is connected to a multifrequency receiver, which receives the digits and passes them to the processor. The processor decides, from the prefix, whether to connect a vacant number announcement immediately, to connect the call to a CIB operator, or to look up the called number in the files.

For situations in which local offices are not equipped to identify the called number on intercepted calls, operator number identification (ONI) is provided at the AIC. Intercepted calls in these offices are routed to the AIC via existing intercept equipment in the local office. The local office may handle all intercept traffic in a single trunk group without indication of the type of intercept, or it may send signals to the AIC to indicate operator class, vacant number, or trouble intercept.

Files of unassigned numbers are stored in magnetic disc memories. Two are furnished for reliability, and each contains a complete list of the unassigned numbers in all central offices served by the AIC. The processor uses this information to compose an announcement or to transfer the call to an intercept operator at the CIB. In areas where AIS has been installed, intercept files may be updated immediately via teletypewriter or data link channels. This leads to more timely and more accurate information.

Recorded words and phrases, including numbers, are supplied by a 96-track announcement machine. Again, there are two announcement machines for reliability. The output of each track can be connected to customer lines through the switching network.

The locations of the recorded numbers, words, and phrases are stored in the central processor, which selects the items required for an announcement in the proper sequence for the particular intercept situation. Timing pulses from the announcement machines are synchronized with the start of each

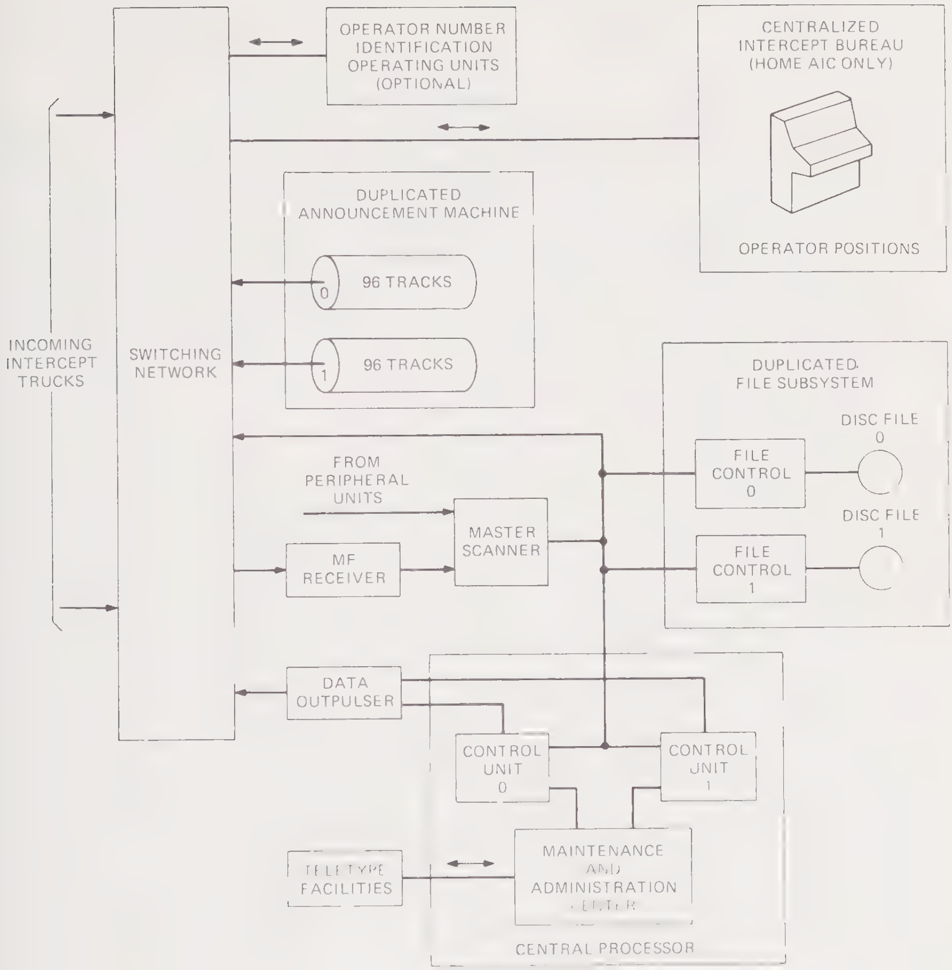


Fig. 9-39. Automatic Intercept Center

recording, and the processor uses these to change connections from one word to the next in handling a call. The design of the central processor is the same as that developed for the No. 2 ESS, and many of the equipment units have been adapted from Electronic Switching System designs. The program structure and maintenance strategy closely follow those of the No. 2 ESS.

The intercept file represents a large data base that requires frequent updating. A typical installation may have as many as 500,000 records and may require as many as 18,000 changes per day. A new minicomputer File Access System (FAS) provides for efficient updating and for an off-premises backup of the entire file.

9.7 PRESENT SITUATION AND TRENDS

Local switching is characterized by a large existing plant undergoing linear growth of about 2 million lines per year and local traffic increasing at a yearly rate of 5 percent. Most of the equipment in use today is Step-by-Step and No. 5 Crossbar; however, the trend is toward Electronic Switching Systems for both growth and modernization. Toll traffic has been increasing at a yearly rate of about 10 percent, double the rate of increase for local traffic, but the volume, of course, is much lower. Today, No. 4 Crossbar and Crossbar Tandem meet most of the toll switching demand. In the field of operator services, a large force is required to meet demand. Automation, changes in the rate structure, and efficient use of personnel will tend to keep the size of the operating force under control.

9.7.1 LOCAL SWITCHING

Table 9-4 shows the census of local switching systems used in the Bell System as of January 1, 1976. Today, Step-by-Step equipment is an important part of the local network; over 60 percent of the systems are Step-by-Step, and 33.9 percent of all Bell System lines are served by Step-by-Step Systems. Panel and No. 1 Crossbar Systems have the highest average number of lines per system; this reflects their design for application in large metropolitan areas. No. 5 Crossbar serves the greatest number of lines of the systems listed and is second only to the Step-by-Step community dial offices (CDOs) in number of systems. In the future, demand for new local switching is expected to grow at a lower rate than the demand for new toll switching. However, because the average age of local switching systems is greater than toll switching equipment, many new local installations will be caused by retirements of existing systems. In general, new installations will be Electronic Switching Systems, thus allowing the introduction of services such as call waiting, call forwarding, and speed calling. Use of ESS will result in more flexible routing and office code usage, savings in floor space, and less maintenance expense.

9.7.2 TOLL SWITCHING

Table 9-5 shows the census of toll switching systems installed as of January 1, 1976, their class, and the amount of traffic switched by each. Seventy-nine percent of the present Bell System toll switching (in CCS BH) is done by 177 No. 4 Crossbar and 210 Crossbar Tandem switching systems. These are located in major metropolitan areas. About 20 percent of toll switching is done by 702 Step-by-Step and No. 5 Crossbar combined local-toll systems. These serve more sparsely populated areas, where demand is too small to warrant a larger capacity No. 4 Crossbar or Crossbar Tandem system. The No. 4 Crossbar Systems now switch over 55 percent of the toll load. Because of their capabilities (e.g., large capacity, 4-wire network, and electronic translation), No. 4 Crossbar, No. 1 ESS toll, and No. 4 ESS are expected to handle most of the toll growth.

TABLE 9-4
CENSUS OF LOCAL SWITCHING SYSTEMS
(JANUARY 1, 1976)

TYPE OF SWITCHING SYSTEM	NUMBER OF SYSTEMS	PERCENT OF TOTAL SYSTEMS	TOTAL LINES (MILLIONS)	PERCENT OF TOTAL LINES	AVERAGE LINES PER SYSTEM
Step-by-Step	1669	16.8	18.3	27.0	10,950
CDO (Step-by-Step)	4388	44.0	4.7	6.9	1070
Panel	55	0.6	0.9	1.3	16,300
No. 1 Crossbar	310	3.1	6.7	9.9	21,600
No. 5 Crossbar	2700	27.2	26.5	39.2	9800
No. 1 ESS	637	6.4	9.8	14.5	15,400
No. 2 ESS	185	1.9	0.8	1.2	4330
TOTAL	9944	100.0	67.7	100.0	6800

TABLE 9-5
TOLL SYSTEM CENSUS AND UTILIZATION
(JANUARY 1, 1976)

TYPE	CLASS				TOTAL	SWITCHED CCS/BH (MILLIONS)	PERCENT OF TOTAL CCS/BH	AVERAGE SIZE IN CCS/BH (THOUSANDS)
	1	2	3	4				
No. 4 Crossbar	10	63	86	18	177	14.4	55.6	81
Crossbar Tandem	0	4	101	105	210	6.1	23.5	29
No. 1 ESS	0	0	2	21	23	0.2	0.8	8.7
No. 5 Crossbar	0	0	41	300	341	2.5	9.7	7.3
Step-by-Step	0	0	3	358	361	2.7	10.4	7.5
TOTAL	10	67	233	802	1112	25.9	100.0	

9.7.3 OPERATOR SERVICES

Today, operator services in the Bell System require a force of about 150,000 people, with an annual expense of over 2 billion dollars. Sixty-one percent of the present operator positions handle toll traffic, and the remaining 39 percent provide various number services. Most toll positions are switchboards, but 32 percent of toll positions are TSPS positions. Fig. 9-40 shows the present operator facility positions.

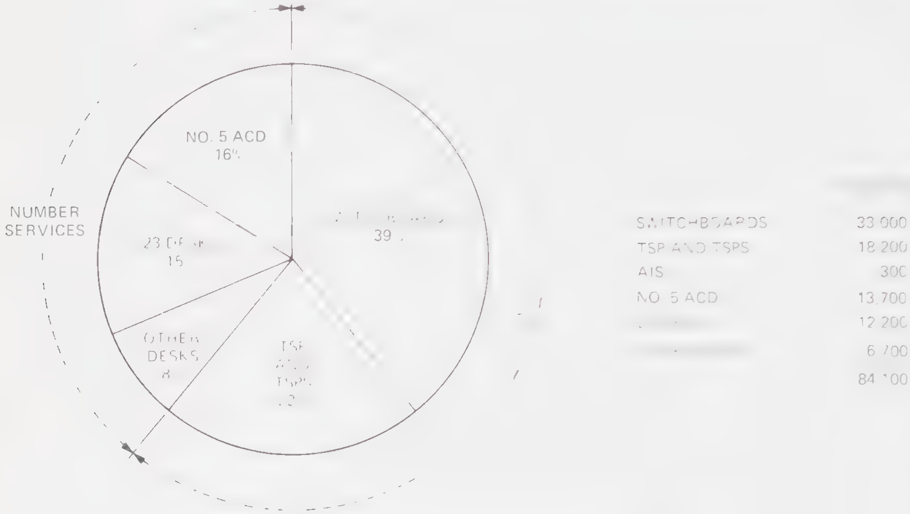


Fig. 9-40. Distribution of Present Operator Facilities

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10 Transmission Systems

This chapter provides a reasonably complete summary of the transmission systems now used in the Bell System and includes some history of their evolution. An extensive list of references is provided at the end of the chapter as a guide to supplementary reading.

10.1 LOOP TRANSMISSION

A loop connects each telephone customer to a central office. The loop must be capable of handling 2-way voice-frequency communication (either voice or data) and also of handling the ringing signal and signals generated by the telephone for controlling the switching mechanisms in the central office. Loops must be ready for use at any time, even though they are idle a large percentage of the time. Loops must be inexpensive to install and maintain, they should require a small amount of physical space, particularly in urban areas, and they must be readily accessible to accommodate changes in service and in customers.

The loop between the central office and the customer usually consists of a 2-wire pair that forms a transmission line and, throughout most of its length, is in a cable containing many pairs. The two wires are twisted about one another and operated in an electrically balanced mode with respect to ground to improve their transmission properties.

10.1.1 PHYSICAL DESCRIPTION OF THE LOOP PLANT

The interface between the loop plant and the central office switching equipment is a cross-connecting facility known as the *main distributing frame* (MDF). Section 11.2 gives a description of the functions and characteristics of the MDF, and Fig. 6-23 shows its location relative to other systems.

Loop cables generally leave the central office in underground conduits. The conduit systems provide physical protection for the cables and also allow new cables to be added inexpensively along a route over a long period of time without having to dig up the streets each time a new cable is placed. The conduit systems are usually multiple-duct structures with standardized duct diameters. Ducts with diameters of 3-1/4 or 3-1/2 inches have been extensively used. More recently, a standard 4-inch diameter has been adopted, and all new installations employ this size. The duct diameters are the principal factors determining the maximum number of cable pairs that can be placed in a cable sheath. Cables used in underground conduit systems are nearly always stalpeth-sheathed,[1] with each conductor insulated with a paper-pulp mixture and with pairs grouped into units of 50 or 100 pairs. Typical cables consist of 2700 pairs of 26-gauge, 1800 pairs of 24-gauge, or 110 pairs of 22-gauge copper conductors, with a nominal mutual capacitance of 0.083 μF mile.

The principal hazards to which underground cables are subjected are the entrance of water and careless digging by workers of other utilities, building contractors, and highway construction crews. Water can enter underground cables through defects or improperly installed splice closures. The entry of any significant amount of water into the core of pulp-insulated cables will render a large number of the circuits inoperative. To help keep out water, dry air under 10 lbs/in.^{2} pressure is pumped into most of these cables by air dryers installed at the central office. These systems are designed so that air pressure anywhere along the cable is sufficient to prevent water in a flooded manhole from entering the cable through a small sheath defect.

Because of their high weight per unit length and the need to branch frequently along the route, underground feeder cables usually are placed in lengths just sufficient to span adjacent manholes. Manhole spacings vary from 400 feet to 700 feet in metropolitan areas. Branching off from the main underground feeder cables are first the branch feeder and then the distribution cables that extend to the customer's premises. These cables generally contain fewer pairs than the main feeder cables (fewer than 900 pairs for branch feeders; fewer than 300 pairs for distribution cables). These cables may be placed aerially on poles or may be buried without the use of conduit. Branch feeders differ only in size and perhaps gauge from main feeders.

Until recently, much of the distribution cable plant was aerial and consisted of lead-sheathed, pulp-insulated conductors equipped with hermetically sealed terminals to provide connection points between the individual cable pairs and the aerial drop wires extending to customers' premises. The hermetically sealed terminals are required to keep moisture out of the cables. Most aerial cables are placed on poles in close proximity to power lines, and safe practices had to be developed for joint occupation of pole-line routes by power and telephone company cables.

Aerial plant presents several difficulties to telephone engineers. The cables are subjected to wide temperature variations (taken as +140°F to −40°F), to lightning and storm damage, to man-made damage, and to possible contact with power conductors. Contact with a power line may result in arcing and burning through of the cable sheath and the placing of potentials on telephone cables sufficient to damage other equipment in the telephone system.

1. A type of telephone cable sheath having a corrugated aluminum tape applied longitudinally without overlap over the core, followed by a corrugated steel tape applied longitudinally with a soldered seam, then a polyethylene jacket overall.

To avoid the latter problem, protective equipment must be placed in the central office and at the customer location.

Hermetically sealed terminals are expensive and costly to install. The advent of polyethylene-insulated conductor (PIC) cables in the mid-1950s opened the way for radical innovations in distribution plant design. PIC cables are color-coded for easy identification and, unlike pulp-insulated cables, do not require hermetically sealed covers for satisfactory operation. Since sealed distribution terminals are not required, a family of ready-access terminals was developed for use with PIC cables. No attempt is made to prevent humid air from entering the ready-access terminal or the cable core. PIC distribution cable and ready-access terminals have become Bell System standards during the past decade, bringing with them significant hardware economies. Unfortunately, the ready-access terminal has made pair access so easy that in some situations these terminals have been subjected to excessive activity. This excessive activity has complicated maintenance and administration and has increased upkeep costs.

The susceptibility of aerial cable to storm and vehicular damage, as well as aesthetic considerations, has caused the telephone companies to expand their programs of burying cables in the distribution plant. Implementation of this program has required the development of a family of trenchers and plows, a new "waterproof system" of telephone hardware, and a new design called the *serving area concept* (SAC). The waterproof system now available to the field consists of special cable, closures, and connectors that are all filled with grease-like compounds to prevent the entry of water. The serving area concept also is applicable to aerial plant.

In SAC design, a region is divided into serving areas containing 350 to 600 living units. A feeder/distribution interface (FDI) is used in each serving area between the feeder and distribution network, and most craft force activity takes place at this point. The distribution cable in a serving area is sized for the ultimate expected service demand, with a minimum of two pairs per living unit, whereas feeder cables are added as needed.

In a simplified view of SAC, a typical loop can be summarized as follows: large cables leave a central office via underground conduit, connection is made to smaller buried feeder cables which enter an FDI, distribution cables leave the FDI and enter pedestal (if access is needed) or buried closures, where pairs are connected to buried service wires (analogous to drop wires) extending to a customer's living unit. On the customer's premises, the service wires terminate at a station protector, and inside wiring is run to the telephone set (the 500-type set is the system standard). See Fig. 10-1.

10.1.2 LOOP TRANSMISSION CHARACTERISTICS

The telephone or data set converts the information to be transmitted into an appropriate electrical signal. It is the function of the 2-wire transmission line to convey this signal to a central office where the line may be switched or

Fig. 10-1. Physical Layout of the Loop Plant

permanently connected to another circuit over which the signal is transmitted to its destination.

Ideally, the signal arriving at the central office should be an exact replica of the transmitted signal. It is well known that ideal transmission occurs when the relative amplitudes and phases of transmitted sinusoids are received unchanged. However, the transmission medium does indeed affect the amplitudes and phases of transmitted sinusoids, and signal distortion results. In addition, the cable pair is in close proximity to other circuits, and energy from signals on these other circuits may be coupled into the pair, resulting in noise and even intelligible conversations. This phenomenon is known as *crosstalk*.

Other types of interference to which telephone cables may be subjected include that from power lines, radio broadcast stations, and electrical machinery. The transmission circuit therefore must be designed to give low distortion to the telephone signal, while giving high immunity against crosstalk and noise. The use of a balanced twisted pair results in acceptable transmission at voice frequencies and is economical. However, although capacitive coupling into a balanced twisted pair is low, the mutual pair capacitance is large since the wires are close together. As will be shown, this capacitance causes high loss at high frequencies.

The electrical behavior of wire lines can be determined from their four primary constants. These are resistance per unit length (R), inductance per unit length (L), conductance per unit length (G), and capacitance per unit length (C). The series resistance per unit length represents loss in the wire conductors, whereas the shunt conductance per unit length represents loss in the insulation surrounding the conductors. At high frequencies, the four primary constants are themselves functions of frequency, but at voice frequencies they may be assumed constant. Table 10-1 shows how each of these quantities may be computed for a given frequency for pulp-insulated cable in the different wire gauges in common use. Fig. 10-2 shows how the four primary constants are used in an equivalent circuit that models a small length of transmission line.

TABLE 10-1*
PRIMARY CONSTANTS FOR TRANSMISSION LINE EQUIVALENT CIRCUIT (PULP-INSULATED CABLE)

CABLE GAUGE	PRIMARY CONSTANT†	A	B	C	D	N	P
19	R	86.0	0.1921×10^{-3}	0.5936×10^{-8}	0	0	0
22		173.0	0.1471×10^{-3}	0.342×10^{-8}	0	0	0
24	ohms/mile	274.0	0.3151×10^{-4}	0.6165×10^{-8}	0	0	0
26		440.0	0.1271×10^{-4}	0.3545×10^{-8}	0	0	0
19	L	0.8925×10^{-3}	0	0	0	-0.617×10^{-6}	0.3408
22		0.8744×10^{-3}	0	0	0	-0.2077×10^{-6}	0.4409
24	henrys/mile	0.9539×10^{-3}	0	0	0	-0.383×10^{-6}	0.3366
26		0.9957×10^{-3}	0	0	0	-0.311×10^{-8}	0.7333
19	G	0.84×10^{-7}	0	0	0	0.5983×10^{-10}	1.426
22		0.82×10^{-7}	0	0	0	0.584×10^{-10}	1.426
24	mhos/mile	0.84×10^{-7}	0	0	0	0.5983×10^{-10}	1.426
26		0.79×10^{-7}	0	0	0	0.5626×10^{-10}	1.426
19	C	0.845×10^{-7}	0	0	0	-0.1052×10^{-9}	0.2335
22		0.825×10^{-7}	0	0	0	-0.1028×10^{-9}	0.2335
24	farads/mile	0.845×10^{-7}	0	0	0	-0.1052×10^{-9}	0.2335
26		0.795×10^{-7}	0	0	0	-0.99×10^{-10}	0.2335

* From "Transmission Data for Exchange Area Cable," Transmission Section, Vol 104, AT&T Transmission Department, 1962.

† Primary Constant $= A + Bf + Cf^2 + Df^3 + Nf^P$, where f = frequency in Hertz.

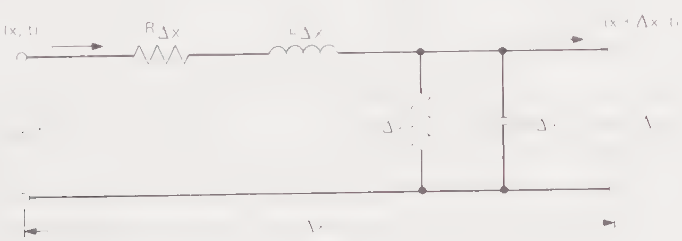


Fig. 10-2. Circuit Model of a Small Length of Cable

The circuit model of Fig. 10-2 may be used to derive a pair of differential equations relating the current and voltage along the line. If the line is infinitely long or is terminated in an appropriate impedance, the voltage at distance x is given in terms of the voltage at distance zero by

$$V(x) = V_o e^{-\gamma x}. \qquad (1)$$

γ is called the propagation constant and is given by:

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta. \tag{2}$$

The real part of γ is called the *attenuation constant*, α (nepers per unit length), and the imaginary part of γ is called the *phase constant*, β (radians per unit length). The voltage expression shows that a sinusoid of radian frequency ω and amplitude V at the distance $x = 0$ will be reduced in magnitude by the factor $e^{-\alpha x}$ and shifted in phase by $-\beta x$ radians at distance x. γ may be computed if R, L, C, and G are known at the required radian frequency ω. In the voice-frequency range up to 4 kHz, $R >> \omega L$ and $\omega C >> G$. Hence,

$$\gamma \approx \sqrt{j\omega RC} = (1 + j)\sqrt{\frac{\omega RC}{2}}. \tag{3}$$

Thus, for voice frequencies, the attenuation and phase constants are of equal magnitude and vary as the square root of frequency. Also, for small attenuation, both R and C should be as small as possible.

10.1.3 LOAD COILS

The expression for γ may be used to derive a relationship between the primary constants which, if satisfied, will ensure distortionless transmission (that is, α constant with frequency and β proportional to frequency). If R, L, G, and C are constant in the voiceband, and if $RC = LG$,

$$\gamma = \sqrt{(R + j\omega L)\left[\frac{G}{R}\right](R + j\omega L)}$$

$$= \sqrt{\frac{G}{R}}\,(R + j\omega L) = \sqrt{RG} + j\omega\sqrt{LC} \tag{4}$$

and distortionless transmission results.

Unfortunately, the primary constants of exchange cable do not have the relationship required to produce distortionless transmission. In fact, $RC >> LG$. In attempting to achieve the desired relationship, it is not desirable to increase G since an increase in attenuation will result [see equation (4)]. on the other hand, decreasing R requires too much copper. While increasing L has many difficulties, it has been found to be the most practicable approach. The effective distributed inductance can be increased by placing lumped inductances called *load coils* periodically along the cable. This method effectively increases the distributed inductance for low frequencies and results in more nearly ideal transmission performance from the cable. However, at higher frequencies, the cable is essentially capacitive, and the lumped inductances cause the line to behave like a low-pass filter with a cutoff frequency of $(\pi\sqrt{L'C'})^{-1}$, where L' is the inductance of the load coil and C' is the total shunt capacitance of the cable between load coils.

Loading schemes used in the Bell System are catalogued with a letter to indicate the spacing between successive load coils, followed by a 2-digit number to indicate the value of inductance used. *H88 loading* means that 88-mH coils are separated by 6000 feet of cable. Fig. 10-3 shows the insertion loss (related to attenuation) for loaded and nonloaded cable. Fig. 10-4 compares the effects of loading using different values of inductance and with different distances between load coils. The smaller the separation of the load coils, the larger the bandwidth obtained (C' is smaller); the use of a larger inductance results in a smaller attenuation. In the Bell System, 85 percent of all loaded loops are the H88 type, and the remaining loaded loops are H44 type.

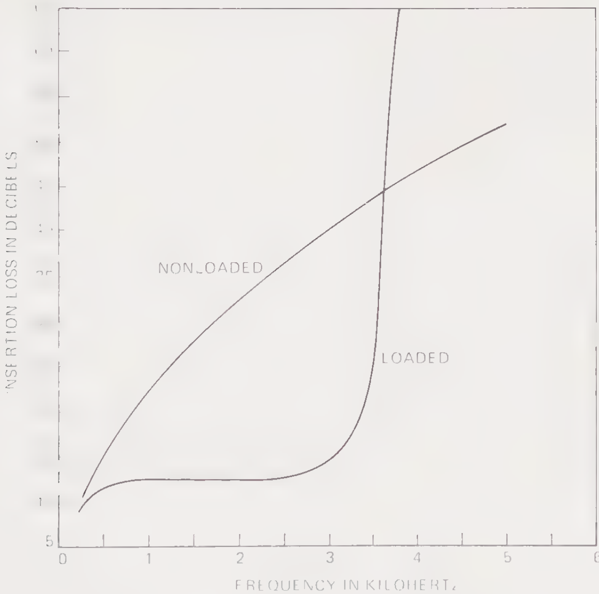
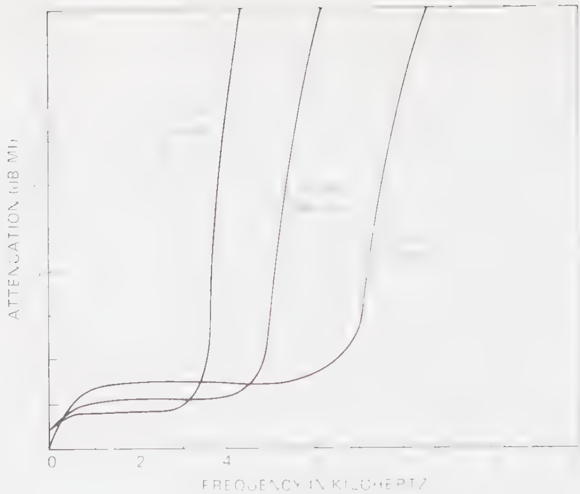
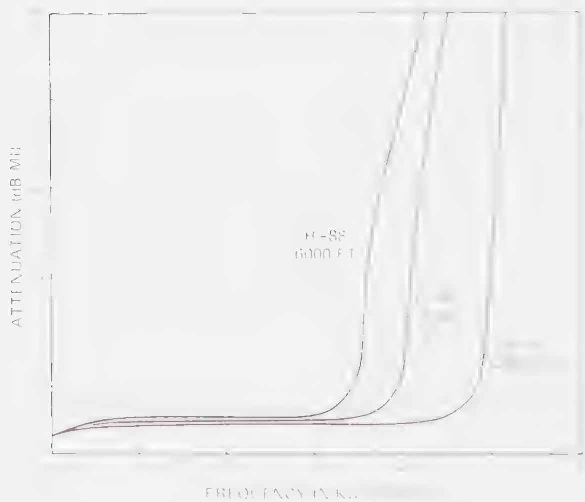


Fig. 10-3. Effect of Loading on 54 Kilofeet of 24-Gauge Cable

It is possible for a cable to be improperly loaded. In order to facilitate association of party-line customers in the outside plant, a long-time telephone company practice has been to provide for multiple appearances of the same cable pair at many distribution points and branch feeder cables. These multiple appearances (which are not in the direct current path between central office and customer) are called *bridged taps.* Fig. 10-5 shows the violent swings in loss versus frequency that are characteristic of a loaded loop containing a loaded bridged tap. To avoid such a characteristic, rules have been established that limit the length of loaded or nonloaded bridged taps associated with a given customer. These rules are covered in Table 10-2.



(a) EFFECT OF LOAD COIL INDUCTANCE



(b) EFFECT OF LOAD COIL SPACING

Fig. 10-4. Effects of Load Coil Inductance and Spacing on Attenuation

10.1.4 SYSTEMS OF LOOP DESIGN

Various methods of loop design are in use in the Bell System. These include resistance design, long-route design, and Unigauge design. These different systems of design attempt to cost-optimize the layout of the loop cable plant and are described in the following paragraphs.

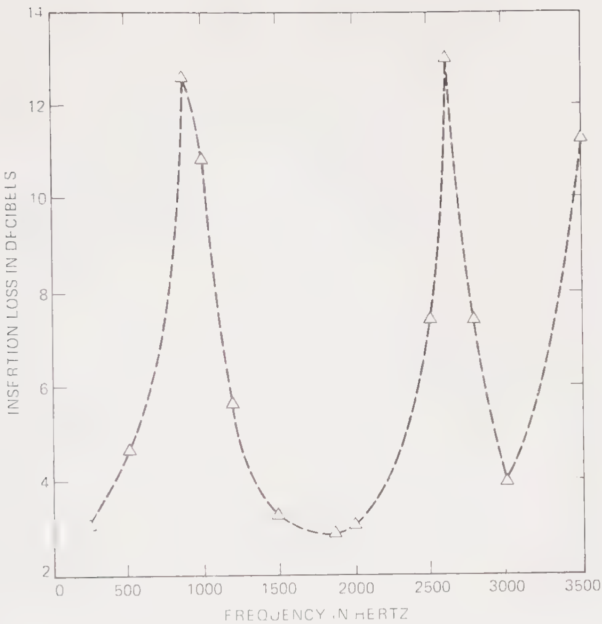


Fig. 10-5. Insertion Loss of Loop With Loaded Bridged Tap

At present, resistance design is the most generally used system. The prescription is to use the finest-gauge cable that will produce a loop cable resistance of less than 1300 ohms. This resistance limitation, together with loading and bridged tap rules, controls the transmission loss. The 1300-ohm limit ensures that central office signaling and supervisory equipment (including the Step-by-Step type) will function on the loops. Resistance design rules are given in Table 10-2 and are shown schematically in Fig. 10-6, which also shows the maximum-length loop that can be provided with each cable gauge. Mixed gauges are used to produce loops of intermediate lengths.

The maximum-length loop that can be designed using resistance design rules is 75 kilofeet. A small fraction of telephone customers are located more than 75 kilofeet from a central office. Many existing central offices cannot detect dial pulsing and on-hook or off-hook signals on loops whose resistance exceeds 1300 ohms. Furthermore, the transmission loss on such loops is at best only marginally acceptable. For these reasons, telephone companies have used various devices to serve loops whose length exceeds the resistance design limit. Long-route design is a codification of those practices. The motives behind establishing long-route design rules are to bring the transmission loss statistics under control, to permit a long loop to be designed by prescription, and to save inventory, administrative, and training costs by reducing the number of equipment types used, thus standardizing the loop electronics. The major long-route design rules are summarized in Table 10-3.

TABLE 10-2
LOOP LAYOUT RULES
(RESISTANCE DESIGN RULES)

(1) Loop resistance should not exceed the central office signaling and supervisory limit or 1300 ohms.

(2) On all loops of 10 kilofeet or longer, 500-type telephone sets should be used rather than older types.

(3) No bridged tap longer than 6 kilofeet should be used on nonloaded loops.

(4) All loops of 18 kilofeet or longer should be loaded.

(5) (a) H88 loading should be used.

  (b) Load spacing deviation should not exceed 500 feet.

  (c) Central office end section should equal 3 kilofeet.

  (d) Customer end section plus bridged tap should equal at least 3 kilofeet, but not exceed 15 kilofeet.

  (e) No bridged taps should be connected between load coils.

  (f) No loaded bridged taps should be used.

An objective measure of the acceptance of long-route design is the sales record of the hardware used to implement it. Sales of the 2A range extender are about 100,000 per year. Over the period from its introduction in early 1972 to August 1973, sales of the range extender with gain (REG) were almost 70,000. Thus, acceptance for the treatment of zones 16 through 28 (1300-ohm to 2800-ohm loop resistance) appears to be good. Zone 36 (2800-ohm to 3600-ohm loop resistance) treatment has not been well received because a field-mounted repeater cabinet has been required. In some divisions, this treatment is barred entirely; an alternative is the use of larger size wire, although this is not economically attractive. Recently, a new handset with 3-dB gain, which has eliminated the need for a repeater, has made zone 36 treatment attractive.

The wide use of resistance design for loops has resulted in widespread appearance of four gauges of cable in the loop plant. The use of coarse cable involves a huge expense for the Bell System. It is estimated that if all applications currently requiring 19-, 22-, and 24-gauge cable could be served instead by 26-gauge cable, one hundred million pounds of copper would be saved annually. Unigauge design has as its object the replacement of coarse-gauge cable requirements with 26-gauge requirements.

The cost advantage of Unigauge design is not limited simply to a reduction in the amount of copper required by the Bell System. There are basic engineering and placing costs associated with the installation of any cable, and consequently the larger (in number of pairs) the cable placed, the lower the cost of each cable pair. Furthermore, a simplification of outside plant en-

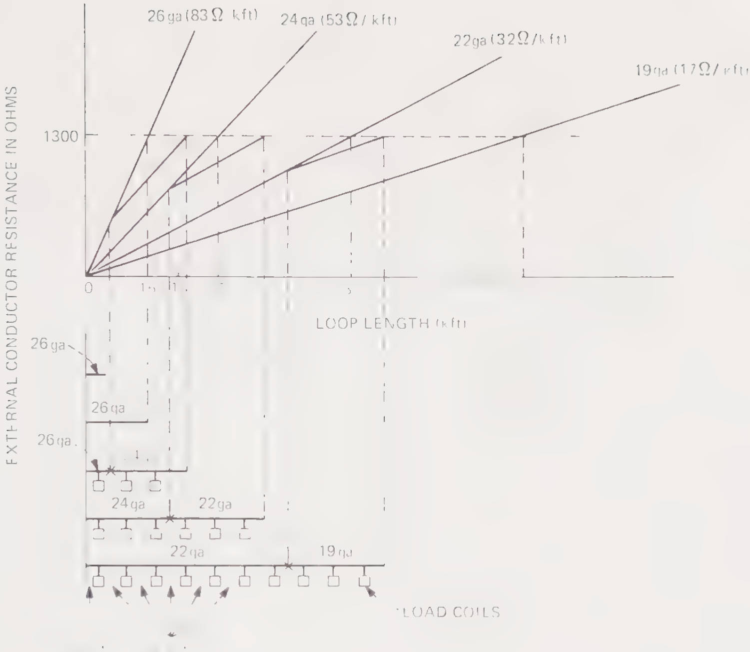


Fig. 10-6. Resistance Design Procedure

gineering is achieved, since it is necessary to engineer only a single gauge of cable plant. There is a reduction in inventory and supply expense since spare facilities need only be provided in a single gauge. Finally, the underground conduit system is used more efficiently because with 26-gauge cable a greater number of cable pairs can be placed within a cable sheath and, consequently, more cable pairs per duct can be provided.

In its basic form, Unigauge design extends the application of 26-gauge cable to all loops within 30 kilofeet of a central office. Thus, 96.7 percent of all loops can be served with a single gauge of cable (see Fig. 10-7). Extending the use of 26-gauge cable to 30-kilofoot loops does, however, introduce important signaling and transmission problems. Range extension circuits must be used to extend the office range from the present 1300-ohm limit to a 2500-ohm limit, and transmission loss and frequency distortion must be reduced by compensating networks with gain.

In order to realize the fullest economic advantage from the Unigauge concept, it is desirable to share the required voice-frequency electronics among groups of lines. Only in common-control switching systems can this be accomplished practically.

The line diagram of the recommended Unigauge plant configuration is shown in Fig. 10-7. Note that a 72-volt battery is used on all loops longer than 15 kilofeet, instead of the normal 48-volt battery. Furthermore, 5 dB of midband gain is used with equalization included for these long unloaded

TABLE 10-3
LONG-ROUTE DESIGN RULES

RESISTANCE ZONE	CONDUCTOR RESISTANCE RANGE (OHMS)	GAIN REQUIRED	SIGNALING AID REQUIRED	NOTES
13	0-1300	None	None	
16	1300-1600	None	2A Range Extender	1,2
18	1600-2000	4 dB: REG	REG	3
28	2000-2800	6 dB: REG	REG	3,4
36	2800-3600	9 dB: E-6 Repeater or	Dial Long Line	5,6
		6 dB: REG and 3 dB: handset	REG	6

Notes

1. Step-by-Step and Crossbar offices only.
2. No more than 12 customers per kilofoot allowed.*
3. May use E-6 repeater plus dial long line circuit instead.
4. No more than 12 customers per kilofoot allowed between 2500 and 2799 ohms.*
5. Repeater must be between 1000 and 1250 ohms from office.
6. No more than 12 customers per kilofoot allowed between 3300 and 3600 ohms.*

* To limit proportion of calls having two such loops (relatively poor transmission).

loops. Modified H88 loading is used on loops longer than 24 kilofeet, with the first load coil located 15 kilofeet from the central office. Some additional rules must be followed concerning the lengths of bridged taps associated with any given loop.

Unigauge design is optimum for areas where a substantial number of customers are located between 15 kilofeet and 30 kilofeet from the central office and where the number of special-service circuits (such as private lines, foreign exchange lines, PBX trunks, and PBX tie trunks) is very limited. Residential suburban areas are likely candidates.

10.1.5 CARRIER SYSTEMS FOR LOOPS

A most pressing problem in many areas of the Bell System is providing economical service on long loops. A survey of loops in 1964 showed that 1.5 million, or 3.25 percent of all Bell System customers, were served by loops

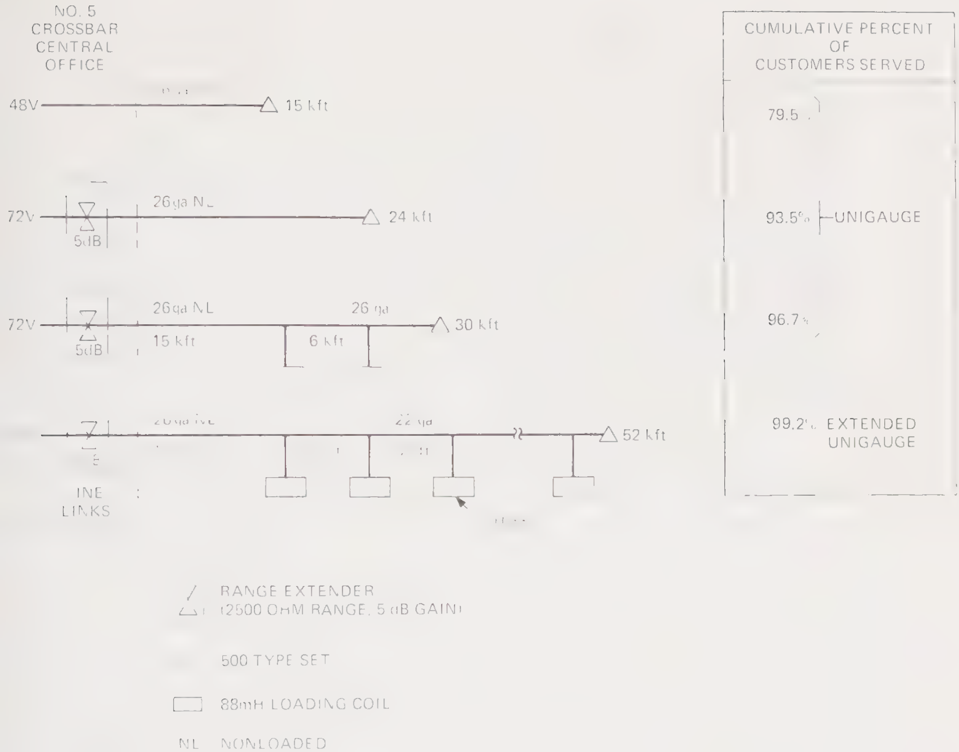


Fig. 10-7. Unigauge Loop Layout

exceeding 30 kilofeet in length. These 3.25 percent of the customers used only 1.7 percent of the working Bell System loops, but accounted for 11.2 percent of the total outside plant investment. In other words, a lot of money was spent on these loops compared with the small proportion that they represented. This disproportionate expense was due to special engineering and plant effort and to the greater amount of plant required.

Economic factors are not the only causes for the Bell System's search for alternative means of providing rural route service. The transmission performance of long loops with respect to noise and loss is decidedly inferior to that of general loops. The system objective for 1-kHz insertion loss is a maximum of 8 dB. Thirty-nine percent of long-loop subscribers are served by lines whose insertion loss at 1 kHz exceeds 8 dB; the corresponding percentage for general loops is 5 percent.

Noise problems in the long-loop segment of the outside plant also are considerably more severe than in the general loop plant. One of the major reasons is that because of the high cost of long loops, a higher degree of party-line development has occurred than in the general plant. Thus, long loops frequently have grounded ringers with attendant poor circuit balance. Forty-seven percent of long loops have noise that exceeds the 20-dBrnC objective set for Bell System loops. The increasing tendency away from party lines and the desire to upgrade service and transmission performance constitute another impetus for the development of new long-loop transmission plans.

One approach generally used to alleviate the problems mentioned above involves pair-gain systems. These systems place more than one customer on a single pair of wires and may be divided into two categories: those with concentration and those without concentration. Systems without concentration dedicate a transmission channel to each customer, whereas concentration (blocking) systems provide nondedicated channels. The probability of blocking is then a function of the load offered to the system by the customers and should be taken into account when installing and maintaining such a system. A concentrator is basically a switch that has more input lines than output lines and provides access by the input lines to some or all of the output lines; consequently, it is a blocking device. If telephone traffic is not too heavy in a given area, a concentrator-type system may be employed to forestall cable relief on a route. Where traffic patterns are heavy, nonblocking pair-gain systems must be used. Both analog frequency-division-multiplex (FDM) systems and digital time-division-multiplex (TDM) systems fall into this category; several customers are multiplexed onto a single pair of wires.

10.1.6 OBJECTIVES FOR LOOP CARRIER SYSTEMS

For many years, performance objectives for loops were limited to those parameters most essential for intelligibility and quality of speech transmission. Although loss and noise criteria are specified, as noted previously, loop objectives usually have been implied through proper design of the cable plant (e.g., resistance design rules contain restraints on bridged-tap length and loaded-line length). Now, however, the use of electronics in the loop plant necessitates the establishment of a comprehensive set of well-defined transmission objectives. This work is under way.

It is important to note that trunk objectives are not applicable to loop carrier systems. Trunk objectives are designed to yield a given grade of service on a certain fraction of calls. Thus, trunk objectives are set on groups of trunks, and although occasionally a connection may be poor, a customer normally gets a good connection. On the other hand, a loop is dedicated to a particular customer, and hence bounds must be set on the performance of individual loops to ensure that each customer receives satisfactory service.

10.1.7 IMPLEMENTATION OF LOOP CARRIER SYSTEMS

10.1.7.1 Analog Systems

Fig. 10-8 is a block diagram of an analog carrier system representative of those in use on loops. Note that hybrid circuits at the customer's line appearance at the central office and at the customer's telephone set separate the signals moving in opposite directions. These hybrids are necessary because the received and transmitted energies must be separated for processing in the modems and must be recombined for the central office line appearance and the customer's telephone set. (This procedure is of course unnecessary in nonrepeatered baseband telephone circuits.) In Fig. 10-8, high-pass and low-pass filters are used to isolate the transmitted and received energies at the central office, since both appear simultaneously on the same wire pair. The received energy is at quite a low level because it has been attenuated by the transmission medium, but the transmitted energy is at a high level; the filtering must be adequate to ensure that the transmitted energy does not block the receiver or affect its operation. A bandpass filter in the modem for each channel extracts the information belonging to that channel.

Another system component not generally found in baseband telephone loops is the analog repeatered line. Fig. 10-8 shows that repeater circuits are placed at discrete locations along the length of the transmission pair. These circuits restore the transmitted signal, which has been attenuated and distorted in traversing the transmission path.

10.1.7.2 Digital Systems

Fig. 10-9 is a block diagram of a digital carrier system representative of those used for loop transmission. As in the case of the analog systems, hybrid circuits are necessary to separate and combine the transmitted and received energies that are processed in different portions of the modem. In transmission, the modem acts upon preconditioned (amplified, band-limited, etc.) input signals to produce a digital encoding of the analog signals at prescribed time instants. The binary signals representing the sampled analog inputs are then sent on the transmission line in a prescribed sequence by the multiplexer. At the receiver, a demultiplexer must be synchronized with the transmitting multiplexer so that the received pulses may be detected and routed to the appropriate channel. The synchronization scheme and circuitry of the digital system are analogous in function to the frequency-division scheme and bandpass filters of an analog system. The synchronization circuits are shared by all channels in a digital system.

In contrast to analog loop systems, digital systems usually use two 2-wire pairs, each pair being dedicated to a particular direction of transmission. The signal transmitted over each pair occupies half the bandwidth of the signal that would have been necessary if a single pair had been employed for both directions of transmission. Generally, the choice of two pairs rather than one pair for transmission in digital systems results in considerable economic savings. As shown in Fig. 10-9, a digitally repeatered line connects the central office with the customer.

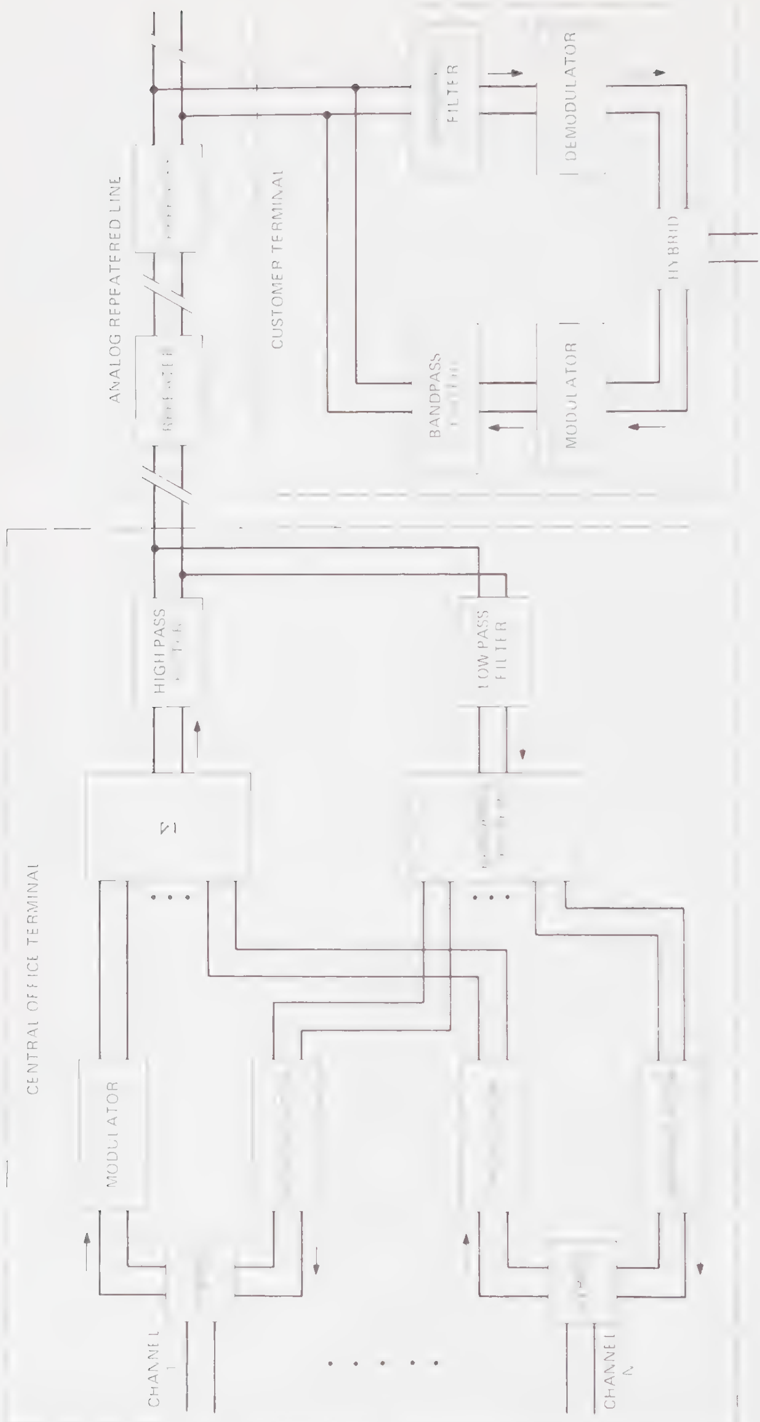


Fig. 10-8. Analog Loop Carrier System

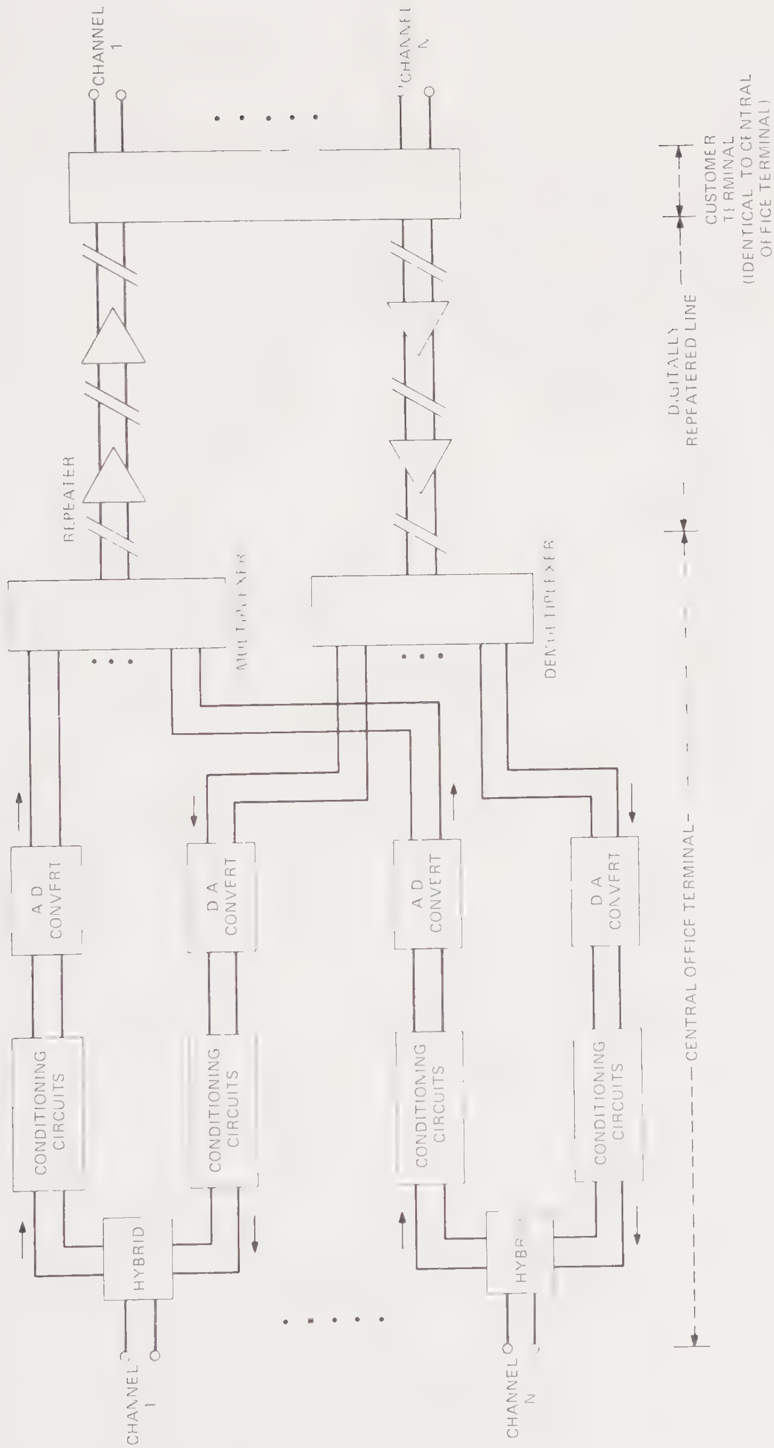


Fig. 10-9. Digital Loop Carrier System

10.1.8 AVAILABLE CARRIER SYSTEMS FOR LOOPS

Several analog carrier systems are presently in use in the Bell System loop plant. These include single-channel, 6-channel, and 8-channel systems. All are double-sideband amplitude-modulation systems.

The single-channel carrier systems enable a second circuit to be carried on an existing physical wire pair. Use of presently available single-channel carrier systems is restricted to locations within 15 kilofeet of the central office (with 26-gauge cable). A new system, SLC-1, available in 1975, contains a compandor allowing use within 18 kilofeet of the central office. These systems may not be used on loaded lines, so that 18 kilofeet is the maximum range, even if lower than 26-gauge cable is available for the physical pair. Single-channel systems find application when deferment of a new cable is desired or the added line is to be temporary.

Eight-channel systems having frequency allocations from 8 kHz to 64 kHz and 88 kHz to 144 kHz in the opposite direction recently have become available. In more frequent use are 6-channel systems that occupy frequency bands from 16 to 56 kHz and 76 to 116 kHz. The ranges of these systems are limited by powering considerations to a 2000-ohm total dc loop resistance or by transmission requirements to 140 dB of total loss (three repeaters each separated by 35 dB of loss). Both systems find use on routes where the long-term cost of adding cable for relief exceeds the long-term cost of the required number of systems. Such routes can be identified by economic evaluation; typically, they are longer than 40 kilofeet.

The Subscriber Loop Multiplexer (SLM) is a digital carrier system that concentrates 80 subscribers onto 24 channels, which are then multiplexed onto two 2-wire pairs. The SLM employs a delta modulation scheme and T1 repeaters and has many automatic maintenance features. The system is suitable for use on routes where required cable or structure[2] relief would be expensive. Since a high initial cost is incurred with the SLM, it is applied to lumped situations where an immediate high fill can be obtained or where a high growth rate is expected. If an initial high fill justifies its use, the cost of accommodating new customers is very low. Since concentration is used, the traffic load cannot be too great or the system will not be able to be filled to its nominal line capacity and a higher cost per line will result.

The Subscriber Loop Carrier (SLC-40) is a digital carrier system providing 40 full-time speech channels between a central office terminal (COT) and a single remote terminal (RT) which may be either in an outside cabinet or rack-mounted for inside installation. Using T1-type digital repeater line facilities, the RT can be located up to 102 kilofeet from the COT on 22-gauge buried cable. The maximum separation of RT and COT is approximately 150 kilofeet without special power arrangements and up to 50 miles with the use of the remote power feed, originally designed for SLM. The RT can connect customers on cable pairs up to 900 ohms or 5 dB loss beyond the RT. This

2. Structure refers to poles or conduit.

results in a range of some 26 kilofeet on 22-gauge loaded cable and almost 50 kilofeet if 19-gauge cable is used. It also can be used over radio systems that handle T1-type transmission. The modulation and signaling are performed in per-line channel units which can be added as customer demand develops, thus minimizing common equipment. This results in a low start-up cost and makes the system economical in long-route, low-growth areas, as well as in shorter loop or higher growth areas where cable and structure relief are expensive. The system provides maintenance and alarm status information to the COT and has a simple, straightforward maintenance plan.

Although the carrier systems described in this section are designed for permanent use, operating companies sometimes install them in the loop plant as a temporary measure to defer additions, relieve budget pressure, or consolidate future projects. Carrier systems can be reused and are sometimes considered movable plant.

10.2 EXCHANGE TRUNK TRANSMISSION

10.2.1 TRANSMISSION IN THE EXCHANGE AREA

Historically, telephone transmission was divided in the minds of the general public into local and long distance service. Local calling seemed a simple, usual thing, the very essence of telephone service; long distance calling was unusual, appeared to involve special procedures, and was considered as something different. The technologies underlying local and long distance transmission originally involved differing constraints of usage, cost, etc. and therefore called for different principles and approaches. Over the years, technology has evolved so that similar solutions have been applied to problems in both areas. The distinction between local and long distance has thus become less clear, although one still tends to consider "exchange" situations or "toll" situations.

This section will show the evolving technology and operations that provide transmission services in local exchange areas. It will be seen that the term exchange trunk transmission can cover transmission facilities, used for local or toll public telephone service, or special services, and may involve transmission distances ranging from one mile or less to several hundred miles.

Exchange trunk transmission finds application in the following elements of the public telephone network:

(1) *Direct Trunks*—Trunks connecting central offices (class 5 offices). These trunks are generally within a relatively compact area that is served by a given toll center. Occasionally, they connect more distant end offices, especially where a substantial point-to-point traffic demand exists. (These are referred to as end office toll trunks.) Direct trunks have a median length of 8 to 10 miles and a median trunk-group size of 18 to 20 trunks. For a given central office, they are provided at a ratio of about one direct trunk for every 10 to 20 customer lines.

(2) *Toll-Connecting Trunks*—Trunks providing access from a central office to a toll center or office of higher rank. These trunks also have a median length of 8 to 10 miles and are provided at a ratio of about one trunk for every 40 to 70 customer lines.

(3) *Operator Trunks*—Trunks providing access to assistance operators. They are a form of toll-connecting trunk since they provide access from a central office to the toll network.

(4) *Metropolitan Intertoll Trunks*—Trunks connecting nearby class 4 toll centers or providing access from a class 4 toll center to nearby primary, sectional, or regional centers. Thirty-five percent of all intertoll trunks are less than 62.5 miles in length.

In addition to these applications in the public telephone network, the same types of facilities also are used for parts of special-service circuits.

Table 10-4 shows data from a recent sampling of exchange trunks from class 5 offices (not including intertoll trunks). The table shows how cross section (the number of trunks between a pair of buildings) and the distance between the two buildings are related. This data implies a certain constraint on the market for high-capacity exchange transmission systems. Specifically, cross sections become thinner as the distance between buildings increases. In nearly half of the cases in the sample, the distance between buildings is less than 10 miles, and in 80 percent of these cases, the cross section is less than 180 trunks. Achieving economies of scale in the exchange area by combining many channels together using multiplex techniques would at first glance seem to be possible only for short trunk lengths. Further economies of scale can be achieved by concentrating trunks into large-capacity backbone routes. This tends to be done naturally in large metropolitan areas (see Fig. 5-8) and is being further accentuated by present planning techniques.

In short transmission systems, the cost of the terminals is considerably greater than the transmission line costs. Therefore, unless terminals are very inexpensive per channel, simple baseband transmission on paired cable is the preferable method for these applications. For long exchange trunk routes, multiplex techniques prove economical, since line costs now become significant and multiplex techniques reduce the per-channel cost. At present, the economic breakeven point for baseband transmission on paired cable versus T1 digital carrier is about 8 miles, although this can vary considerably in any specific exchange area; there is no minimum economic length for trunks provided on T1 Carrier Systems that connect to a No. 4 ESS. In general, the small cross sections for long exchange applications dictate that multiplex transmission systems be designed for relatively modest channel capacity compared with those used in long-haul toll systems.

The Bell System exchange transmission plant has evolved subject to this constraint. As recently as 1963, over 75 percent of all trunks under 25 miles in length used voice-frequency facilities. For trunks between 25 and 50 miles in length, the ratio was reversed, with 75 percent involving some form of

TABLE 10-4
RELATIONSHIP OF DISTANCE BETWEEN TWO BUILDINGS
AND CROSS SECTION
FOR EXCHANGE TRUNKS FROM CLASS 5 OFFICES
(EXCLUDING INTERTOLL TRUNKS)

PERCENTAGE OF CASES IN EACH MILEAGE CROSS-SECTION BAND

		DISTANCE BETWEEN BUILDINGS (MILES)						TOTAL PERCENTAGE OF CASES IN EACH CROSS-SECTION BAND
		0 TO 5	5 TO 10	10 TO 15	15 TO 20	20 TO 25	OVER 25	
Cross Section (Number of Trunks)	Over 195	5.0%	3.4%	0.8%	0.2%	0.1%	0%	9.5%
	180 to 195	0.4	0.4	0	0	0	0	0.8
	160 to 180	0.4	0.7	0.2	0.1	0	0	1.4
	140 to 160	0.7	0.5	0.2	0	0	0	1.4
	120 to 140	0.9	1.1	0.2	0.1	0	0	2.3
	100 to 120	1.0	1.3	0.6	0.1	0	0	3.0
	80 to 100	1.1(M)	2.0	0.4	0.1	0	0	3.6
	60 to 80	1.3	2.9	1.3	0.2	0.1	0	5.8
	40 to 60	1.6	2.7	2.7	0.6	0.1	0.1	7.8
	20 to 40	2.3	6.3(M)	6.3	2.2	0.3	0.3	17.7(M)
	Under 20	3.6	10.2	14.6(M)	10.5(M)	5.3(M)	2.5(M)	46.7
	Total Percentage of Cases in Each Mileage Band	18.3	31.5	27.3	14.1	5.9	2.9	100.0

M = Median cross section in mileage band.

carrier-multiplexed circuits, the majority using systems designed specifically for short-haul applications.

In recent years, almost all exchange area trunks have used paired cable as the transmission medium. Very short trunks use loaded wire pairs without electronics, moderate-length circuits use voice-frequency repeaters or T1 digital carrier, and longer trunks use type N analog carrier or T1 carrier. In special instances, analog radio systems are used. In the future, it is expected that long trunks will be grouped into larger cross sections, where traffic is sufficient, to achieve economies of scale by using T2 digital carrier on special low-capacity paired cable, digital carrier on coaxial cable, and digital microwave radio.

In the following sections, the transmission systems used to provide exchange trunk transmission will be treated in greater detail. It should be recognized that the transmission portion of a given trunk may consist of several different types of transmission facilities. Trunk layouts generally reflect fundamental facility installation plans based on long-term growth forecasts. In planning the network growth, operating company engineers examine the capacity of existing facilities, present and projected demand for trunks, and possible routes between central office buildings. Factors that are considered include cost, ability to meet service dates, circuit diversity (to minimize the impact of outages), and transmission performance.

10.2.2 VOICE-FREQUENCY TRANSMISSION

With the exception of a relatively small amount of open-wire construction in rural areas, voice-frequency circuits utilize paired cable transmission media similar to loops. Within the exchange area, these circuits involve cables with hundreds of pairs of solid copper (sometimes aluminum) conductors, with plastic or paper-pulp insulation. The conductors are predominantly 24 gauge, with 26 gauge becoming more common; 22, 19, and occasionally finer or coarser gauges also have been used. Most paired cable used in the exchange plant is equipped with inductive loading as described in Section 10.1.

The loss plan adopted for the public telephone network uses control of trunk loss to achieve proper received volumes and controlled talker echo (see Section 6.3). The maximum inserted connection loss of a direct trunk is 5 dB, and that of a toll-connecting trunk is 4 dB. The attenuation of 22-gauge, H88-loaded cable is 0.79 dB/mile, which implies a maximum length of only 5 miles for a toll-connecting trunk and 6.3 miles for a direct trunk without additional amplification.

Compensation for voice-frequency loss is possible with the addition of voice-frequency repeaters, usually located in switching office buildings. Two approaches are used. The original approach uses two one-way V-type amplifiers (one for each direction of transmission) inserted into the 2-wire line, with a 2-wire to 4-wire terminating set at each end of the repeater. The terminating set contains a hybrid, a balancing network, and suitable attenuators. Fig. 10-10 shows the arrangement.

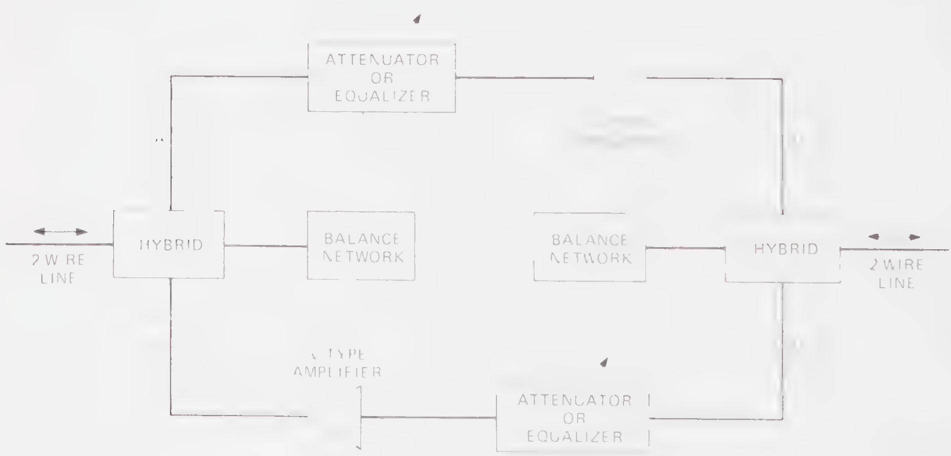


Fig. 10-10. Two-Wire Voice-Frequency Repeater

The hybrid is a 4-port network and has the property that if the balance network impedance matches the impedance of the 2-wire line over the bandwidth of interest, there is high attenuation between port B and port A and, similarly, between ports B′ and A′. This attenuation is known as the *transhybrid loss.* The attenuation between port B (or B′) and the 2-wire line is approximately 4 dB, as is the attenuation between port A (or A′) and the line.

The combination of fixed amplifier and attenuator (or equalizer) can be adjusted to compensate for line loss, up to a value that approaches the relatively high transhybrid loss. The requirements on maximum gain and effectiveness of balance-network impedance match are set to avoid regenerative oscillation. Suitable means must be provided to pass dc signaling around the repeater.

Until the metallic facility terminal (MFT) was introduced, the usual amplification technique for 2-wire trunks (as well as for subscriber line applications) was the negative impedance (E-type) repeater. The operation of this repeater can be understood if the loss-versus-frequency (loss slope) characteristic of the line is considered to result from a shunt R and C across the line, in combination with the characteristic R_0 of the line. If an active network is connected across the line so that the impedance looking into its input is a negative R shunted by a negative C, the net impedance of the line is R_0, and the undesirable loss elements are negated.

It can be shown that a low-input-impedance current amplifier exhibits the property that the impedance seen looking into the output is a negative multiple of a feedback impedance connected from output to input. The usual practice is for the negative-impedance circuit to be connected to one winding of a 3-winding transformer; the other two windings are inserted in series with the line. Arrangements are made to pass dc signaling around the transformer.

The MFT transmission modules, employing integrated circuit technology, are now being used instead of E-type repeaters in 2-wire applications. The MFT transmission units use active equalization and precision hybrid balance rather than the negative impedance technique.

10.2.3 SHORT-HAUL ANALOG WIRE LINE CARRIER

Analog carrier systems meeting the needs of longer exchange trunks are the N and ON carrier families. The original system, N1, was introduced in 1950 and used vacuum-tube technology. It provided 12 channels on two cable pairs, with a system range of 15 to 200 miles. This was followed by O carrier, providing 16 channels on two open-wire pairs. Types ON1 and ON2 followed, providing 20 and 24 channels, respectively, on tandem open-wire and cable facilities.

Solid-state techniques were applied to N1 line repeaters, resulting in the N1A transistorized repeater. This featured reduced line-power requirements. The N2 terminal, a transistorized replacement for the N1 terminal having essentially the same features (12 channels), was introduced in 1962. A later N3 terminal introduced in 1964 extended the number of channels to 24.

The most recent line repeater design is the N2, an improved solid-state plug-in repeater. Fig. 10-11 illustrates, in block diagram form, the N2 terminal and the first two N2 repeaters on the line. The transmission lines for all N Carrier Systems have similar features and address the short-haul market for system lengths up to 250 miles. Initially, N Carrier Systems were used in high-density urban areas to make more efficient use of wire pairs. With the advent of short-haul digital carrier systems (see Section 10.2.4), the field of application for new N Carrier Systems shifted toward the longer, lower-density, lower-growth routes; however, growth of N systems has continued at about the same pace.

N Carrier Systems are applied to a wide variety of nonloaded cables, ranging from 16 gauge to 24 gauge and including pulp- and plastic-insulated cable. A specific system design, including repeater spacings and gains, is required before a route is established. Repeater spacings are determined on the basis of allowable noise, cable loss, and loss slope for available cable. The design procedure involves determination of the signal levels at repeater inputs and outputs. It is necessary that inputs are not so low as to be susceptible to interference and crosstalk from other N systems or other services in the cable, and outputs are not so high as to be a source of interference. Careful system layout, installation, alignment of levels, and equalization are required to meet performance objectives. A typical repeater spacing is about 5 miles, but this varies with system design, based on choice of cable and system layout.

N carrier design permits both directions of transmission in the same cable sheath. Therefore, the crosstalk characteristics of the cable enter significantly into the design. As shown in Fig. 10-11, signals from the output of a repeater can couple directly (or indirectly via other voice-frequency pairs in the same cable) into the input of repeaters carrying other signals in the same or opposite direction. This results in crosstalk noise, which is in addition to the normal thermal noise of the amplifiers. The coupling paths from the output to input of a given repeater generally have enough loss so that the repeater does not become regenerative; rather, it is interference between systems accumulating from repeater to repeater that produces the undesired crosstalk noise. In the N system, this crosstalk is controlled through a concept known as *frequency frogging.*

A knowledge of the line frequency assignments is required to understand frequency frogging. As indicated in Fig. 10-11, the bandwidth occupied by the channels on the line is 96 kHz, either from 36 to 132 kHz or from 172 to 268 kHz. Opposite directions of transmission between repeaters (or between terminals and first repeaters) are never given the same frequency assignment. Therefore, near-end crosstalk (NEXT) is controlled by frequency assignment at the repeater input. As the composite multichannel signal passes through the repeater, it is modulated from the high-band assignment to the low-band assignment, or vice versa, by a 304-kHz local oscillator. In the process, the channel near the 268-kHz band edge is translated to the 36-kHz end of the band, and in a similar manner, the 172-kHz end becomes the 132-kHz end. This frequency inversion from one section to the next also tends to cancel the loss-versus-frequency slope across the 96-kHz band. This simplifies the equalization required to correct for cable loss.

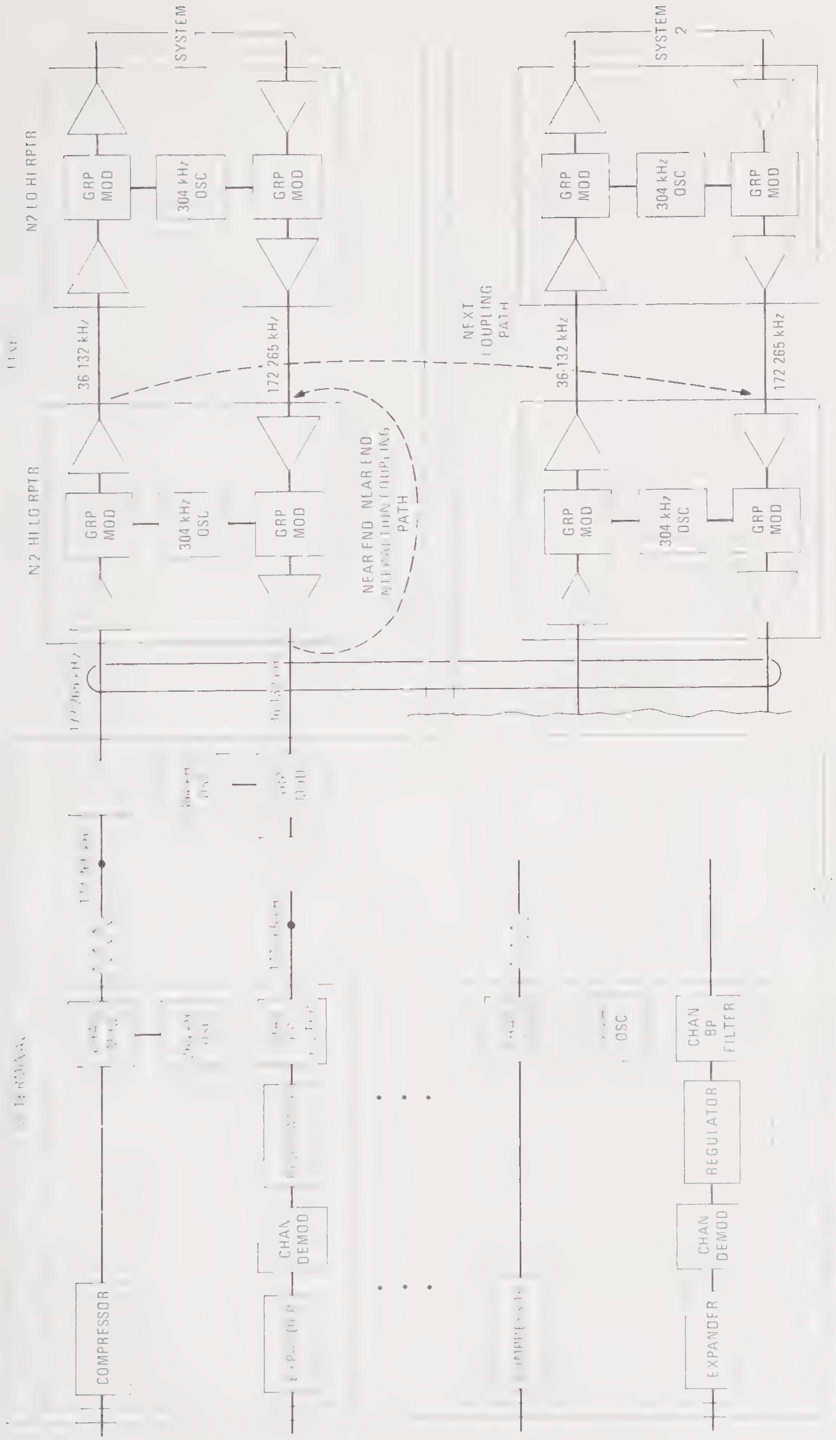


Fig. 10-11. N2 Carrier System

Note that the two directions of transmission occupy different frequency bands, making it theoretically possible to use one pair of wires for both directions of transmission (equivalent 4-wire transmission). Recent improvements in filter design techniques have made this mode of operation practical, and directional filters for 2-wire operation of N carrier are now available.

The choice of signal format for the line is based on a desire to simplify and economize terminal design. These considerations also affect the design of the line itself. The N1 and N2 systems use double-sideband transmitted-carrier (DSBTC) transmission. Thus, twelve 4-kHz channels occupy $8 \times 12 = 96$ kHz. DSBTC permits simple detection of the voice signal, since the carrier is present at the receiver. The N3 system is single-sideband (24 channels $\times$ 4 kHz = 96 kHz), but the carriers are transmitted with 8-kHz spacing to make the line signals similar to N1/N2 and to provide necessary frequency information at the receiver to correct for the frequency shifts that can occur on the line. Frequency shifts occur because the local oscillators used for frequency frogging in each repeater are not synchronized and therefore can differ in frequency. Thus, small departures from the 304-kHz modulator frequency can cause frequency errors of a few Hertz in the signals after frequency translation. These deviations are cumulative from repeater to repeater and can amount to as much as 150 Hz in a system if not corrected. This is not a problem with DSBTC, as the carrier is present for detection and the carrier and sideband have been shifted identically. With single-sideband N3, a frequency correction circuit operates in conjunction with the transmitted carrier to correct the frequency shifts.

The N3 terminals are more complex than the N1/N2 terminals, but they provide 24 channels on the line rather than 12, thereby reducing the net channel-mile cost of longer systems. The larger number of channels with ON1 and ON2 has a similar effect. A sample study of N Carrier Systems in the Bell System showed that the median length for N1/N2 was slightly more than 20 miles, whereas N3/ON had a median length of 50 miles. A new terminal, N4, has been designed to be compatible with N3 terminals at substantially lower cost.

N systems have one feature that tends to increase the complexity of the terminals, but has a major impact on economic line design. As mentioned above, line noise and crosstalk are important considerations in determining the repeater spacing (and therefore the cost of the line). Each channel unit in the terminal has a circuit called a *compandor* (*comp*ressor—exp*andor*), which reduces the subjective effect of noise on telephone circuits. Briefly, the compandor consists of a compressor at the transmitting terminal and an expandor at the receiving terminal. The compressor dynamically adjusts the amplitude of input speech signals at a syllabic rate so that the dynamic range of all talker inputs is reduced. The low-level signals are raised, and the high-level signals are unaffected, resulting in a substantial improvement in signal-to-noise ratio for low-level talkers on the line. In a complementary manner, the expandor reverses this process at the receiver by introducing loss to lower the lower-level signals to their normal value, but leaving the higher-level signals unaffected. The expandor loss tracks the compressor gain so that, on an overall basis, the net loss of the circuit is not affected by the compandor.

The important effect of this process can be demonstrated by looking at the intervals when there is no speech present but customers are still connected. No speech is effectively the worst case of a low-level talker. During these intervals, the expandor is inserting the maximum loss and thereby reducing the background noise (both thermal and crosstalk). Subjectively, this reduction is equivalent to about a 20-dB system noise improvement. This significant improvement permits a more lenient and thus less costly line design. Although compandors produce a substantial improvement in voice transmission, it should be noted that they produce undesirable effects on data signals that employ amplitude modulation.

10.2.4 SHORT-HAUL DIGITAL CARRIER

Time-division-multiplex and digital transmission provide certain advantages in transmission and circuit design. These techniques have found widespread use in the exchange transmission environment since their introduction in the early 1960s in the T1 Carrier System. Time-division-multiplexed carrier has found great acceptance because of the following system features:

(1) Terminal multiplex equipment can be made compact at a low price and can take maximum advantage of latest advances in solid-state digital circuits.

(2) Highly reliable circuit techniques can be used to provide a rugged transmission line that does not require a complex design procedure and elaborate lineup adjustments.

(3) A variety of services can share the line without the need to establish a line design based on the requirements of the most sensitive service.

(4) If line error rates (to be discussed at greater length) are acceptably low, impairments effectively result only from terminal signal processing and are not a function of system length.

The economic advantages have been such that the T1 Carrier System has lowered the economic distance for carrier systems in the exchange plant to less than 10 miles.

10.2.4.1 T1 Carrier

T1 digital carrier was the initial Bell System short-haul digital transmission line. A review of the T1 system features, hardware details, design and operational considerations, and maintenance techniques will assist in understanding exchange digital systems.

The transmission media for T1 can be pulp, air-core PIC, or jelly-filled PIC cables from 16 to 26 gauge. Metropolitan area trunk (MAT) cable, a new low-capacitance cable with 25-gauge copper conductors optimized for trunks in metropolitan areas, also can be used for T1. The signal transmitted is a 1.544-megabit-per-second pulse stream, which may be generated by a variety of terminals such as D banks (see Section 10.5.1), T1WB data terminals, etc. Signals are applied directly to cable pairs in a bipolar format in which positive or negative pulses, always alternating, represent one state and ground represents the other state. An example of a bipolar signal is shown in Fig. 10-12. Use of bipolar signals provides four significant advantages:

(1) A bipolar signal spectrum has the significant portion of the signal power density below the signaling rate frequency (the reciprocal of the pulse period). A polar signal has twice the bandwidth.

(2) A bipolar signal has a null in the power density spectrum at direct current and at integer multiples of the signaling rate. The lack of components near direct current avoids problems of dc (baseline) wander in ac-coupled input, output, and equalization circuits.

(3) The bipolar signal can be examined at any point along the transmission path, and any single-bit transmission error can be detected. If an error occurs in a 1, thereby converting it to a 0, adjacent 1s will be of identical polarity, violating the coding rule. If an error occurs in a 0, thereby converting it to a 1, there will be two successive 1s of identical polarity, again violating the rule.

(4) A bipolar signal has good transition density for timing recovery.

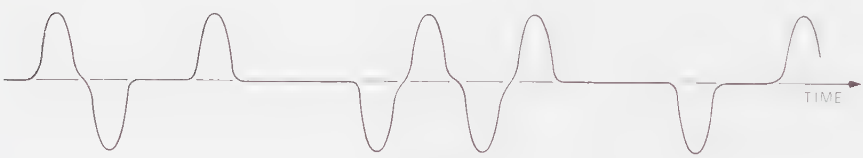


Fig. 10-12. Bipolar Signal

Property (2) is useful for remote maintenance margin testing (discussed subsequently). Property (3) is useful for maintenance, because working lines can be monitored automatically for excessive bipolar violation errors.

Error performance is a transmission performance quantity that must be controlled in digital system design. Line errors produce impulse noise in voice-frequency channels and can introduce serious errors in data transmission. A high occurrence of errors can cause terminals to lose synchronization, which is catastrophic (until reframing occurs) in time-division-multiplex systems. If line errors occur at rates less than, for example, 10^{-6} errors per bit transmitted, noise and signal distortion will be determined primarily by the terminal coding and decoding circuitry. The T1 objective is for 95 percent of all systems to have an error rate better than 10^{-6} errors per bit.

Sources of error in T1 systems are similar to sources of noise and interference in analog multiplex carrier systems. Misequalization, interference from other services occupying the cable, and electronic circuit noise, etc., are sources of error. To better understand how these sources of error are controlled when a system is engineered, the components of a T1 repeatered line and the T1 regenerator that is its essential element will be examined.

The T1 line regenerator, or repeater, is a solid-state, plug-in unit, suitable for pole mounting or manhole placement and usually powered over the transmission pairs from the central office. Nominal spacing between repeaters is 1 mile. The repeater performs three functions: (1) equalization of the input pulse stream to correct for linear distortion, (2) timing extraction, so that the appropriate timing strobe can be provided to the regenerator, and (3) decision as to the value of the input pulse information, with corresponding regeneration of a correct and properly shaped output pulse stream.

Input equalization is required because the paired-cable medium is not a distortionless line, and therefore the input pulse stream will have been subjected to amplitude and phase distortion resulting in a waveform in which individual pulses tend to be broadened in time and to smear into each other, causing intersymbol interference. For proper regeneration, it is necessary for the regenerator to be able to identify and distinguish individual pulses. These effects of the medium can be corrected by proper preequalization at the regenerator input. The optimum equalization does not correct for line distortion over the complete signal bandwidth but rather achieves a balance between noise and intersymbol interference. The amount of equalization required is determined by the type and length of cable used and also is influenced by temperature and manufacturing variations.

T1 lines are self-timed; that is, timing information is extracted from the input waveform. Since a bipolar signal spectrum has a null at the signaling rate, timing cannot be extracted directly from the bipolar signal; it is convenient to convert it to a unipolar signal to extract the timing information. Rectification and clipping is one way to achieve this, with an appropriate tuned circuit used to recover the timing information.

As mentioned previously, T1 carrier can be applied to a wide variety of cables. Although all cables exhibit an attenuation characteristic that increases with frequency, the loss-versus-frequency shape varies with different cable types and will change for a given cable with variations in temperature. For simplicity of system engineering and installation, a single set of equalization shapes was specified for the initial T1 regenerators developed. These regenerators used a series of fixed equalizers (actually line build-out networks) with variously shaped slopes, one of which was selected for each regenerator location based on a measurement of cable loss at the half-signaling frequency, 772 kHz. With the line build-out approach to equalization, a fixed amplifier gain shape is used, and cable loss is built out to the full section loss shape. Allowances were made in the measurement and build-out selection process for temperature effects, variations between cable pairs which are caused by manufacturing tolerances, and the granularity inherent when only 12 build-out codes are used.[3]

T1 systems must be designed to cope with impulse noise generated by switching equipment in central offices. This type of impulse noise couples into carrier systems in the cables leaving the central office, where pairs used for voice-frequency trunks and carrier pairs occupy the same sheath. Usually, the repeater spacing in the first section out of an office is shortened so that the carrier signals are not allowed to be attenuated to too low a level, thereby achieving greater margin relative to impulse noise.

From the crosstalk noise allocation, it is possible to determine the total number of T1 systems allowed in a given cable sheath. As an example, in a typical 900-pair, 22-gauge pulp-insulated cable, operated in a single cable configuration with each direction of transmission in separate selected nonadjacent binder groups within a common sheath, near-end crosstalk is not a problem for the systems in the selected binder groups. Repeaters are located at maximum 6000-foot spacings. However, in a typical 900-pair sheath with 50-pair binder groups, only four binder groups can be selected for each direction in order that a nonadjacent position be maintained. Therefore, 200 is the maximum number of systems permitted in the cable if a 6000-foot spacing is required. If adjacent binder groups must be used, the poorer crosstalk coupling loss in that case permits a total of only 50 systems to be operated in the entire sheath. If separate sheaths are used for each direction of transmission, near-end crosstalk is eliminated and only far-end crosstalk remains as a possible constraint. In practice, with existing regenerator designs this does not limit full utilization of available cables.

Operation and design of T1 systems is on a span basis. A span is defined as the aggregate of all span lines between two central office buildings. A span line is a regenerative-repeatered line extending from an office repeater bay in one office to an office repeater bay in another office. For longer routes, a number of span lines may be connected in tandem and, together with channel banks on each end, constitute a 24-channel T1 system. By engineering and maintaining on a span basis, span lines can be connected (hardwired) together as required to provide longer trunks without the need to engineer the system on a custom end-to-end basis. An average system contains four span lines and is 15 miles long. Additional span lines can be added to augment the span

3. The latest series of T1 regenerators utilizes an automatic line build-out circuit. This determines the amount of buildout required by providing an adjustable loss circuit that operates on the input pulse stream. This circuit adjusts for temperature-induced variations in the received pulse stream and simplifies installation since line build-out selection is not required.

cross section by following a basic span design applicable to all span lines on that route.

Maintenance operations also are organized on a span basis. A span will have spare span lines provided to "make good" failed lines by patching when a working line fails.

T1 trouble isolation also is organized on a span basis. A fault location method is provided that helps to locate failed regenerators without recourse to tracing the signal from manhole to manhole. As mentioned previously, the signal format on the line was chosen to be bipolar to avoid baseline wander, with the result that there is a spectrum null at direct current. The regenerators, however, will transmit a signal that is not bipolar, provided the sequence of 1s of the same polarity is not so long as to create an excessive dc component. If the sequence of 1s transmitted reverses polarity, not at every 1, but after, for example, every 1500 time slots, a strong spectral component will be apparent in the pulse stream at 1.5×10^6 divided by 1500 = 1000 Hz. On a short-time basis, the signal is unipolar, but on a longer-time basis, the polarities cancel out. It is possible to extract, through a 1000-Hz filter, the strong 1000-Hz component at any point along the line.

In practice, there are 12 different filters, tuned to separate frequencies in the audio band, with a different filter located at each regenerator location. By reversing the polarity of the transmitted 1s after an appropriate number of time slots, causing one of the 12 audio-frequency components to be produced, it is possible to verify that digital transmission has reached the corresponding filter. The audio output will be present only at the selected filter output. This audio tone can be brought back to the central office on a loaded voice-frequency pair and detected. All filter outputs are connected to the same return pair, since only one pattern is applied at a time. All regenerator outputs at a location can be connected to a given filter, because the bipolar spectrum of the working lines that are not being tested has a very small power density at audio frequencies. The density of 1s versus 0s also can be varied, so various amounts of baseline wander can be introduced during the time the polarity is in one direction. This variable wander can be used to test for marginal performance at a suspected repeater.

T1 carrier has had wide application to metropolitan networks because of favorable cost and operational experience. As experience has been gained about factors influencing performance, it has been possible to evaluate the consequences of changing the operating parameters or of improvements in design and engineering methods. One result of these studies has been a new digital line design that achieves an increased signaling rate (and therefore a greater number of channels) by establishing a tighter balance between cable characteristics and regenerator design. This new line, T1C, utilizes techniques similar to the latest T1 design and provides for transmission at a 3.152-megabit-per-second rate in 22-gauge pulp-insulated cables, with the same regenerator spacings as T1. When D channel banks are combined with a new M1C multiplex, the system will provide 48 voice-grade channels. Because the signaling rate is twice that of T1, the equalization of the regenerator must accommodate a greater line loss at the higher frequencies required to support the 3.152-megabit-per-second rate. Automatic line buildout is used to simplify engineering and installation. The engineering rules and design methods used provide the greater control of crosstalk and interference required by the higher signaling rate. Fault location principles are similar to those for T1.

T1 carrier also is being expanded into rural areas currently served by N Carrier Systems. This application is known as *outstate T1*. The advantages of simplified design and installation and the ability to interconnect with metropolitan digital networks, together with expanding circuit demand as rural areas develop, have stimulated interest in long T1 systems for rural networks. T1 generally has been restricted to system lengths of less than 50 miles, partly to minimize the accumulation of errors, but primarily because of maintenance administration difficulties. New engineering and maintenance techniques have been formulated to ensure proper performance, to provide rapid restoration of service failures, and to provide efficient fault location and repair up to distances of 150 miles.

10.2.4.2 T2 Carrier Line Transmission

The second level of the digital hierarchy provides transmission at 6.312 megabits per second. T2 is the digital system utilizing paired cable that currently provides transmission at this rate. T2 provides intercity digital transmission for distances up to approximately 500 miles. With M12 multiplex terminals, T2 transmits four DS-1 signals, equivalent to four T1 lines. This corresponds to 96 voice-grade channels or one PICTUREPHONE channel.

T2 utilizes a separate 22-gauge low-capacitance (LOCAP) cable for each direction of transmission. This new cable features low loss and controlled crosstalk, permitting repeater spacings of 14.8 kilofeet on repeatered sections of buried or underground cables not adjacent to office or powering stations. Aerial cable sections and sections adjacent to offices or powering stations require reduced spacings. The T2 system design is based upon a maximum of 250 repeater sections in tandem. Most systems are constructed in blocks of 24 T2 lines, of which one line is for protection with automatic switching to switch traffic from a working line to the protection line when errors on the former become excessive. In fully developed systems with D channel banks, this represents a cross-section block of 2208 voice-grade channels. The LOCAP cable is being manufactured in 27-, 52-, and 104-pair sizes, and a 2-cable route will be able to provide a maximum cross section of 8832 voice-grade channels. Because of the large cross sections available, T2 lines serve the intermediate distance intertoll trunk market, connecting population centers between which traffic can be grouped to take advantage of economies of scale.

The T2 repeater consists of two separate one-way regenerators powered over the transmission pairs. They may be mounted in manholes or above ground. The regenerator for each direction of transmission is mounted in a separate apparatus case. The T2 regenerator performs the same functions as the T1 regenerator: equalization, timing extraction, and regeneration.

Equalization is achieved with a combination of fixed equalization and automatic line buildout (ALBO). Five codes of equalizers feature different amounts of fixed equalization, selected on the basis of the cable route makeup. The ALBO consists of a variable equalizer controlled by a feedback signal developed from the fully equalized pulse stream at the ALBO output. Timing is extracted from the equalized pulse stream by rectifying, clipping, and passing the resultant signal through a narrow crystal filter tuned to 6.312 MHz. The output pulse stream is recreated by comparing the equalized input signal with a reference at the instant the timing circuit produces a strobe pulse.

The pulse stream is in a modified bipolar format called bipolar with six zero substitution (B6ZS). In this format, 1s alternate in polarity as in T1, but a special code word is substituted when six 0s occur in a row in the original signal. This avoids loss of energy in the tuned timing extraction circuit. In addition, the restriction to no more than five 0s enables rapid detection of a loss of signal. Maintenance is also aided by the bipolar format, which permits rapid error detection. Note that the B6ZS format is defined to be the DS-2 signal and is required from every terminal that will be connected to the T2 line.

T2 lines are divided into maintenance spans that can contain up to 44 repeaters in manhole, office, or intermediate power points. As an aid to sectionalization of troubles, the received signal at each end of the maintenance span is monitored on each T2 line. If errors in the B6ZS format exceed a threshold, appropriate alarms are activated. The signal is modified appropriately to eliminate format violations at any error rate, or, in case of total signal interruption, a special all-1s signal is inserted. This is done to avoid erroneous error detection beyond the span where the fault occurred. Note that violation-removal circuits do not correct errors; rather they only prevent the false indication of errors in succeeding spans.

Fault location is accomplished by a method similar to that used in T1, with a special test signal containing a strong audio component coupled through one of 22 bandpass filters located at regenerator locations. In the T2 system, the output of the filter is fed to an audio amplifier which is powered over the return audio pair. This amplifier only operates when the dc polarity of the current on the fault pair is in a given direction. A maximum of 44 locations can be accommodated by using a second set of filters identical to the first, with the added provision that the amplifiers be connected to the fault pair with inverted polarity. The polarity of the current supplied will then determine which set of 22 filters becomes active.

T2 lines are being used for intertoll trunks and private-line service between cities. It is likely that as a nationwide digital network evolves, T2 will be an important component. The system error requirement for T2 is that 95 percent of all systems have an error rate less than 10^{-7}. This error rate is an order of magnitude better than the error rate objective for T1. These error objectives are being reevaluated to have a consistent nationwide digital network allocation. It is evident that T2 has been designed to more stringent requirements than T1, since the maximum length of T2 lines is about 500 miles, an order of magnitude greater than the usual maximum for T1, and the error objective is an order of magnitude better.

The error objective for the individual regenerators that make up the 250 permitted in tandem is that 99.98 percent of all regenerators must have better error rates than 10^{-}[illegible] errors per bit. The error allocation rule implies that the probability of a line of 250 regenerators having an error rate of 10^{-}[illegible] errors per bit or poorer is 250 times the probability of a single regenerator having 10^{-}[illegible] errors per bit. With regard to jitter, it has been shown that 250 T2 regenerators in tandem have an rms jitter accumulation much better than the line objective of 10 nanoseconds.

10.2.4.3 Large-Capacity Exchange Digital Coaxial Lines and Radio Systems

As mentioned previously, there is a definite reduction of exchange trunk-group size as trunk-route lengths increase. Large capacities generally could be justified only where a large number of trunk groups could be multiplexed together for transmission over a long enough distance to make the savings in line costs large enough to offset the cost of multiplexing. With analog techniques, the multiple stages of multiplexing needed to achieve a large cross section are costly. There are, however, applications in which analog microwave radio systems with moderate cross sections of 100 to 1200 channels have been used to overcome difficult geographic situations, such as mountain or water crossings, where paired-cable land or underwater facilities are difficult to place. This will be discussed in Section 10.2.5. Also, radio and coaxial cable systems are used over moderate distances in metropolitan areas to transmit groups of intercity trunks from central-city toll centers to metropolitan junctions or regional switching centers located in nearby suburban or rural areas. In many cases, these trunks are sent on to distant cities over the toll network without demultiplexing, and the short-haul broadband section forms part of the long-haul toll network. These represent two cases in which large-capacity and moderate-capacity short-haul analog systems are attractive.

Recently, with the development of low-cost digital multiplexing, it has been possible to develop large cross-section digital systems for economical applications in exchange trunking. These are intended as express backbone systems with low-cost arrangements for adding and dropping voice channels. Thus, T1 lines, as presently provided, could be used to feed the high-capacity system at convenient add-drop points. The trunks would remain digitally encoded from trunk terminal to trunk terminal, with all the advantages of a digital format regarding conventional transmission impairments, mixture of different services, and maintenance.

Two systems operate at the DS-4 rate of 274.176 megabits per second, equivalent to 4032 voice-grade channels, 168 DS-1 digroups (T1 equivalents), or 42 DS-2 channels (T2 equivalents). One of these systems (T4M) is a coaxial cable system that uses two 0.375-inch coaxial tubes per 2-way, high-speed channel and provides up to 10 working channels and one protection channel on COAX-22 cable. The second system (DR18) is a digital microwave system that operates in the 18-GHz frequency band and provides seven working channels and one protection channel per system. The DS-4 digital rate is also utilized in the long-haul WT4 waveguide system which is described in Section 10.3. A third system (3A-RDS) is a microwave radio system in the 11-GHz band, operating at the DS-3 rate.

T4M Digital Line

The T4M digital line is a metropolitan area system, but can be used for applications of up to 500 miles. It has manhole-located regenerators powered over the coaxial tubes and located up to 5700 feet apart. As with T2, the line is divided into maintenance spans. The maximum length of a span is 111 miles between terminating offices, where equipment for maintenance and restoration is located. Add and drop arrangements can be provided within the maintenance span without the need to provide span-terminating equipment on through systems and without requiring additional protection lines over and above the common protection line.

T4M uses a polar rather than a bipolar signal on the line. Thus, only a single decision threshold is required instead of the two thresholds used for the 3-level bipolar signal. This provides increased margin, although certain advanced techniques are required to extract timing information and to compensate for cutting off the transmitted spectrum at low frequencies.

Design of regenerators to operate at a 274.176-megabit rate has involved meeting many circuit packaging and manufacturing challenges. The T4M system features extensive use of hybrid integrated circuit technology. Design principles have involved consideration of many of the same factors as in the digital systems mentioned previously. However, T4M is different in one important way: interference between systems operating in a coaxial cable is not significant because of the high degree of shielding provided by the coaxial structure. As in all digital systems, a factor of importance is intersymbol interference. Allowance must be made in the design of the decision, timing, and cable equalization circuits so that even with normal environmental, production, and component aging tolerances, the regenerator will be error-free. Automatic equalization without the need for installation adjustment is provided by automatic line buildouts. Four repeater codes have been developed to cover the full cable loss range of 0 to 56 dB at 137 MHz, the half-signaling frequency.

No routine testing of regenerators is contemplated, and a regenerator is considered to be operating satisfactorily with bit error rates better than 10^{-7} error per bit. A fault location scheme derived from the audio detection scheme used in T1 and T2 Carrier Systems is expected to locate any regenerator with an error rate above 10^{-6} errors per bit. Violation monitors and removers are located at maintenance span-receiving terminals to detect errors and to prevent them from passing on to connecting spans or equipment down the line. An error rate of 10^{-6} errors per bit will initiate alarms and a switch to a protection system.

The full system (500-mile) error objective of T4M is less than 10^{-6} errors per bit for 99.9 percent of the time per line. The jitter accumulation objective is no more than six time slots peak-to-peak (22 ns) over 500 miles. This value avoids a requirement for special dejitter circuits over and above those provided in M34 multiplexers. (See Section 10.4.)

DR18 Digital Radio System

The DR18 Digital Radio System also operates at the DS-4 rate of 274.176 megabits per second. Operating in the 18-GHz band, the system utilizes the advantages of digital techniques for reliable operation. Use of digital transmission avoids the strong buildup of signal impairments that would occur in an analog system with the many repeaters required by the close repeater spacing needed in this frequency band. The spacing is expected to be from 1 to 5 miles, depending on the attenuation characteristics of the environment. Because propagation is strongly affected by rain, spacing will be shortest in those areas of the country with high precipitation rates, such as the South, and longest in the dry areas of the West.

As the system will be rooftop- or pole-mounted, the physical arrangements must be quite compact, requiring the use of hybrid integrated circuit technology. Four-phase differentially coherent phase-shift keying (4ØDCPSK) is used. Digital information is modulated on the RF carrier by varying the electrical path length between the RF source and the transmitter filter by means of digital switches. The phase of the carrier can assume four states: 0 degrees, ±90 degrees, and 180 degrees. The information is contained in the changes of phase. Each transition, or change of phase, represents two information bits. Detection is coherent by comparison of the phase of the received modulated carrier with a separately recovered reference carrier. The detected signal is regenerated at each radio repeater location. Use of 4ØDCPSK provides immunity from interference between radio channels on the given route and nearby routes. It is expected that up to eight distinct geographical routes will be able to be served from a given repeater site.

Automatic protection channel switching is provided by a one-for-N switching arrangement. Protection spans will probably contain about 10 hops, governed primarily by the need to drop or add radio channels.

A single antenna will be used for both directions of transmission. Horizontal and vertical polarization will be used to provide discrimination. Four channels with horizontal polarization and four channels with vertical polarization, when combined, occupy half of the 2-GHz system bandwidth to provide each direction of transmission.

The physical arrangement is a pole-mounted antenna "canister" that contains plug-in transmitters and receivers for seven working channels and one protection channel. For a rooftop installation, the canister is mounted on a stub pole supported by a platform secured to the building roof. For repeaters mounted on telephone company premises, power will be obtained from the telephone building's supply. Remote locations will use commercial power with battery backup. A 100-kilobit-per-second maintenance channel superimposed on one or more of the RF channels will be provided to locate faults or to make measurements of important repeater characteristics without the need for gaining access to units at each repeater site.

3A Radio Digital System (3A-RDS)

The 3A-RDS is a high-capacity digital carrier system that operates at the DS-3 rate of 44.736 megabits per second. It provides for a total capacity of 560 DS-1 signals, or 13,440 voice channels, in the 11-GHz radio band. It will accommodate 22 DS-3 channels including protection channels.

The 3A-RDS is intended primarily for applications on high-density intercity routes up to approximately 250 miles, as feeder for T4M or WT4 systems, and to provide route diversity within the network. It may prove to be particularly useful as a transmission system where cable placements are impractical such as river and lake crossings, major arteries, historic areas, or restricted public properties. Repeater spacings range from 6 to 25 miles depending on local rainfall intensity.

3A-RDS utilizes a combination of existing TN-1 analog radio equipment (see Section 10.3.3.3) and a 3A-RDT digital terminal. The 3A-RDT provides for the digital processing modulation and demodulation steps necessary for transmitting the DS-3 signal over a TN-1 radio channel. Regeneration will be required at approximately every other repeater site; at these sites, a 3A-RDT regenerator will be provided in addition to the TN-1 radio equipment.

10.2.5 SHORT-HAUL ANALOG MICROWAVE SYSTEMS

Analog short-haul microwave systems have been used in the exchange area and in adjacent rural areas to provide services over routes where geographic obstacles or high construction costs for land-line facilities make radio attractive. A number of systems have been developed to operate in the various common-carrier microwave bands available for these services.

Notable among the systems currently used are two families of systems that operate in the 6- and 11-GHz frequency bands. These systems can be operated individually or in pairs to provide inband or crossband diversity when required by radio propagation or reliability requirements. The systems operating in the 6-GHz band are known as TM, and the systems operating in the 11-GHz band are known as TL.

Both systems can be operated with the same antenna or with antennas especially designed for the appropriate band. A single antenna with dual polarization is used to provide both directions of transmission. Appropriate frequency assignment plans avoid system interference at repeater points. TM provides up to eight 2-way nondiversity radio channels, utilizing 16 radio channel assignments, with a combination of frequency frogging and dual-polarization to control interference. TL provides up to six 2-way channels utilizing 24 radio channel assignments. Twelve frequencies are used for a given hop, and the remaining 12 are used for adjacent hops. By interchanging transmit and receive channels between each half of the assigned band, the frequency plan avoids system interference to the required extent.

TL and TM systems have been combined to provide crossband diversity. Crossband diversity involves feeding a radio channel in each system (therefore in each band) with the same signal at the transmitting end. At the receiving end of the radio path, the most suitable signal is selected for further transmission down the line. Crossband diversity is quite effective in improving the reliability of 11-GHz systems. For an 11-GHz system without crossband diversity, half of the total outage objective is allocated to rain attenuation. In addition, the propagation effect of rain affects all 11-GHz channels on a given hop in a similar manner. Use of a 6-GHz channel together with an 11-GHz channel effectively eliminates rain outages. The remaining outages caused by electronic equipment failures are mitigated by the two parallel systems.

Such diversity arrangements on a one-for-one basis are considered by regulatory authorities to be wasteful of the frequency spectrum, which is a limited natural resource. Therefore, restriction of diversity in low-fill systems (where hot-spare equipment can mitigate electronic failures economically) and permission only to employ one-for-N diversity for high-fill systems (where hot-spare arrangements are costly) means that simple crossband diversity will be phased out in the coming years. Spatial diversity, i.e., operation on the same frequency over separate paths, can provide increased reliability, although at increased cost.

TL and TM systems can carry up to 1200 voiceband channels per radio channel using conventional FDM multiplex techniques; the maximum route capacity for TL systems is 7200 voice circuits and for TM systems, 9600 voice circuits. The frequency-modulated RF signal is reduced to baseband at each repeater point where appropriate FDM multiplex equipment is provided to facilitate the dropping and adding of channels. Repeater station spacings can vary from 5 to 35 miles, depending upon the geography and propagation conditions. Direct-radiator antennas such as parabolic dishes or horn reflectors may be used. Also, periscopic radiators with parabolic dishes on the ground pointing up to a passive "directing reflector" which is mounted on a tower can be used in some circumstances. Occasionally, in order to avoid obstacles lying in the direct line-of-sight path, "passive repeaters" consisting of two antennas connected back to back or large "billboard" reflectors are used to change the direction of the path.

Both systems have solid-state construction and operate from battery supplies charged from commercial power. They feature simplified maintenance with convenient replacement of defective units. Alarm and order-wire systems are provided, and various trouble conditions occurring in unattended repeater stations are reported to attended offices.

The TN-1 system operating in the 11-GHz frequency band, mentioned in Section 10.3.3.3, is used for exchange as well as long-haul applications.

10.3 LONG-HAUL CARRIER

10.3.1 EARLY LONG-HAUL SYSTEMS

The first widely used Bell System long-haul carrier system was the C system. Operating on open wire, the C system provided three 2-way single-sideband voice channels in the 5- to 30-kHz frequency range, in addition to one 2-way channel at voice frequency per pair of open-wire lines. The nominal repeater spacing was 120 miles. Automatic pilot regulation was provided to correct for variations in open-wire transmission loss with changes in temperature. The first commercial application of the C system was between Pittsburgh and St. Louis in 1925.

In 1938, a substantial increase in long-haul capacity on open wire was achieved through the J system, which provided twelve 2-way single-sideband channels in the 36- to 142-kHz frequency range on one pair of wires. The J system frequency allocation was designed for compatibility with earlier systems, so that J system signals could be transmitted on open-wire lines already carrying signals of systems such as C carrier. Optional frequency allocations and sideband orientations were provided to reduce crosstalk interference. The J system modulation plan involved the first use of the 60- to 108-kHz 12-channel group band, which has become a Bell System and worldwide standard building block for multiplex equipment. The J system uses approximately 60-mile repeater spacing. Automatic regulation on four line pilots is provided in order to compensate for slope and flat gain transmission deviations on the repeatered line. The initial commercial use of J carrier was made in 1938 on a 250-mile Dallas to San Antonio route. Application of J carrier thereafter was rather limited.

The K system was the first Bell System carrier system developed for use on cable. The K system provided 12 single-sideband channels in the 12- to 60-kHz frequency range for transmission on 2 pairs of nonloaded 19-gauge aerial or underground cable. Crosstalk interference was controlled by the use of pairs in separate cables for opposite directions of transmission, by frogging between cables at every repeater, and by signal balancing at designated repeaters. Nominal repeater spacing was 17 miles. Automatic pilot regulation was used to compensate for repeatered line transmission deviations. The first K Carrier System installation was made on the 150-mile route between Toledo and South Bend in 1937, and by 1950 a substantial portion of the long-haul voice-circuit-miles was on K carrier.

10.3.2 COAXIAL ANALOG SYSTEMS—L CARRIER

The L-type family of SSB AM Carrier Systems was designed in order to provide the maximum available channel capacity on a pair of coaxial cables, consistent with the state of repeater art at the time of its development. The L-type systems were designed to meet high-quality Bell System objectives for 4000-mil transmission.

Following the fundamental inventions of the coaxial unit by C. S. Franklin in 1928 and the feedback amplifier by H. S. Black in 1930 and utilizing the 1929 coaxial system patent application of Espenschied and Affel, planning and development of a coaxial system for Bell System use commenced in the early 1930s. In 1936, an experimental coaxial system on 0.270-inch cable was successfully demonstrated between New York and Philadelphia. In 1941, the first commercial Bell System service was begun on a 200-mile route between Minneapolis, Minnesota, and Stevens Point, Wisconsin. The first commercial system, L1, transmitted 480 4-kHz voiceband channels on 0.270-inch cable, with repeaters spaced 5.5 miles apart. Later, cable diameter was increased to 3/8 inch (the size that became the standard for L1 as well as future L Carrier System designs). On 3/8-inch cable, L1 system capacity was increased to 600 channels, and repeater spacing was increased to about 8 miles.

In progressing from the L1 to the L5 design, an overall increase of 18:1 was achieved in channel capacity per 3/8-inch coaxial pair. This increase in capacity was attributable to (1) progressively shorter repeater spacings on standard 3/8-inch cable, (2) improved noise figure, linearity, and load capacity of the repeaters, and (3) the application of more advanced system design techniques. Each successive generation of coaxial system employed a repeater spacing one-half that of the preceding one, so that the older system could be readily and economically converted to the newer one by installing intermediate repeaters. The conversion of existing systems to new, higher-capacity systems was economically attractive because the dominant portion of repeatered line cost was the cost of installed cable.

10.3.2.1 Channel Capacity Growth

Table 10-5 summarizes the growth in channel capacity per 3/8-inch coaxial cable pair progressing from the L1 through the L5 systems.[4]

TABLE 10-5
L SYSTEM CAPACITY PER 3/8-INCH COAXIAL PAIR

SYSTEM CHARACTERISTIC	L1	L3	L4	L5
Service Date	1946*	1953	1967	1974
Voiceband Channel Capacity	600	1860	3600	10,800
Repeater Spacing (miles)	8	4	2	1

* As previously noted, initial service on an L system was provided in 1941 on 0.270-inch cable.

4. World War II interrupted exploratory work on L2, which accordingly was never carried through to development and manufacture.

As Table 10-5 indicates, the channel capacity per coaxial pair has risen from 600 channels (1 mastergroup) in L1 to 10,800 channels (18 mastergroups) in L5, with repeater spacing reduced in steps from 8 miles in L1 to 1 mile in L5. Additional growth in system capacity also has been realized over the years by increases in the number of coaxial pair units within a cable sheath. Table 10-6 shows, for example, that the maximum number of coaxial pairs per sheath increased from the 4 pairs used in L1, 6 pairs used in L3, and 10 pairs in L4, to the present 11 pairs in L5. Table 10-6 also indicates the number of available working coaxial pairs, assuming multiline protection switching of working pairs with a spare or protection pair of coaxial units. As a result, the number of working coaxial pairs in Table 10-6 is shown to increase from the 3 pairs in L1, through the indicated steps, to the 10 pairs in L5. Taken together with the capacity growth per coaxial pair shown in Table 10-5, the overall growth in available channel capacity on a route is as shown in the last line of Table 10-6. As indicated, the total channel capacity per route increased from 1800 in L1 to 108,000 in L5, an overall increase of 60:1.

TABLE 10-6
TOTAL ROUTE CAPACITY ON MULTIUNIT COAXIAL CABLE

SYSTEM CHARACTERISTIC	L1	L3	L4	L5
Coaxial Pairs	4	6*	10	11
Working Pairs	3	5	9	10
Channel Capacity per Pair (from Table 10-5)	600	1860	3600	10,800
Channel Capacity per Route	1800	9300	32,400	108,000

* The L3 channel capacity shown was achieved in 1960 when the coaxial-12 design became available. Prior to 1960, L3 service was on the coaxial-8 design, for which L3 route capacity (3 working pairs and 1 spare pair) was 5580 channels.

10.3.2.2 System Transmission Plan and Repeater Performance

The transmission plan of a coaxial analog system specifies the bandwidth, repeater spacing, and signal transmission levels so that prescribed channel objectives are realized over the life of the system. In order to transmit a particular bandwidth on a specified cable, the repeater spacing is determined by the available gain, noise figure, load-carrying capacity, and nonlinear performance of the repeater, and by the margins that are required to allow for cable and repeater variations which are caused by aging, temperature variations, and manufacturing tolerances.

Table 10-7 illustrates how the basic repeater noise, load capacity, and nonlinearity were improved as coaxial system design progressed from L3 through L5. In comparing the repeater performance parameters of Table 10-7, note that the noise, load capacity, and nonlinearity improvements from L3 through L5 were achieved at progressively higher top-channel frequencies.

TABLE 10-7
PERFORMANCE OF L3, L4, AND L5 BASIC REPEATERS

REPEATER PARAMETER	L3	L4	L5
Top Frequency (MHz)	8.3	17.5	60.6
Channel Capacity	1860	3600	10,800
Repeater Spacing (miles)	4	2	1
Load Capacity (dBm)	16	21	24
Noise Figure* (dB)	11	6.5	5.5
Second-Order Distortion* M_2 (dB)†	-61	-70	-66
Third-Order Distortion* M_3 (dB)†	-96	-99.8	-110
Insertion Gain* (dB)	44	33	31

* Top-channel performance.

† M_2 and M_3 are second- and third-order modulation coefficients that characterize repeater nonlinearity in terms of the output voltage of an applied fundamental and its second and third harmonics. These coefficients are defined as 20 log of the ratio of the amplitude of the harmonic of interest to the square (for second order) or cube (for third order) of the amplitude of the fundamental.

Table 10-7 shows, for example, that operating at one-half the L4 repeater spacing and more than three times the L4 top-channel frequency, the L5 basic repeater has a 1-dB better noise figure, 3-dB higher load capacity, and 10-dB better third-order nonlinearity than the L4 basic repeater. All parameters are referred to their respective top-channel frequencies. Top-channel L5 repeater insertion gain is slightly lower than in the L4 repeater, despite the higher top transmitted frequency, in accord with the 2:1 reduction in repeater spacing.

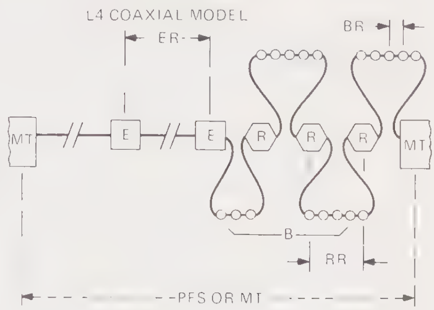
10.3.2.3 Repeatered Line Design Considerations

Line repeaters are powered over the coaxial lines from remote power feed stations. Alternating-current supplies were employed in the L1 and L3 systems and direct-current supplies in the L4 and L5 systems. The coaxial cable is placed in the ground at a nominal depth of 4 feet. In L1 and L3, aboveground repeater stations were used; in L4 and L5, all repeater stations are below ground, with manhole access. Fig. 10-13 shows a typical L4 or L5 repeatered line layout between two main station power feed points. The maximum permissible spacing for an L5 power feed link is 75 miles. In specifying this limit, repeatered line equalization and line powering over the cable tend to be the controlling factors. At 75 miles, the L5 power-feed span limit is a convenient submultiple of the L4 power-feed span limit, thereby facilitating L4 to L5 conversion.

MODEL / MILES*	L4 COAXIAL		L5 COAXIAL	
	AVG	MAX	AVG	MAX
BASIC RPTR (BR)	2	2	1	1
REGULATING RPTR (RR)	12	12	6	7
EQUALIZING RPTR (ER)	44	54	30	38
POWER FEED (PF)	–		60	75
POWER FEED SWITCH (PFS)	120	150	120	150
MAIN TERMINAL (MT)	120	·	240	·

SYSTEM CAPACITIES	L4			L5		
NO. COAX PAIRS	12	20	22	12	18	22
NO. MGS	30	54	60	90	144	180
NO. 4 kHz	18,000	32 400	36 000	54 000	86 400	108 000

*BASED ON THE NATIONAL AVERAGE



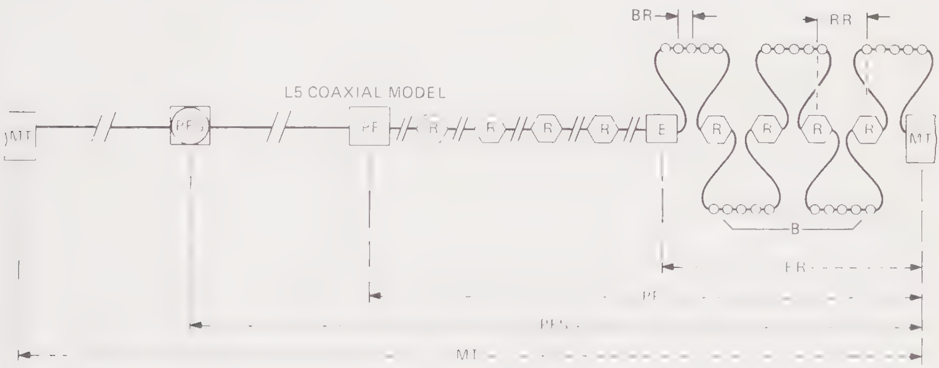


Fig. 10-13. Coaxial Repeatered Line Layouts

The L5 basic repeaters, spaced at nominal distances of 1 mile, are fixed-gain repeaters designed to match the loss (at nominal temperature) of 1 mile of 3/8-inch coaxial cable. Line build-out networks are used in basic and regulating repeaters where shorter-than-normal cable spans are required. Minimum repeater spacings of 0.5 mile and maximum spacings of 1.9 miles are permissible under prescribed L5 spacing rules. The inherent high degree of spacing flexibility of analog cable systems is realized through the careful design of repeater spacing rules. This flexibility is of substantial practical and economic value in solving route engineering and layout problems that often occur, for example, in congested metropolitan areas or in long river crossings.

As shown in Fig. 10-13, L5 regulating repeaters are located at nominal intervals not exceeding 7 miles. Pilot-controlled regulating repeaters dynamically compensate for cable loss variations which are caused by changes in ground temperature. Regulating repeaters also incorporate phase-shaping networks in order to produce a significantly less linear phase-shift-versus-frequency characteristic for the L5 repeatered line than for earlier systems. This minimizes the cumulative inphase addition from repeater to repeater of third-order modulation products.

At intervals not exceeding 38 miles from adjacent L5 power feed main stations, a midspan equalizing repeater provides a manually adjustable bump[5] equalizer, which corrects for residual time-invariant manufacturing deviations, and a deviation equalizer, which corrects for normal repeater characteristics and for predictable average manufacturing error. Similar sets of adjustable bump equalizers and deviation equalizers are located in the adjacent power feed main stations. At these stations, additional manually adjustable bump equalizers are provided to facilitate finer-grained equalization of the 75-mile line characteristic.

Pre- and post-regulation and equalization in equal parts are employed widely in L4 and L5 regulation and equalization plans. The primary advantages of pre- and post-regulation and equalization techniques for a specific repeatered line layout are a reduction in required repeater power output and a reduction in signal-to-noise penalties caused by deviations from an ideal transmission characteristic.

10.3.2.4 Current Use and Future Possibilities

The major market for L5 during the 1970s is expected to be in the relief of coaxial and radio systems currently operating along the major North-South and East-West corridors in the intercity network. An expanded L5 system, which can provide up to 13,200 voice channels per coaxial pair, is being developed. This increased capacity is derived mainly by reducing the spacing between mastergroups (see Section 10.4.2) and, to a lesser extent, by slightly increasing the top operating frequency. With additional design effort, VSB digital mastergroup equipment, previously designed for L4 applications, could be extended to transmit a 13.29-megabit-per-second digital signal (22 kilobits per second per voice channel displaced) in a specific mastergroup assignment on an L5 or an expanded L5 system. Digital transmission on coaxial mastergroups is currently of interest in the DDS network (see Section 12.4) for large cross-section data circuit requirements.

Analysis and exploratory development work indicate that further exploitation of 3/8-inch coaxial cable for analog transmission beyond the expanded L5 65-MHz capability is technically feasible. Studies of system design, device capability, and the coaxial medium itself suggest that a system with a 150-MHz top-channel frequency can be achieved on 3/8-inch cable. The existing 3/8-

5. A bump equalizer has a gain-frequency characteristic with maxima or minima that can be adjusted.

inch coaxial plant is a tremendous asset, and every attempt will be made to exploit it for as many channels as it can be made to carry economically.

10.3.3 TERRESTRIAL RADIO

10.3.3.1 Existing FDM-FM Systems

Background

The first microwave radio systems grew largely from the accelerated advancement of microwave circuit technology that occurred during World War II. This technology, coupled with a pressing need for a wideband transmission facility for the burgeoning commercial television industry, led to the first system, TDX, which went into service between Boston and New York in 1948. The TDX system was followed by the TD-2 system in 1950. Over the years, the TD-2 system has spread across the country to form a vast communications network that has become a major segment of the Bell System toll plant. Although system growth was stimulated by the needs of television, the public telephone network quickly took over as the major user of microwave radio systems. Today, long-haul microwave radio systems operating in the 4- and 6-GHz common-carrier bands provide approximately 60 percent of the circuit-miles in the toll network. Only about 9 percent of the radio channel-miles are devoted to television.

System Description

Long-haul microwave radio systems use intermediate frequency (IF) heterodyne-type radio transmitters and receivers. In these systems, each transmitter and receiver is fixed-tuned to the frequency of a particular radio channel in one of the frequency bands allocated by the Federal Communications Commission for this type of service. By means of a heterodyne or mixing process involving a local oscillator signal, each transmitter and receiver shifts or translates the information-bearing signal between the frequency of the radio channel and an IF band centered at approximately 70 MHz. The fact that the radio equipment usually bears the system name (e.g., the TD-2 transmitter-receiver bay) leads to the impression that the systems consist solely of this equipment. This is not the case, as is illustrated by the block diagram of a radio system shown in Fig. 10-14. The elements of this figure are described in the following paragraphs. The example shown, with three regular channels and one protection channel, is for illustrative purposes only. The actual number of channels depends on the number of circuits needed on the route and the radio frequency band in which the system operates.

Current radio systems use low-index frequency modulation to transmit the information-bearing signal, referred to generally as the *baseband signal* (multiplexed voice channels, data, etc.). Thus, a device called an *FM terminal transmitter* (FMT) is required to translate the baseband signal to a frequency-modulated signal in the IF band of the system. This FM signal is then applied to the IF input of the radio transmitter for the particular radio channel on

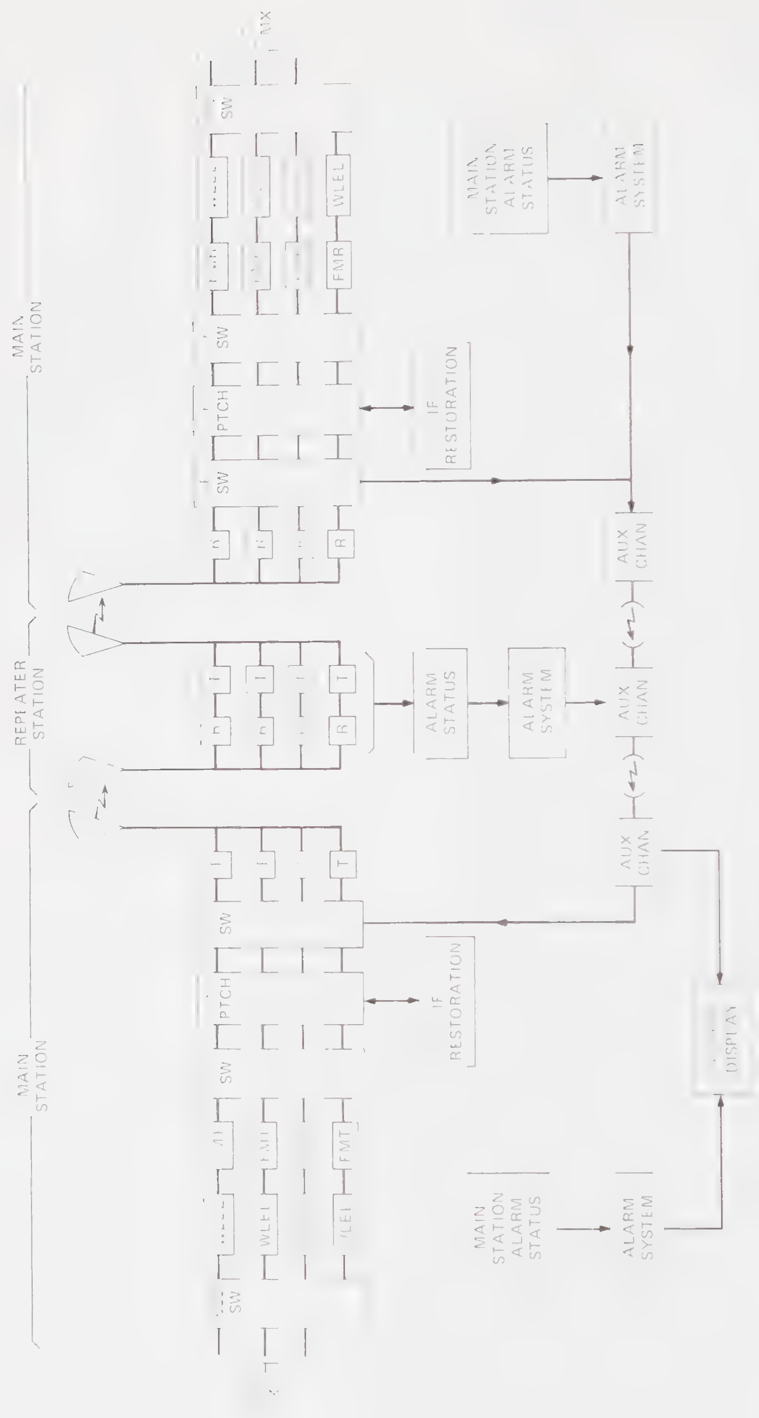


Fig. 10-14. Simplified Block Diagram (for One Direction of Transmission) of Radio System Composed of Three Regular Channels and One Protection Channel

which the information is to be carried. Similarly, an *FM terminal receiver* (FMR) is used to take the IF output of a radio receiver and recover the baseband signal from it. The baseband width that can be accommodated extends from direct current to about 8 MHz for the 4-GHz radio systems and to about 12 MHz for the 6-GHz systems. The radio channel bandwidth is wider in the 6-GHz band, thereby permitting the 6-GHz systems to transmit a wider baseband signal.

The radio transmitters and receivers are always located as close as possible to the antenna tower to minimize losses in the antenna waveguide system. At a multiplex location, the FM terminals similarly are located in close proximity to the radio equipment to minimize IF cable losses. In many cases, this leaves the FM terminals at a considerable distance from the multiplex terminals (up to 1000 feet typically, but up to a few miles in some instances). A wire-line entrance link (WLEL) is used to connect the multiplex terminals to the FM terminals. The WLEL is a coaxial cable facility that, depending on its length, may or may not be repeatered. The link includes baseband amplifiers and cable equalizers to compensate for the loss and attenuation shape of the cable. The transmitting link contains a preemphasis network that shapes the transmission levels across the baseband in a manner proportional to the radio system noise characteristic. This is done so that all voiceband circuits will have about the same signal-to-noise ratio after passage through the system. The receiving link contains a complementary deemphasis network that removes the shaping and reestablishes flat transmission levels at the input to the receiving multiplex terminals.

Standby protection facilities, which can be switched automatically into the transmission path, must be provided to meet overall system reliability objectives. Two basic switching systems are used: one to serve the FM terminals and WLELs, the other to serve the radio transmitters and receivers in what is called an *IF switching section*. An IF switching section constitutes from one to ten hops of radio bounded by IF switching equipment. Within the section, a radio channel, serving as a standby protection channel, can be substituted automatically for any one of the regular channels. Both the FM and IF switching systems provide protection in the event of equipment failure. In addition, the IF switching system provides protection against deep frequency-selective fades that may make a regular channel temporarily unusable.

To complete the system, facilities must be provided to transmit switch control information from one end of an IF switching section to the other, to connect unattended radio stations to alarm centers, and to interconnect all stations by telephone for maintenance personnel. Often these facilities are provided by a narrowband auxiliary radio system dedicated to this function. Finally, route branching, restoration considerations, and other needs necessitate the inclusion of an IF patch bay at the ends of the IF switching sections to provide flexibility in channel routing.

TD and TH System Evolution

The TD Radio Systems operate in the 4-GHz (3700- to 4200-MHz) common-carrier band. As already noted, the first major system, TD-2, was developed in the late 1940s. In its initial form, TD-2 carried 480 voiceband circuits or one television signal on each of five 2-way radio channels. A sixth 2-way channel was reserved for protection. Thus, the capacity of a fully equipped route was 2400 voiceband circuits. The worst-circuit noise objective was 44 dBrnc0 for a 4000-mile system. Repeater spacings on the first routes ranged from 20 to over 40 miles, with an average of about 30 miles. Over the years, as choice sites became more difficult to obtain and as route layouts became less than optimum because of route congestion, the average spacing diminished. Today, it is slightly less than 26 miles.

Small improvements, particularly in repeater noise figure and system equalization, permitted the capacity to be increased by a modest amount to 600 circuits per TD-2 radio channel in the early 1950s. A major advance in TD-2 route capacity came in the mid-1950s with the introduction of the horn reflector antenna system. The impact of the horn antenna system can be seen in Fig. 10-15(a) and 10-15(b) and is discussed below.

At each radio station, two different radio frequency channels are used to provide a 2-way broadband channel, one for receiving and one for transmitting. In the initial TD-2 plan, these channels, each 20 MHz wide, were separated by guardbands of equal width. This is illustrated in Fig. 10-15(a). It was intended that these guardbands be provided to minimize the possibility of interference between channels on routes that converged on previously installed routes. After the introduction of the horn reflector antenna and its associated circular waveguide system, the transmission of both vertically and horizontally polarized signals became possible with typically 30 dB of isolation between the two polarizations.[6] Use of horn reflector antennas therefore permitted the guardbands to be used for the transmission of so-called *interstitial channels* having opposite polarization to the regular channels as shown in Fig. 10-15(b). As a result, TD-2 route capacity was doubled to 6000 voiceband circuits (10 regular channels and 2 protection channels) in the late 1950s.

TD-2 was, of course, an all electron-tube system. In the early 1960s, a new, essentially solid-state system, TD-3, was developed. Using the same radio channel plan as TD-2, the TD-3 system was designed for 1200 voiceband circuits per radio channel, double the capacity of TD-2. Further, the worst-circuit 4000-mile noise performance was to be 41 dBrnC0, 3 dB lower than TD-2. These objectives were achieved. However, primarily because of cost considerations in the expansion of existing systems, the TD-3 transmitter/receiver bay did not replace the TD-2 bay in manufacture. In-

6. A delay lens antenna, capable of handling only vertically polarized signals in the 4-GHz band, was used prior to the introduction of the horn reflector antenna. The horn reflector antenna and circular waveguide system can simultaneously carry vertically and horizontally polarized signals at 6 and 11 GHz, as well as at 4 GHz, and thus may be used with radio systems in all three frequency bands.

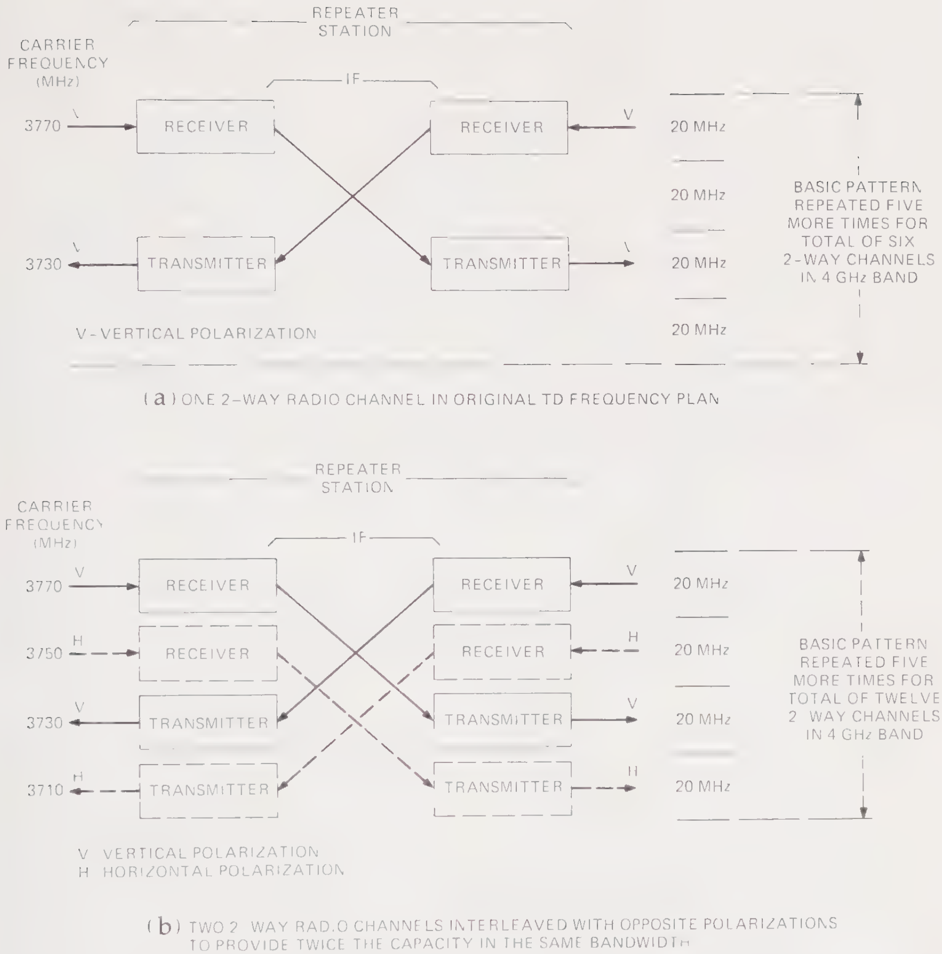


Fig. 10-15. Increase in TD System Capacity Through the Use of Vertical and Horizontal Polarizations

stead, TD-2 continued in production for use in filling out existing TD-2 routes. TD-3 was used for most new route construction.

TD-3 development gave new insights and technological advances that benefited TD-2. Through the introduction of new circuits and the improvement of existing ones, TD-2 capacity was also increased to 1200 circuits per radio channel by the late 1960s, but at 44 rather than 41 dBrnC0 noise performance. Today, both TD-2 and TD-3 are carrying 1500 circuits per radio channel, with both approaching 43 dBrnC0 noise performance as a result of continuing development effort. A new low-cost transmitter/receiver bay, TD-3D, replaced both the TD-2 and TD-3 type bays in manufacture in 1973. Further system improvements, including still higher voiceband circuit capacity, are being pursued.

The TH systems operate in the 6-GHz (5925- to 6425-MHz) band. TH-1 was developed in the mid-1950s and, except for the IF protection switching system, is a vacuum-tube system. Wider channels in this band (30 MHz) permitted TH-1 to be designed for 1860 voiceband circuits per radio channel. This gave a route capacity of 11,160 circuits (6 regular and 2 protection channels). The worst-circuit 4000-mile system noise objective for TH-1 was 45 dBrnc0 which, over the years, has been bettered through the introduction of many improvements.

TH-3 is a solid-state system, except for the traveling wave tube output amplifier, developed in the late 1960s to meet a worst-circuit 4000-mile noise objective of 41 dBrnc0 with 1800 circuits. As with TH-1, a major application of TH-3 is as an overbuild on existing TD routes, thereby substantially adding to the route capacity while utilizing existing structures and facilities.

Current effort is directed toward increasing the loading of TH-3 to 2400 circuits per radio channel.

10.3.3.2 Comparison With Coaxial Systems and Other Considerations

Overall, the fact that the microwave radio systems utilize the atmosphere as the transmission medium between repeater locations is perhaps the most obvious, and in some respects, the most significant difference between radio systems and coaxial systems. One important consequence of using this "free" medium is that repeater costs constitute a much greater part of the total system cost than in coaxial systems. For this reason, considerable effort has been directed over the years to reducing the cost of radio repeaters and associated equipment. Furthermore, because the air space is in the public domain, many design aspects of new radio systems, as well as the application of existing systems, are directly influenced and constrained by the rules and regulations of the Federal Communications Commission. For example, recent rule changes restricting the number of channels that may be used for protection purposes have necessitated the accelerated development of a new IF protection switching system (designated 400A) that will permit both 4- and 6-GHz channels to share common protection channels. These same rule changes also have resulted in the development of hot, standby space-diversity system arrangements at 4 and 6 GHz for low-capacity route applications, for which frequency-diversity protection is no longer permitted.

Fitting more and more voiceband circuits into existing channel bandwidths is desirable, of course, both from a purely economic viewpoint and from the standpoint of efficient spectrum utilization. With increased loadings, however, come problems of interference between adjacent channels that previously could be ignored. As the interference contribution to the total noise increases, effort must be expended to reduce other noise contributors to keep the total noise within objectives. Geographic congestion of both Bell System and non-Bell System radio routes magnifies the problem of interference.

To date, radio systems have been one of the most economical means of providing high-capacity routes. Of course, as the capacity of the coaxial systems has increased, the cost advantage of radio has decreased. However, there is additional capacity to be developed and improvements to be made in the existing radio systems, which should continue to make them highly competitive with coaxial systems for some time to come.

10.3.3.3 Current and Future Developments

At the end of 1973, there were 79,400 route-miles of TD and 11,400 route-miles of TH radio. This vast network will be used as part of a nationwide Digital Data System (DDS) by inserting a specially processed 1.544-megabit DS-1 signal in the normally unused bottom portion of the baseband spectrum (see Sections 5.3 and 12.4). This is illustrated in Fig. 10-16. The system, designated the 1A Radio Digital System (1A-RDS) and referred to popularly as DUV (data under voice), makes use of special terminals to encode the DS-1 signal into a 0.772-megabaud signal. Service to 5 cities began in 1974 and grew to 24 cities by the end of 1976.

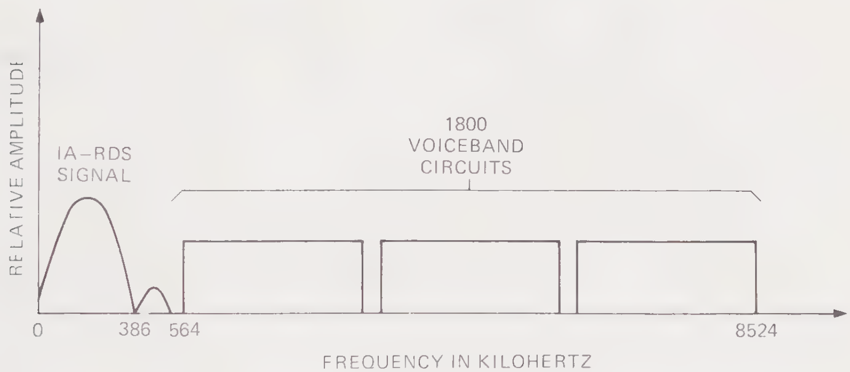


Fig. 10-16. Baseband Spectrum of 1A-RDS Digital Signal Plus Typical FDM Load

Use of the 11-GHz band (10,700 to 11,700 MHz) has been limited to short-haul radio systems, primarily because transmission in that band can be severely attenuated by heavy rainfall. However, there are situtations in which the use of 11 GHz is feasible and highly desirable in conjunction with the 4- and 6-GHz long-haul systems. These situations include the use of 11-GHz channels for protection on combined 4- and 6-GHz routes and as regular channels in congested areas where further extension of the 4- and 6-GHz systems is not possible. The TN-1 system has been developed for these as well as the short-haul applications discussed in Section 10.2.5. It will have a maximum route capacity of 12 radio channels as compared with 6 for the TL systems described in Section 10.2; a radio channel will have a capacity of 1800 voiceband circuits, the same as the TL system. Production of the TN-1 system began in 1974.

Perhaps the most exciting forthcoming development is single-sideband (SSB) radio. Exploratory work was started in the late 1960s on a 4-GHz system that could transmit 3600 SSB voiceband circuits in each 20-MHz radio channel. Essentially, this is equivalent to putting an L4 carrier signal on radio. Particular emphasis has been given to designing a sufficiently linear repeater with adequate dynamic equalization to give satisfactory system performance in the presence of normal fading. A field test to determine the feasibility of this type of system was conducted in 1974 and confirmed the basic design goals. Development of a 6-GHz version was then started, and a 4-GHz version may follow. The SSB systems probably will be introduced principally as conversions or overbuilds of existing FM radio routes and are expected to provide an economic means for extending the capacity of the intercity radio network. The impact of the use of SSB radio will likely be in the deferment of new buried system construction.

10.3.4 WT4 MILLIMETER WAVEGUIDE SYSTEM

During the last decade, various ways of implementing the nationwide telephone network in digital terms have been examined, but none has proved practicable. There are basically two reasons for this. First, attractive digital technology for providing long intercity circuits was not available; long-haul digital coaxial systems, forerunners of the T4M system, were not economically competitive with L4 or L5. Note that repeatered line costs are a very important factor in long-haul systems, a different situation from short-haul carrier systems in which digital systems have proved attractive. Second, with analog space-division voiceband toll switches, the potential economies of digital connections between growing digital exchange area networks of T1 systems could not be realized. It now appears that these two basic difficulties may gradually disappear. No. 4 Electronic Switching Systems will provide digital toll switching, and a long-haul digital transmission system, the WT4 waveguide system, has been developed and may become attractive for new construction when the demand for circuits in buried facilities exceeds the capacity that can be achieved on existing coaxial cable installations.

10.3.4.1 Channelizing Plan

The WT4 system is a long-haul (4000-mile), high-capacity digital facility utilizing buried circular waveguide as the transmission medium. In the system designation, WT4, the "W" stands for waveguide and the "T4" indicates that it is a transmission system channelized to carry the 274.176-megabit-per-second DS-4 bit rate on each broadband channel. The transmission plan for the system provides 60 digital channels in each direction of transmission, with each channel using 2-phase DPSK modulation. A fully loaded WT4 system can carry nearly 230,000 2-way PCM voice circuits.

10.3.4.2 Medium Fabrication and Placing

As noted in Section 6.1.3.5, two types of waveguide medium (dielectric-lined and helix) will be used on a WT4 route. Normally, about 98 percent of the waveguide installed will be dielectric-lined. In both cases, the steel waveguide tubes have a wall thickness of about 0.15 inch and are drawn to very close dimensional tolerances on diameter, roundness, and straightness to control mode conversion. As shown in Fig. 10-17, the waveguide tubing itself is supported by spring-mounted rollers inside a steel sheath 5-9/16 inches in diameter with 3/16-inch walls. The manufactured lengths of sheath will be joined in the field by welding and will be buried 4 feet under ground. The waveguide lengths are then joined, also by welding, and pushed into the completed sheath. Thus, the finished structure will be extremely rugged and is expected to be highly resistant to mechanical injury. Corrosion protection will be provided for the sheath, and a dry nitrogen atmosphere will be maintained inside both waveguide and sheath.

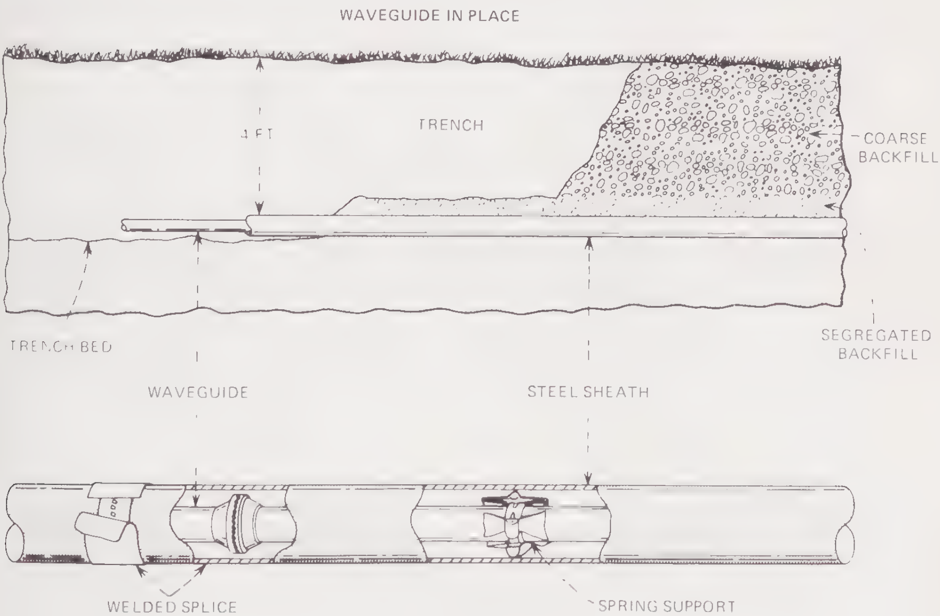


Fig. 10-17. Buried Waveguide

10.3.4.3 Right-of-Way and Repeater Spacing Requirements

Right-of-way requirements for waveguide are similar to present coaxial cable requirements, except that there can be no sharp bends. The minimum radius of curvature will be about 250 feet, determined by the elastic limit of the steel sheath. This condition may cause a curved right-of-way to be required in some bends, but causes no serious limitations in following elevation changes in most terrain. Because of the low transmission loss, repeater station spacings of about 25 miles are anticipated. It will thus be possible in most instances to locate the repeater stations near existing roads, providing easy access for commercial power and for maintenance.

10.3.4.4 Repeater and Repeater Station Design

As shown in Fig. 10-18, the received signals from the waveguide are divided at each repeater station into 120 broadband channels (60 for each direction of transmission) by means of a waveguide filter network. The DPSK signal in each channel is then processed by its own repeater. In each repeater, the received DPSK signal is shifted down to an intermediate frequency (IF) centered at 1.36 GHz, amplified, filtered, and equalized. It is then detected and regenerated, after which the signal is a stream of on-off baseband pulses at the 274-megabit-per-second rate, identical to the originally transmitted digital signal. Thus, the original signal is available at each repeater, and broadband channels can be added or dropped or the channel assignment of a given signal can be changed at any repeater station.

For continued transmission in the waveguide, the baseband signal is used to drive a modulator that modulates the phase of a millimeter-wave IMPATT diode oscillator. The output millimeter-wave signals are then recombined onto the waveguide in a filter network similar to that used at the input. The repeater buildings will be above ground with two rooms. One room will contain the repeater electronics under fairly close environmental control, and the other will contain cooling equipment and diesel generator backup power.

10.3.4.5 Protection Switching

A fully loaded WT4 system will consist of 57 working channels carrying service and 3 protection channels. Two of the protection channels will be switched in automatically. The third protection channel will be manually patched in by interchanging cables at the baseband points of the repeaters. A protection switching span may contain up to 12 repeater hops (each hop having a maximum spacing of 25 miles), providing a maximum span length of 300 miles. Error performance will be monitored at the receiving end of the protection span. If the error rate exceeds a predetermined level, the carried signal will be switched automatically from the working channel to a protection channel. When the failed hop is identified, the manual protection channel will be used to replace the failed hop during repair, and the automatic protection will be released. It is estimated that an outage objective of 0.02 percent per 2-way 4000-mile connection will be met.

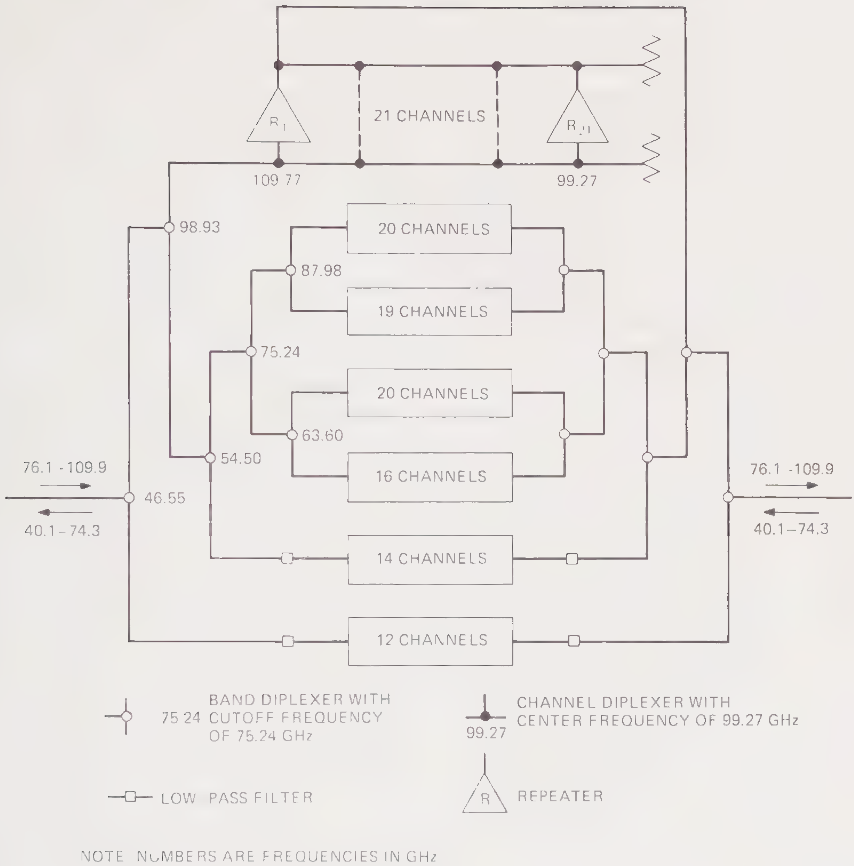


Fig. 10-18. WT4 Channelizing Plan

10.3.5 SATELLITE AND UNDERSEA CABLE SYSTEMS

10.3.5.1 Satellite Systems

In July 1962, the Bell System's TELSTAR demonstrated the feasibility of commercial quality communication via active satellites. In 1963 and 1964, NASA's Syncom satellites demonstrated the feasibility of launching and station-keeping for synchronous satellites. From the time of TELSTAR and Syncom, advances in satellite technology and improvements in launch vehicle capability have led to a viable international satellite communications system. Under the direction of the International Telecommunications Satellite Consortium (INTELSAT), the capacity of international satellites has increased by a factor of 30, from about 300 one-way telephone channels in 1965 to 9000 one-way telephone channels in 1974, and there is at least one working and one protection satellite in each of 3 general areas of the world. Not all these channels can be realized in practice, because INTELSAT must serve the small user, who needs only a few channels but wants to talk to many countries, as well as the large user, who needs large channel groups which can be handled more efficiently. INTELSAT continues to look ahead to larger satellites. The Long Lines Department of AT&T, along with other users, participates in the ownership of earth stations in the United States and leases channels from the Communications Satellite Corporation (COMSAT) for use in providing international telephone circuits.

The advances in satellite capability have led AT&T to include satellites in plans for future domestic long-haul transmission systems. Regulatory action began in 1965 and, after a number of rounds of applications, culminated in 1973 in FCC construction permits to AT&T and COMSAT General in combination.[7] Under this arrangement COMSAT General will procure, launch (through NASA), and own satellites that they will rent to AT&T. AT&T will own several earth stations and the end-link radio-relay systems connecting them to metropolitan junctions, where the voice circuits will enter the existing toll plant. General Telephone and Electronics, through its subsidiary, General Satellite, will participate in this arrangement and will own several additional earth stations and associated connecting systems.

The COMSAT/AT&T system operates in bands at 4 and 6 GHz which are used by radio-relay systems. Since these converge at metropolitan junctions, the earth stations must be remote to avoid mutual interference. A feature of this system is the use of orthogonal polarizations, which doubles the capacity of the frequency bands. Each satellite will transmit 14,400 2-way voice circuits. Two working satellites and one protection satellite are planned. The number of circuits is small relative to AT&T's total circuits, but the circuit-miles are significant. The intrinsic round-trip delay on these circuits (or any circuits provided on a synchronous satellite system) is 0.6 second. This produces a noticeable degradation during speech transmission, even if echo suppressors are properly adjusted; it can sharply reduce the throughput in data transmission when retransmission is employed for error correction.

The 4- and 6-GHz bands are only 500 MHz wide, and this limits the capacity of the first system. There are bands at higher frequencies, approximately 18 and 30 GHz, which are each 2000 MHz wide and will accommodate many more voice channels. At these frequencies, the beams of antennas that will fit within satellites are so sharp that the same frequency can be reused to several different cities. Sharp beams mean high antenna gain, so less transmitter power is needed than for broad area coverage. Also, earth stations probably can be built at metropolitan junctions, avoiding end links. These factors combine to suggest that 18/30-GHz satellites can have much higher capacity than 4/6-GHz satellites. The cost per satellite may be somewhat greater, but considerably less per voice channel. Rain attenuation is severe at these frequencies, but this can be overcome by operating earth stations in diversity pairs, for example, 20 miles apart. Very seldom will it rain extreme-

7. Several other applications also were approved.

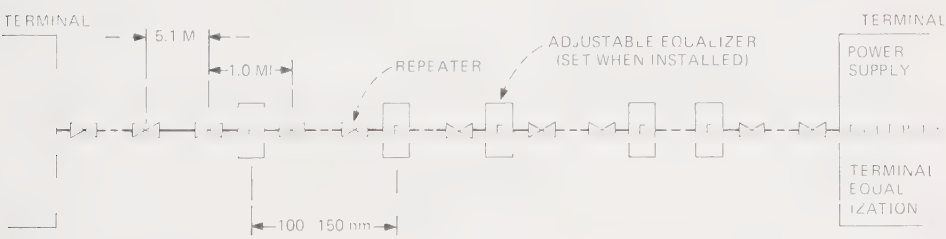
ly hard simultaneously at both stations. The problem of designing a system whose size will meet the needs when the system is placed in service at costs competitive with future terrestrial systems is being addressed.

10.3.5.2 Undersea Cable Systems

Undersea cable systems are analog, repeatered, coaxial-cable systems carrying single-sideband frequency-multiplexed channels. In principle, they are very similar to land coaxial systems. As in land systems, for a specified level of noise and a particular cable, repeater spacing is determined by the need to keep signal levels above a floor set by repeater thermal noise performance and below a ceiling determined by repeater nonlinear distortion. As improved technology makes high-performance amplifiers capable of amplifying broader bandwidths, the per-channel cost of both land and sea systems can be reduced by putting more channels on a single cable (assuming, of course, that the growth in traffic can fill the additional channels).

An undersea cable system consists of cable, repeaters, equalizers, and two shore terminals (see Fig. 10-19). The difference between land and sea coaxial systems stems, of course, from the differences in environment. Because repair of a sea system may take several weeks and is very expensive, reliability is a prime consideration. The objective (which has so far been met in existing systems) is no more than about three or four system interruptions caused by electronic component failure during a projected 20-year system life. (The system may of course last much longer.) This requires levels of reliability about two orders of magnitude better than the objectives for a land system. Such

LOW BAND 1.0 13.5 MHz HIGH BAND 16.5 29.1 MHz
NO. OF CHANNELS 4000
CABLE DIAMETER - 1.7 INCHES
REPEATER SPACING 5.1 NAUTICAL MILES (SEE FIGURE BELOW)



REPEATER TOP FREQUENCY PARAMETERS

G_R 41 dB M_{2R} 72 dB M_{3R} 116 dB

MAX POWER 24 dBm NF 5 dB

MAXIMUM VOLTAGE FOR 4000 NM 5900 + 1000 VOLTS EARTH POTENTIAL 6900 VOLTS

Fig. 10-19. SG Undersea Cable System

improvements in reliability are obtained by conservative design, special manufacturing facilities, extensive use of aging, and detailed inspection at each step of manufacture and assembly.

In addition to reliability, a high order of stability is required, as equalization is easily accomplished only during cable laying. Any serious changes in transmission characteristic after cable has been laid must be compensated by equalization at the terminals or by very expensive deep-sea operations.

It is therefore not surprising that undersea cable components cost about two orders of magnitude more than components for a land system. Transistors for undersea use may cost several thousand dollars each, and even a resistor costs approximately 50 dollars. Part of the cost is due to the small quantity production, but most of it is a result of the special manufacturing facilities and screening at all stages of manufacture. Table 10-8 compares reliabilities and prices for undersea and land coaxial system repeaters.

TABLE 10-8
RELIABILITY AND PRICE COMPARISON OF LAND COAXIAL AND UNDERSEA CABLE REPEATERS

REPEATER	RELIABILITY (FAILURES IN 10^9 HOURS)	PRICE
Land Coaxial	1000	$1000
Undersea Cable	12 (objective)	$100,000

The mechanical design of an undersea cable system is dictated by the high-pressure, highly corrosive, conducting ocean environment and by the need to install the system on the sea bottom, 2 or 3 miles below the surface. The cable contains a composite center conductor made up of a steel strength member surrounded by a copper conductor. Because of the high pressure, a solid dielectric separates the center conductor from the outer conductor (see Fig. 10-20). The repeater housing (see Fig. 10-21) is a pressure vessel with high-pressure seals to carry the center conductor of the cable into the repeater. The repeater electronics operate in an atmosphere of dry nitrogen at a pressure only moderately above one atmosphere.

Power is fed to the repeaters in series over the center conductor of the cable. Although the voltage required for each repeater is low, the large number of repeaters and voltage drop in the cable require voltages as high as 7000 volts at each end in a long system. The repeaters must be able to operate at these voltages, with respect to ground, without breaking down or generating corona-type noise. Furthermore, a cable short involves the discharge of repeater and cable capacitors that produces complicated surge patterns requiring circuitry of various types in order to protect the transistors in repeaters close to the fault.

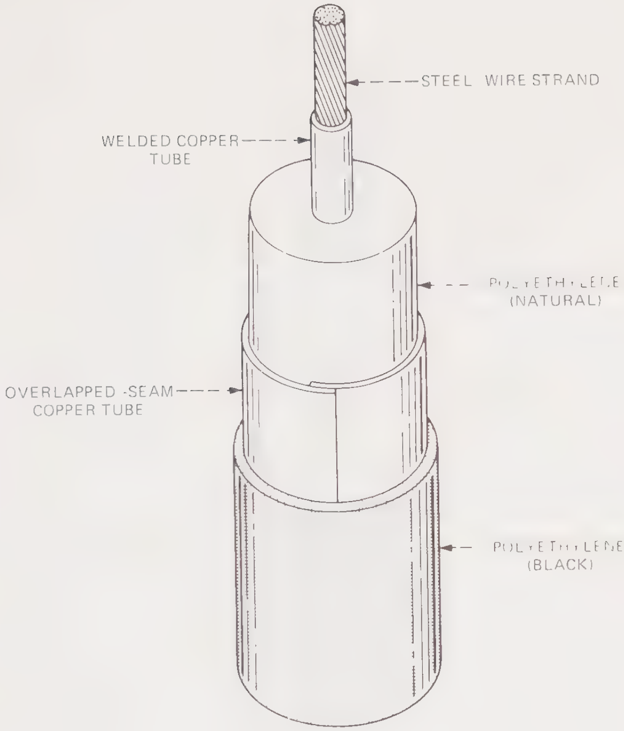


Fig. 10-20. SG Undersea Cable

The high cost of cable and its placement make an equivalent 4-wire configuration (both directions of transmission in one cable) attractive. A single wideband amplifier is used for both transmission bands. (See Fig. 10-22.)

Some advantages of the undersea cable environment over land systems are that no expensive right-of-way must be purchased and large or rapid temperature swings are avoided. However, compensation for temperature changes in the shallow water areas must be considered in the repeater design.

The single most frequent cause of system failures has been damage from fishing vessels in the continental shelf portions. In order to reduce this hazard, these portions use protective steel armor wire over the basic deep sea cable structure, are carefully routed, and, where practical, are buried 1 to 2 feet below the sea bottom.

The first undersea cable system with a transoceanic capability was the SB system, which went into service in 1956 carrying 36 channels (4 kHz) over 2 cables (one in each direction) using about 50 electron-tube repeaters. The SG system, which is scheduled for service in 1976, is the fourth Bell System design and will carry about 4000 channels (3 kHz) in both directions over a single larger-diameter cable with over 700 repeaters (see Table 10-9). The cost

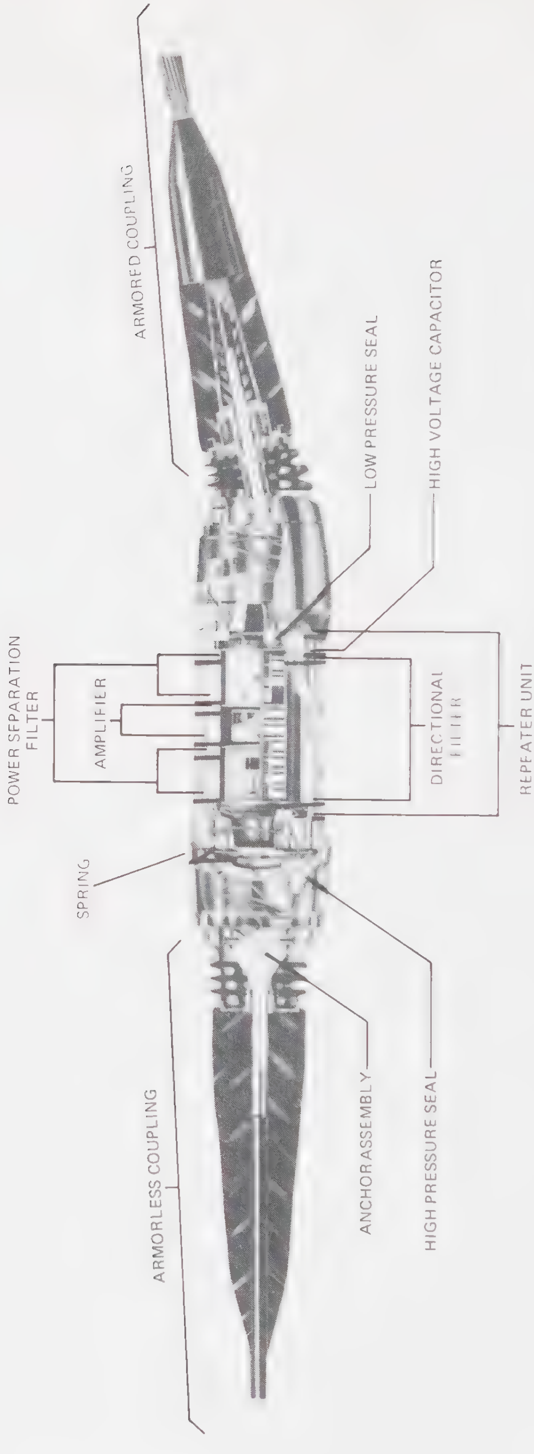


Fig. 10-21. SG Repeater

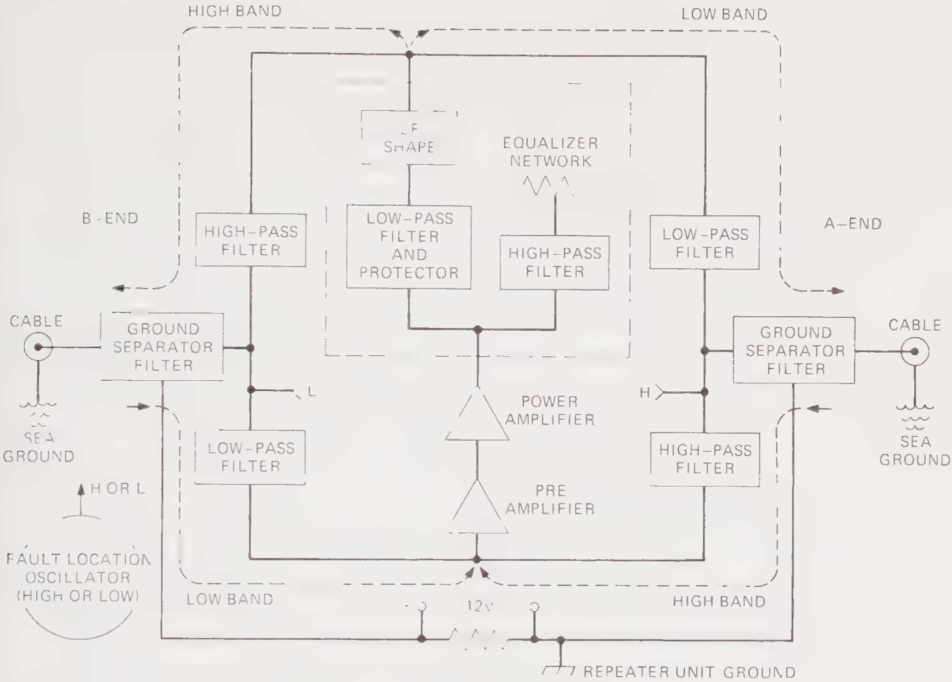


Fig. 10-22. SG Repeater

per channel for a fully loaded system has been reduced by a factor of 30 over this 20-year period.

The alternative system for international communication (except for the very limited number of channels available on HF radio) is of course a satellite system. Comparisons between undersea cable and satellite systems are, however, difficult to make, and it probably will be years before their relative roles for transcontinental transmission are clearly defined.

TABLE 10-9
EVOLUTION OF UNDERSEA CABLE SYSTEMS

SYSTEM	CAPACITY (NUMBER OF CHANNELS)	SERVICE DATE
SB	50	1956
SD	140	1963
SF	845	1968
SG	4000	1976
SH	16,000 (objective)	mid-1980s

10.4 ANALOG CHANNEL BANKS AND OTHER ANALOG MULTIPLEX EQUIPMENT

All analog multiplex terminals employ one or more levels of modulation, filtering, and signal-combining to produce a stack of channels in a frequency band (see Section 6.2). The number of channels in the final stack and thus, indirectly, the number of modulation levels are determined primarily by the line facility bandwidth. The multiplex terminals for the smaller bandwidth systems, which generally use wire-pair line facilities (e.g., N carrier), are basically one-level and are specifically designed and identified as part of the particular system. For the larger bandwidth systems, which employ coaxial cable or radio line facilities (e.g., L5 carrier, TD-3 radio), the multiplex equipment assumes its own identity and is designed and standardized for general use.

10.4.1 ANALOG MULTIPLEX FOR COAXIAL OR RADIO SYSTEMS

10.4.1.1 A-Type Channel Banks

A-type channel banks provide the first stage of multiplexing in the analog message multiplex hierarchy. An A bank translates 12 voice-frequency signals into the 60- to 108-kHz frequency band as single-sideband signals having suppressed carriers with 4-kHz spacing. It performs the inverse process also.

To indicate vintage, A banks have been designated A1 through A6. There are two A-bank designs of primary current interest: A5, found in large numbers throughout the plant, and A6, found in new installations. The two designs are completely compatible in that circuits operate satisfactorily with an A5 bank at one end and an A6 bank at the other end.

A block diagram illustrating the operation of the A5 bank is shown in Fig. 10-23. At the output of the balanced modulator, the resulting double-

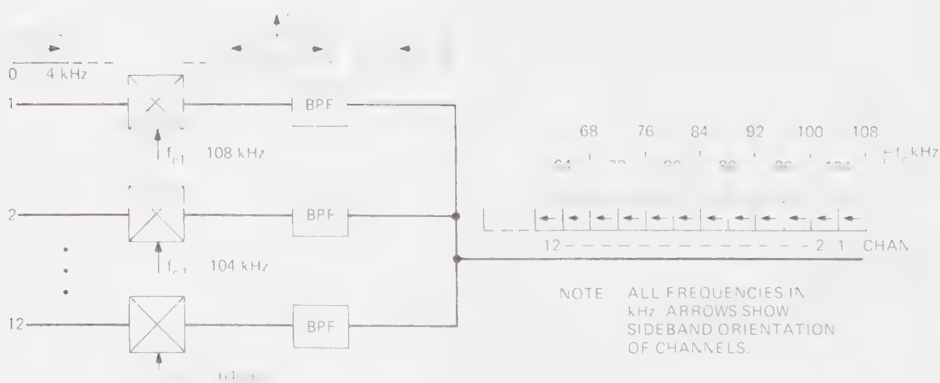


Fig. 10-23. A5 Channel Bank Transmitter

sideband signal is fed to a quartz cyrstal bandpass filter which passes only the lower sideband. Twelve translated channels are combined into a group signal. In the reverse direction, another set of identical bandpass filters selects the individual channels which are in turn translated to voice frequencies by means of 12 demodulators.

The A6 bank shown schematically in Fig. 10-24 differs from the A5 mainly in that the 60- to 108-kHz group spectrum is formed by a 2-step (rather than one-step) modulation process. This was done in order to employ the monolithic quartz crystal filter, whose implementation is optimized at frequencies close to 8 MHz. Other new technology brought into use in A6 banks for cost and size reduction includes a number of hybrid integrated circuits for amplifiers, modulators, and other circuit elements.

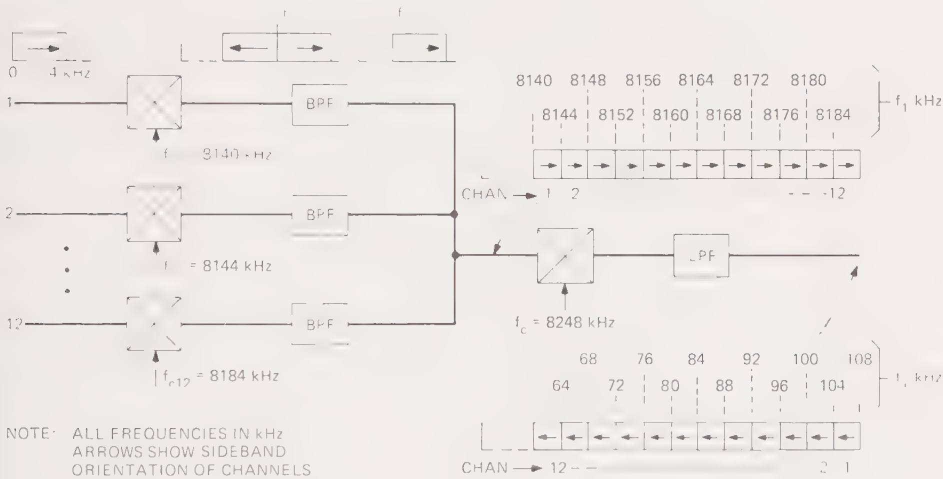


Fig. 10-24. A6 Channel Bank Transmitter

10.4.1.2 LMX Group Bank

The steps in the analog multiplex hierarchy following the formation of a 12-channel group are the formation of a 60-channel supergroup and a 600-channel mastergroup. Fig. 10-25 shows how the group bank in the L multiplex (LMX) equipment is arranged to produce the 60-channel basic supergroup. Note that in both stages of the multiplex so far described there is no space allowed in the spectrum between channels. This is made possible by the very sharp channel filter cutoff characteristics in the A-type channel bank (effective bandwidth: 200 Hz to 3400 Hz) and in the group band filters in the group connectors used to make interconnections between the 60- to 108-kHz ports of a receiving and a transmitting group bank. The bandwidth conserved permits efficient utilization of the line facility capacity.

A precise (frequency and amplitude) pilot frequency, injected at each group modulator input, is used in the receiving group bank to regulate and

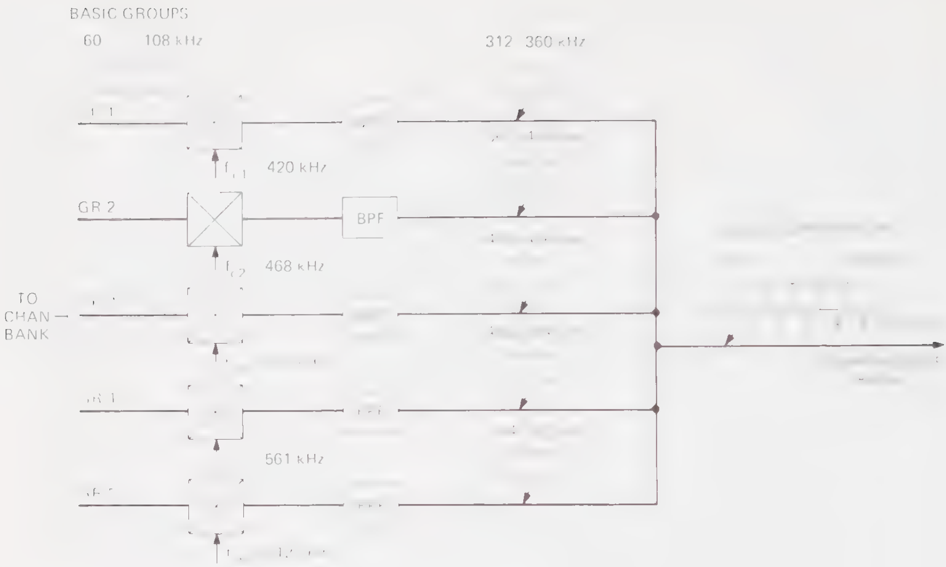


Fig. 10-25. LMX Group Bank Transmitter

maintain group net loss within very close limits. In effect, the five group pilots spaced across the supergroup band and their associated receiving regulators provide a dynamic equalizer function to compensate for amplitude deviations caused by seasonal and other slowly varying changes in the overall transmission facility.

A new multiplex unit, the direct formed supergroup (DFSG), has been designed. This unit combines the channel bank and group bank functions, thus directly producing a 60-channel basic supergroup from 60 individual voice-channel inputs. This will permit more economical multiplexing where it can be applied, but it also will require changes in existing multiplex administration policies (see Section 6.2.3) for the analog FDM network.

10.4.1.3 LMX Supergroup Bank

The LMX supergroup bank combines 10 basic supergroups into a 600-channel basic mastergroup as indicated in Fig. 10-26. This particular frequency format is called U600 ("U" denotes universal application for coaxial cable or radio line facilities). Other formats have been produced in the past (see Section 6.2), but they gradually are being converted to U600 to achieve network efficiencies.

Supergroup regulation is provided in the receiving terminal in a manner analogous to group regulation. In this case, the group 1 pilot is used at its basic supergroup frequency to avoid the cost of an additional, unique supergroup pilot.

The LMX group and supergroup banks may be packaged separately or together, depending on the office needs. The trend is to separate and cable all banks and connectors to distributing frames at the group, supergroup, and mastergroup interfaces. This promotes efficient utilization and permits short interval terminal facility rearrangements to meet changing network patterns.

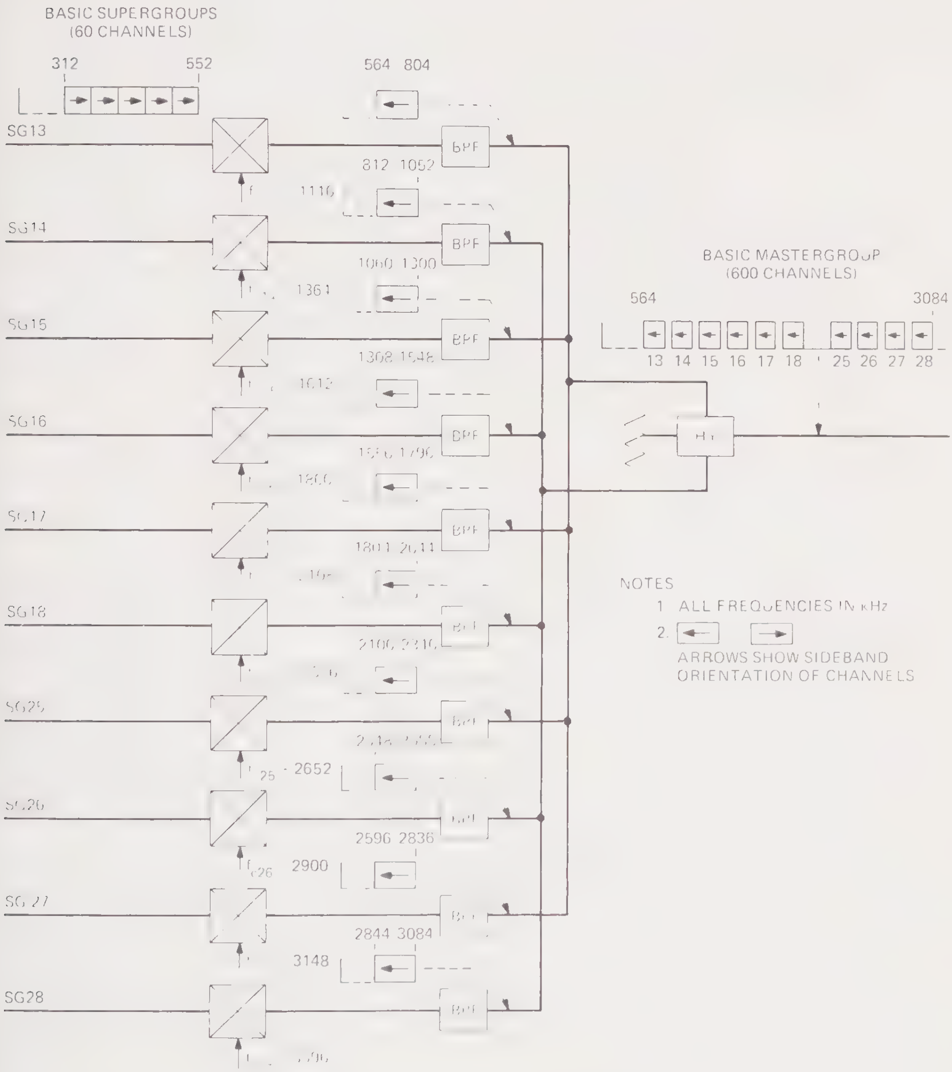


Fig. 10-26. LMX Supergroup Bank Transmitter

10.4.1.4 Mastergroup Multiplex

Mastergroup multiplex (MMX) equipment provides the next level in the FDM hierarchy and is used to form a line-frequency signal for facilities handling more than a single mastergroup (more than 600 channels). These facilities include 1500-channel TD Microwave Radio, 2400-channel TH Microwave Radio, and 3600-channel L4 Coaxial Systems. MMX equipment also is used to provide a basic jumbogroup (6 mastergroups, 3600 channels) signal which is applied to the L5 Coaxial System through the next level of multiplex, jumbogroup multiplex (JMX).

Fig. 10-27 is a simplified block diagram of a transmitting side of the MMX equipment, which forms, in this case, a 6-mastergroup L4 line spectrum. Mastergroup (MG) regulation is provided in the receiving circuit by measuring the basic MG pilot amplitude.

One feature of the spectrum produced by MMX equipment is the spacing of MGs so that it is possible to design branching and blocking filters. These are used to drop and reinsert MGs along radio and coaxial transmission routes without bringing the frequencies of all MGs down to the basic MG level.

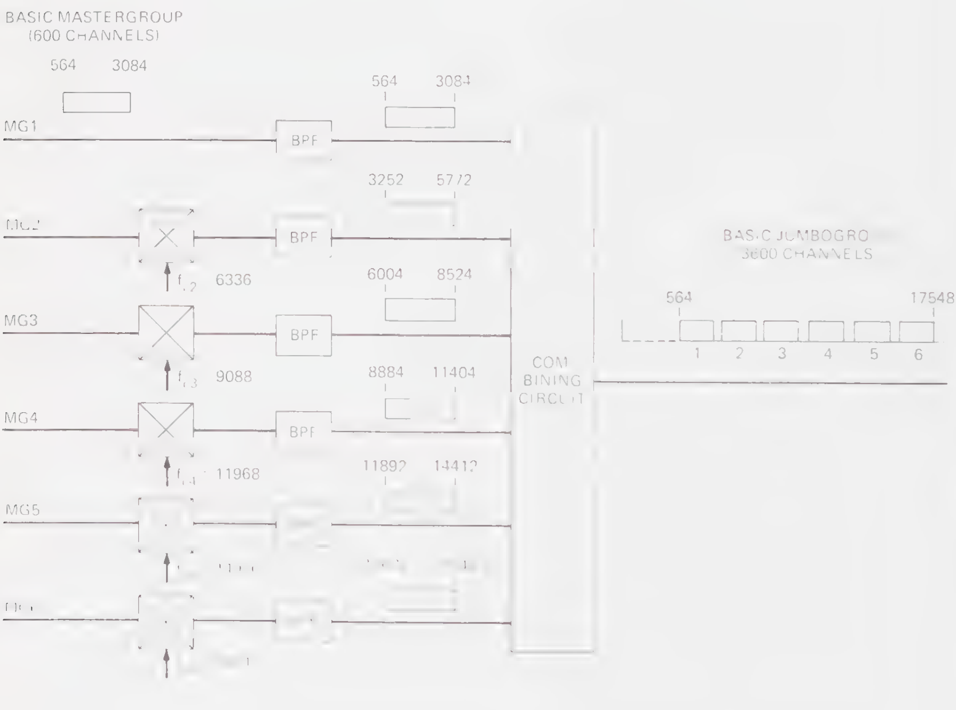


Fig. 10-27. Mastergroup Multiplex Transmitting Block Diagram

10.4.1.5 Jumbogroup Multiplex

The largest complement of channels now used in an FDM arrangement is that provided as the line signal for the L5 Coaxial System by the jumbogroup multiplex (JMX) terminal. The JMX translates the basic 3600-channel jumbogroup (JG) signal in the 0.564- to 17.548-MHz band to either the JG1, JG2, or JG3 position in the L5 line spectrum (3 to 60 MHz). The JMX modulation scheme for the transmitting terminal is shown in Fig. 10-28. The first two JGs involve two steps of modulation, whereas three steps of modulation are used for JG3. The receiving terminal uses two steps of demodulation for JG1 and

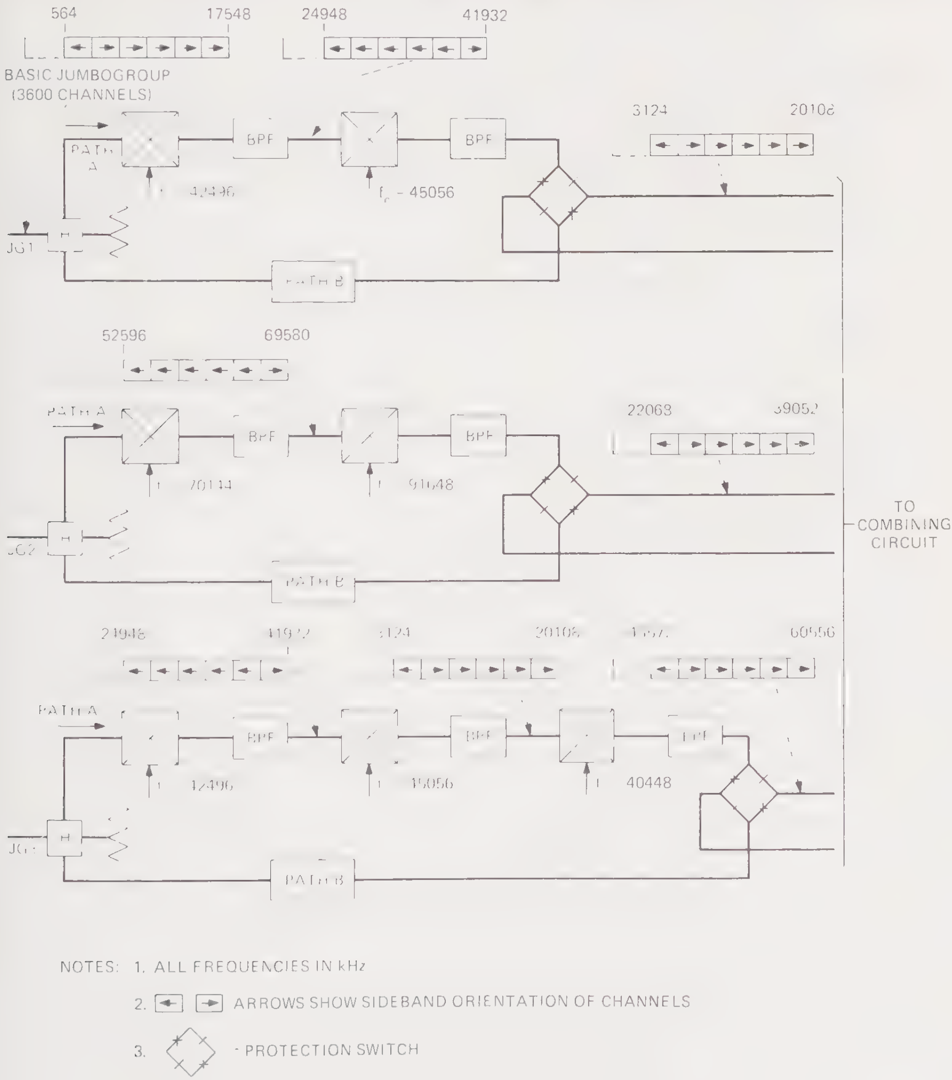


Fig. 10-28. Transmitting JMX Terminal

JG2 and only one step of demodulation for JG3. Thus, four steps are needed to modulate a JG up and down. Multiple steps of modulation are needed to ease filter design and to avoid signal interference problems.

Reliability is of paramount importance because of the large number of circuits involved. JMX provides one-for-one protection using a simple transfer switch and logic circuit. Each basic JG at the output of the JMX receiving terminal is accurately regulated using a JG pilot.

10.4.1.6 Mastergroup and Multimastergroup Translators

The development of mastergroup and multimastergroup translators permits improvements in system capacity utilization. The combination of mastergroup translators has a significant cost advantage over MMX/JMX equipment because of a reduction in the number of modulation steps between basic mastergroup and line frequencies and in protection equipment requirements. The mastergroup translator (MGT) is availble in two types. MGT-A is used to translate a basic U600 mastergroup spectrum to and from one of the six line mastergroups in a basic jumbogroup and supplants the MMX-2 in new mastergroup multiplex additions to existing coaxial and radio routes. MGT-B will be used to perform mastergroup translation to and from the multimastergroup spectrum for expanded L5 (and SSB radio) in the late 1970s. The use of MGT-Bs on L5 (in combination with a slightly higher top line frequency) permits up to 4 more mastergroups to be added to the present 18-mastergroup L5 spectrum. This is accomplished by sacrificing the "guard space" between mastergroups provided in the MMX design for blocking and branching capability. Considering the resultant extra capacity (with the attendant deterral of new route construction), there is little doubt that it is advantageous to give up some flexibility in mastergroup administration.

Fig. 10-29 shows the frequency assignments and the utilization of MGT-Bs and multimastergroup translators (MMGTs) in organizing 22 mastergroups on an expanded L5 line. As indicated, three multimastergroup assemblies of seven, seven, and eight mastergroups each are provided. The spacing between adjacent mastergroups in these assemblies is a fixed value of 168 kHz rather than a constant percentage of the mastergroup guardband center frequency as in the MMX design. The mastergroups are placed into the multimastergroup spectrum by the MGT-Bs, and the multimastergroup assemblies are shifted into the proper line-frequency assignments using MMGTs. A multimastergroup pilot at 13.920 MHz is inserted into each assembly prior to translation and is used for continuity checking and multimastergroup protection switching. The guard space between the multimastergroups is sufficient to permit blocking at line frequencies (for purposes of branching and dropping) at most of the multimastergroup assemblies or combinations thereof. This avoids the need for demultiplexing the entire line signal when access to only a single multimastergroup at a multiplex point is needed.

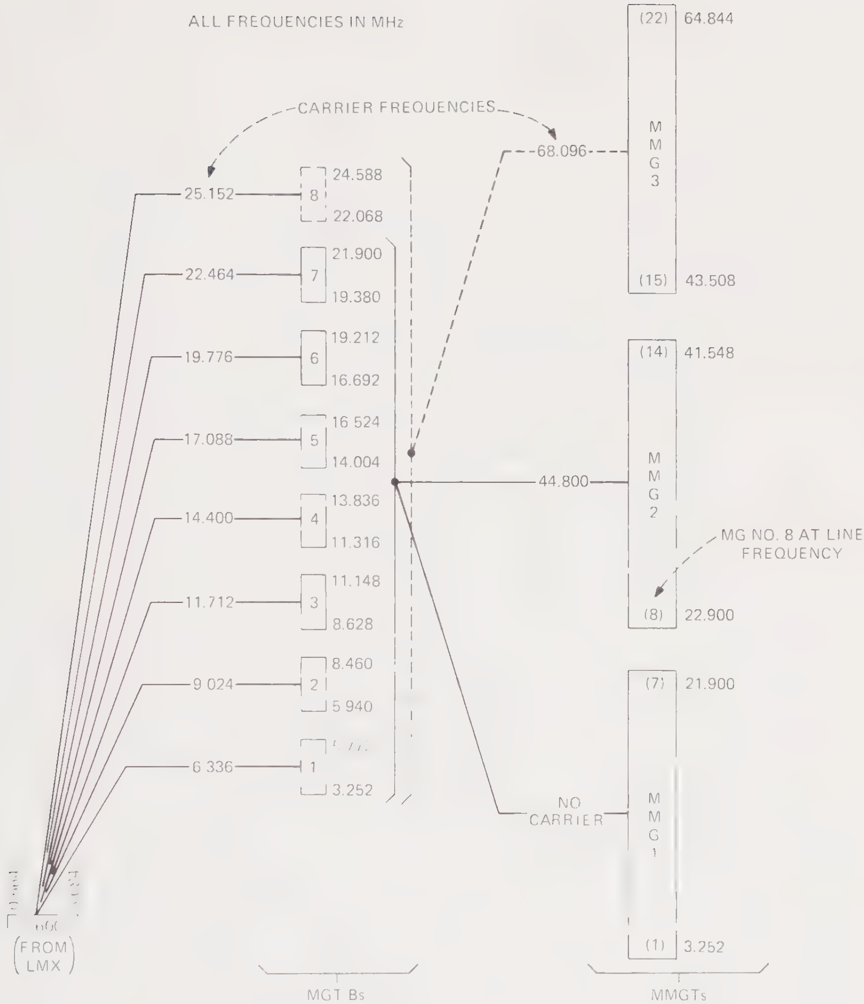


Fig. 10-29. Expanded L5 Frequency Allocation

10.4.2 ANALOG MULTIPLEX FOR WIRE-PAIR SYSTEMS

Multiplex terminals for these systems differ in some details such as number of channels and frequency format, but there are more similarities than differences between them because the important terminal parameters essentially are determined by the characteristics of the wire-pair line. Thus the N2 and N3 terminals, currently in production, will serve as reasonable examples. These terminals interface directly with the N carrier line and, in fact, include the system terminal repeaters.

The N2 terminal uses DSB techniques to multiplex 12 voice channels together into a 96-kHz-wide group signal. Prior to modulation, the volume of each voice signal is compressed at a syllabic rate by a factor of 2:1, thus reducing the total signal volume range. This is required to achieve noise and crosstalk objectives and to allow reasonable repeater spacings on wire-pair facilities. The signal volume range is restored by a complementary expandor after demodulation in the receiving multiplex terminal. Because signal net loss variations that occur between the compressor and expandor would be doubled by the operation of the expandor, each channel is amplitude-regulated in the receiving terminal prior to the expandor. The regulation is controlled by the amplitude of the transmitted channel carrier pilot.

The N3 terminal uses SSB techniques to modulate 24 voice channels into a 96-kHz-wide signal and so doubles the capacity of the N system line at some additional terminal cost. However, on longer routes, the overall per-circuit cost is lower than with N2 terminal use because of the wire-pair savings. In general, the N3 terminal duplicates the N2 functions in that it provides signal compression, expansion, and regulation in addition to modulation and demodulation. Every other channel carrier is transmitted, and the regulators then operate on both of the channels adjacent to the carrier.

10.5 DIGITAL CHANNEL BANKS AND OTHER DIGITAL MULTIPLEX EQUIPMENT

As in frequency-division-multiplex systems, time-division-multiplex transmission involves one or more stages of signal combining (see Section 6.2). In the case of a short-haul T1 Carrier System carrying a 24-channel circuit group, the channel terminal equipment bears a unique relationship to (and is normally thought of as part of) the transmission facility. For the higher bit rate systems (e.g., T2, T4M, DR18, and WT4), the multiplex arrangements have evolved in a hierarchical manner to be consistent with the capabilities of the various media (paired cable, coaxial cable, radio, and waveguide) for high-speed digital transmission.

10.5.1 D-TYPE CHANNEL BANKS

10.5.1.1 General

D-type channel banks perform the conversion between 24 separate analog voiceband channels and the 1.544-megabit-per-second DS-1 signal. The DS-1 signal is suitable for transmission over 1.544-megabit-per-second T1 repeatered lines or over higher-capacity lines with the digital multiplexing equipment described in Section 10.5.2. In addition to coding and decoding the voiceband signals, these banks also have built-in signaling circuits (see Section 11.3) for conversion between dc signaling states and a portion of the 1.544-megabit-per-second DS-1 signal. Each of the D-type banks, D1, D2, and D3, contains channel units that provide the interface between the voiceband circuits and the common units shared by all channels in the bank. There are many varieties of channel units for each D-type channel bank, since they must be able to interface with both 2- and 4-wire circuits having many different signaling arrangements.

10.5.1.2 Comparison of D1, D2, and D3

The first D-type bank, the D1A, was designed to provide a low-cost facility for exchange trunks. The D1A went into service in 1962. The low cost and good performance resulted in rapid growth and a demand for a similar type of bank for use in special-service circuits. The D1B was developed for special-service applications requiring four signaling states. The D1C, also very similar to the D1A, utilizes the signaling bits for the channels to transmit data for TSPS remote operators.

The D2 bank was developed to provide higher-quality transmission performance for toll circuits. The improved performance is gained by using all eight bits allocated to each channel for voice sample encoding, except during every sixth frame when the least significant bit is borrowed for signaling. Another source of improvement is the use of a controlled segmented linear companding characteristic, rather than the nonlinear diode characteristic used in the earlier D1 banks. The bit borrowed for signaling every sixth frame is time-shared so that 4-state signaling is obtained. Because of differences in the signaling format and companding characteristic, the D2 bank is not end-to-end compatible with the D1A or D1B banks.

The D2 bank went into service in 1969. Although it also converts between 24 analog voiceband channels and a 1.544-megabit-per-second DS-1 signal, the encoder and decoder used are common to 96 channels. The D2 bank includes digital processing to interface between a 6-megabit-per-second internal signal and the 1.544-megabit-per-second line signal. The D2 design has 96 channels in an 11-foot 6-inch bay, compared with 72 for D1 banks.

Development of the D3 bank was motivated by advances in integrated circuit technology. The D3 bank was intended primarily as a lower-cost replacement for D1 banks in new manufacture. During development of D3, the advent of digital switching in No. 4 ESS was anticipated. To obtain compatibility with No. 4 ESS and improvements in transmission quality, the D2 signaling format and companding characteristic were used. By using hybrid integrated circuits (HICs) and by putting the sampling gates and filters in the channel unit plug-ins, the D3 banks package 144 channels into an 11-foot 6-inch bay. The D3 bank can be used in both exchange and toll applications.

Two additional developments resulted from D3: the D1D bank and a unitized D3 bank. The D1D is a modification of D1A or D1B, involving replacement of 12 plug-in common units. This modification makes D1D end-to-end compatible with D3. The other development is a unitized D3 that combines D3, loss adjustment attenuators, and switched maintenance access in a bay to obtain toll trunking and maintenance features. The D3 unitized bay packages 96 channels in an 11-foot 6-inch bay.

With the increasing cost of cable facilities, the combination of D3 banks and T1 repeatered lines in large metropolitan areas is more economical than voice-frequency cable pairs for trunks longer than 8 miles and, in many cases, longer than 5 miles. Furthermore, with the introduction of the No. 4 ESS digital switching system, it is expected that toll-connecting trunks using D3 banks at one end and T1 lines will prove more economical than voice-frequency facilities and associated voiceband interface units for any distance. The T2 and T4M repeatered lines now in service and other high-speed lines being developed will increase the use of D-type banks.

10.5.2 DIGITAL MULTIPLEX

10.5.2.1 Multiplex Operation

Digital multiplexes are essentially digital processors. A transmitting multiplex combines in time sequence a number of inputs at one transmission rate to produce a single signal at a higher rate; a receiving multiplex performs the reverse process. The input signals originate from different sources and are in general nonsynchronous. Digital multiplexes employ pulse-stuffing techniques (see Section 6.2.4) to combine the nonsynchronous inputs into a single serial bit stream. The multiplexes also interface with line systems and must provide the appropriate interfaces and line code formats. A large portion of a digital multiplex is associated with the transmission line interfaces.

Fig. 10-30 is a block diagram of a multiplex having N inputs. It illustrates the basic structure of all digital multiplexes, although they differ in specific details of implementation. The input signals are in a line format that usually is not suitable for processing in the multiplexer, and, hence, there is circuitry associated with each input. This circuitry (1) extracts timing information from the signal, (2) regenerates the signal, (3) converts the signal from the line code format into a binary form for processing, and (4) places the information into a small buffer memory. The transmitting common equipment provides the basic timing for the transmitter, combines the N input signals in time, adds housekeeping bits to permit proper demultiplexing at the receiver, and controls the pulse-stuffing operation. The composite multiplexed bit stream must then be converted into the proper line code for transmission, and the necessary signal level must be generated.

At the receiving or demultiplex end, the processes are carried out in reverse order. The common equipment includes a line interface that extracts timing from the incoming signal, regenerates the signal, and converts it from the line code into a binary form for processing. Further, there is circuitry that demultiplexes the signal into its N components and then removes the stuffed time slots from each one. The demultiplexed and destuffed signals are then put into a small memory associated with the per-line output circuits. Each per-line circuit contains a phase-locked oscillator to smooth out timing irregularities created by the multiplexing and stuffing processes. Finally, there is circuitry to convert the binary signal into the line code required and to generate the proper signal amplitudes.

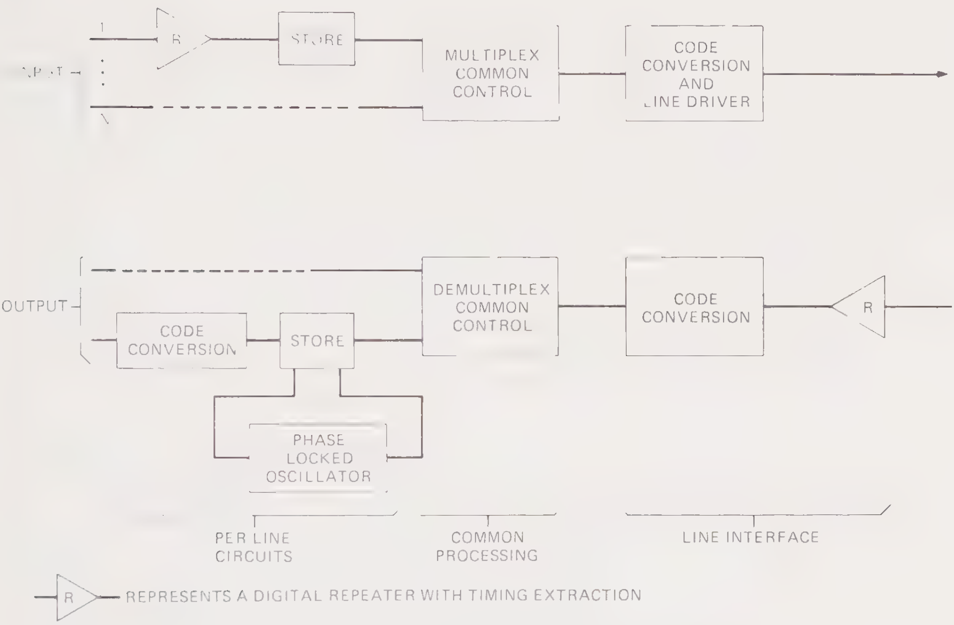


Fig. 10-30. Block Diagram of a Digital Multiplex

10.5.2.2 M12 Multiplex

The M12 multiplex combines four DS-1 signals into a single DS-2, 6.312-megabit-per-second signal. This multiplex was introduced in 1972 with the T2 digital line. M12 multiplex is available in several physical configurations, including both factory-wired bays and individual shelf assemblies.

The multiplexes are available with a time-shared performance monitor that provides an in-service measurement of the error performance of the multiplex, initiates alarms when the error rate is unacceptable ($>10^{-4}$), and provides a visual indication of the location of failures. Automatic M12 protection switching is optional. When protection switching is included, the performance monitor automatically transfers service from the failed to a standby multiplex.

During early installations of the T2 system, a need became apparent for a means of providing a small number of T2 systems as branches off the major route. These branches generally had a low growth rate and small cross sections, and the economics thus were not favorable for the full T2 and M12 equipments. In order to meet this application, M12s were packaged without the performance monitor and without protection switching. These arrangements are designated M12A and M12B and are designed to interface with the T2 intermediate power bay or T2A shelf (M12A) and the DSX2 cross-connect bay (M12B).

10.5.2.3 M1C Multiplex

The M1C multiplex terminal combines two DS-1 signals into a single DS-1C, 3.152-megabit-per-second signal for transmission over the T1C digital line. It is basically similar in technology to the M12. The multiplexes are provided in three different sizes of factory-wired bays. In addition to the multiplexes, each bay contains a switched standby multiplex that can be substituted for a working multiplex.

The initial equipment, available in 1976, has manual protection switching and alarms based on loss of frame by the receiver or loss of the incoming T1C signal. The manual protection switching system can be used to isolate failures and substitute the standby multiplex for a failed multiplex. Automatic switching is planned as an option.

10.5.2.4 M13 Multiplex

The M13 multiplex terminal takes 28 DS-1 signals and generates a single DS-3, 44.736-megabit-per-second signal. This multiplexing is accomplished in two stages. In the first stage, four DS-1 signals are multiplexed into a 6.312-megabit-per-second signal whose format is identical to that of the M12 multiplex signal. In the second stage, seven of these 6.312-megabit-per-second signals are multiplexed up to the DS-3 level. In essence, the M13 multiplex is seven M12 multiplexes plus a single M23 multiplex (where M23 would stand for a single multiplex of seven DS-2s to one DS-3) combined into a single piece of equipment, so that the interface circuits required at the DS-2 level are eliminated. In the previous section, it was pointed out that these line interfaces constitute a significant portion of the multiplex, and, hence their elimination reduces the cost significantly.

The M13 multiplex was developed in lieu of an M23 because the initial application of M13 was to provide access to DS-4 transmission facilities such as T4M and DR18 (see Section 10.2). Since a major application of T4M and DR18 is in congested metropolitan areas where there are extensive T1 networks, the major interface for the high-capacity systems is the DS-1 interface. However, the M13 was structured so that later interconnection from the DS-2 level to the DS-4 level could be accomplished compatibly with an M23 multiplex. That is, the DS-3 outputs of an M13 and an M23 are indistinguishable.

The initial installation of M13 was in 1975 on a route from Newark to Manhattan. The initial equipment had manual protection switching and alarms based upon loss of framing information. A time-shared performance monitor has been designed and can be added to the M13.

Physically, two M13s and the appropriate standby equipment are contained in a single 7-foot uniframe. Since the M13 has two stages of multiplexing, protection and standby equipment are provided for each level. The equivalent of one M12 multiplex serves as a standby for both M13s, giving a 14:1 working-to-spare ratio. The circuitry for the second stage of multiplexing is fully duplicated, because it consists of only five plug-in cards. When the performance monitor becomes available, it will provide in-service monitoring of the error performance of the multiplex and will initiate protection switching to the appropriate standby equipment when necessary.

10.5.2.5 M34 Multiplex

The M34 multiplex serves as the source for the T4M Coaxial, DR18 Radio, and WT4 Waveguide Transmission Systems. This multiplex combines six DS-3 signals into a DS-4, 274.176-megabit-per-second signal at the highest level in the hierarchy. The initial installation of M34 was also in 1975 on the T4M route from Newark to Manhattan. In this application, the M34 was used as a simple stand-alone multiplex without protection switching or elaborate performance monitoring. An error performance monitor and protection system has been designed and can be added.

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11 Associated Systems

Systems closely associated with switching systems and transmission systems are power systems, distributing frames, and signaling implementation. They will be discussed in this chapter.

11.1 POWER FOR COMMUNICATIONS SYSTEMS

Two basic functions are generally provided in power supplies for communication systems: rectification and reserve storage. Rectification is necessary because most devices in telecommunications systems (relays, switches, electron tubes, transistors, and even the telephone set) operate on direct current, whereas energy is supplied by an electric utility in the form of alternating current. A reserve source of energy is needed because telecommunications systems historically have been designed to provide continuity of service, even when the normal source of energy has been interrupted.

Operating companies spend millions of dollars each year in capital and operating funds for equipment whose main function is to ensure that the customer can use his telephone at all times, even to call the power company to report an electric service outage. A standby power system must be provided, and it must be available for instantaneous use, since many calls in progress would be disconnected if power were interrupted, even for only a few milliseconds. Because the power facilities in a switching office or repeater station are used in common by a large number of customers, redundancy is used extensively in order that the failure of a single component or unit does not disrupt system operation.

This service philosophy applies generally to central office switching systems and to transmission systems. Other equipment, such as data stations and key telephone equipment installed on customer premises, is normally not provided with standby power facilities. Reserve power for key systems is available, but is seldom used. Some PBXs have reserve power provisions and other PBXs do not; some may be furnished with reserve power at the option of the customer.

The emphasis throughout the remainder of this section will be on power supply provisions for facilities in central offices, repeater stations, and other operating company installations.

11.1.1 SOURCES OF ENERGY

For almost all telephone equipment in the United States, the normal energy source is alternating current purchased from an electric utility. Energy from this source is rectified, converted, conditioned, or regulated as required for the specific system. Over the years, a number of unconventional power supply systems have been investigated, and some of these have been installed in field trials or in isolated systems. Examples are:

(1) Continuously operated diesel-electric generators (installed at a remote microwave station in the Sierra Nevadas).

(2) Solar cells (used in a rural carrier field trial).

(3) Propane-fueled thermoelectric generators (for remote repeaters and a digital radio system).

The electric utility industry has developed a concept of universal electric service throughout the country. Thus, any proposed application of novel energy sources must be compared with the conventional approach with regard to capital costs and operating expense. On the basis of experience in such comparisons, it appears that unconventional power sources will continue to find only a very limited use in the Bell System.

11.1.2 ENERGY STORAGE

Two energy storage systems are used extensively in the Bell System: electrochemical cells and standby generator sets which are powered by internal combustion engines.

Electrochemical cells provide an instantaneous reserve source of dc power. For this application, lead-acid cells are generally used because of their low cost compared with other electrochemical systems. In principle, these cells are similar to ordinary automobile batteries. However, the cells used for telephone service are engineered for long discharge times (hours) at moderate temperatures, whereas automobile batteries are expected to furnish high engine-cranking currents for short intervals (seconds) over a wide range of temperatures. Furthermore, cells for telephone applications are designed for long life (typically 15 years), whereas most automobile batteries have a normal life of 3 to 4 years. For these reasons, lead-acid cells for telephone applications are manufactured with thicker structural elements and are activated with a weaker concentration of sulfuric acid than automobile cells. Cells for telephone service are purchased in accordance with Bell Laboratories specifications and are available in a wide variety of sizes from 100 to 7000 ampere-hour nominal ratings.

Recently, Bell Laboratories developed a new lead-acid cell, using novel specifications for both materials and fabrication in order to obtain much longer life with greatly reduced maintenance. These so-called round, or cylindrical, cells are now being manufactured for the Bell System according to these specifications.

Nickel-cadmium cells have found limited use in engine-cranking service; these are unsealed cells, commonly called *flooded.* Sealed nickel-cadmium cells have been applied to several pole-mounted transmission systems, where the maintenance needs of lead-acid cells represent a severe operating penalty.

In addition to the short-term reserve provided by lead-acid cells, standby internal combustion engine-generator sets are installed in many telephone company buildings to provide a long-term reserve. For these systems, the energy storage is in the form of liquid hydrocarbon fuel, and a typical communications center may provide fuel storage for 2 days to 3 weeks of continuous operation of essential equipment.

Until recently, most of these sets utilized diesel engines as a prime mover. Application of gasoline engines has been restricted because of stringent safety codes. In the last few years, gas turbine sets were developed and extensively applied, especially in the larger sizes (200 kW and above). The term "gas" is used to distinguish these turbines from the water-driven turbines in hydroelectric plants. Gas turbines were originally derived from, and are still similar to, jet aircraft turbines, and they burn diesel fuel. These units are generally much lighter and smaller than reciprocating engine sets and can be installed in upper floors or even on a building roof, whereas the diesel engine-generator has generally been relegated to the basement.

To gain the benefit of their respective advantages, these two energy storage systems are commonly employed together as shown in Fig. 11-1. The lead-acid cell is employed in a battery plant, which consists of the following four main elements:

(1) A group of lead-acid cells connected in series, commonly called a *battery,* to provide electrical energy in the event of failure of the normal supply.

(2) Rectifiers to convert alternating current to direct current to supply the telephone equipment load, to maintain a proper voltage on the battery, and to recharge the battery after it has been discharged.

(3) Control and monitoring equipment.

(4) Distribution facilities.

The battery plant accepts ac power when it is available and provides a source of dc power which is continuous until the lead-acid cells are discharged. In normal practice, the battery is selected to provide 3 to 8 hours of reserve time. The diesel engine or gas turbine generator set is normally idle and is started only after an outage of the normal electric utility. Its output is then switched in to replace the utility supply, and the rectifiers again assume the load and recharge the battery. The hours of reserve time and the choice of manual- or automatic-start engine-generator are determined by the local telephone company for each location, based on the history of commercial power

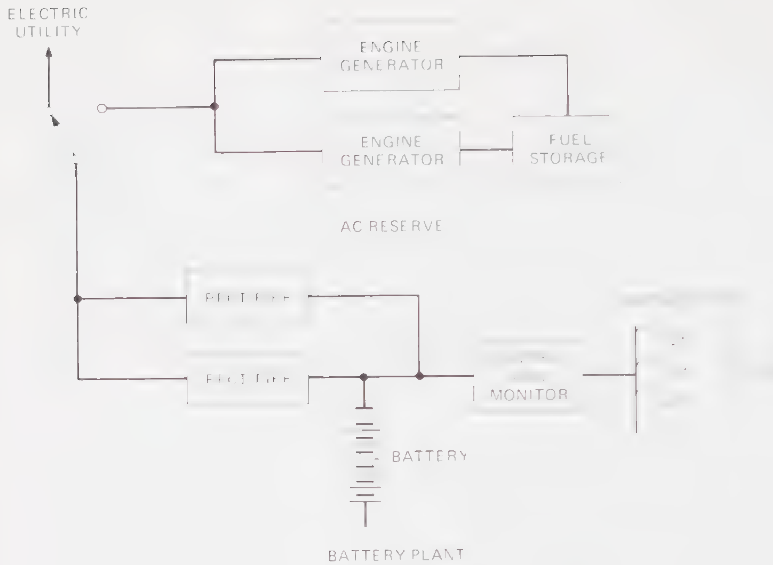

Fig. 11-1. Central Office Power System

outages, round-the-clock availability of operating personnel, and accessibility of the location to service personnel. For example, an important microwave station on a remote mountaintop may have as much as 24 hours of battery reserve, as well as two automatically operated engine-generator sets.

In small community dial offices, a standby engine-generator may not be furnished. In this case, the battery is engineered to provide 24 hours or more of reserve, and a portable engine-generator is brought to the site in the event of a long-term failure.

To defer capital expense until the reserve capacity is actually needed, both batteries and engine-generators may be installed in increments as the office load grows. Battery strings are simply connected in parallel, whereas engine-generator sets must be installed with individual load transfer arrangements.

11.1.3 BATTERY PLANT CONFIGURATIONS

The simplified description of a battery plant just given is adequate to illustrate its operation as a power conversion and energy storage system. However, in order to provide control of output voltage, more extensive plant features may be required.

Voltage control is often necessary because of the voltage characteristics of a lead-acid cell under various operating conditions. A lead-acid cell used in telephone service has an open circuit voltage of 2.06 volts. However, under open circuit conditions, the cell will gradually self-discharge. In order to maintain the cell fully charged and yet avoid excessive water loss or plate corrosion, the cell voltage is normally maintained at 2.17 volts. This is termed "float" operation of the cell. This voltage must be held to within ±1 percent by the rectifiers in the battery plant to ensure optimum battery life. In the event of ac power failure, the cell voltage immediately drops to a value slightly below 2 volts per cell. The initial drop in voltage and subsequent discharge voltage are both strongly influenced by the discharge rate, as illustrated in the typical cell discharge curves shown in Fig. 11-2.

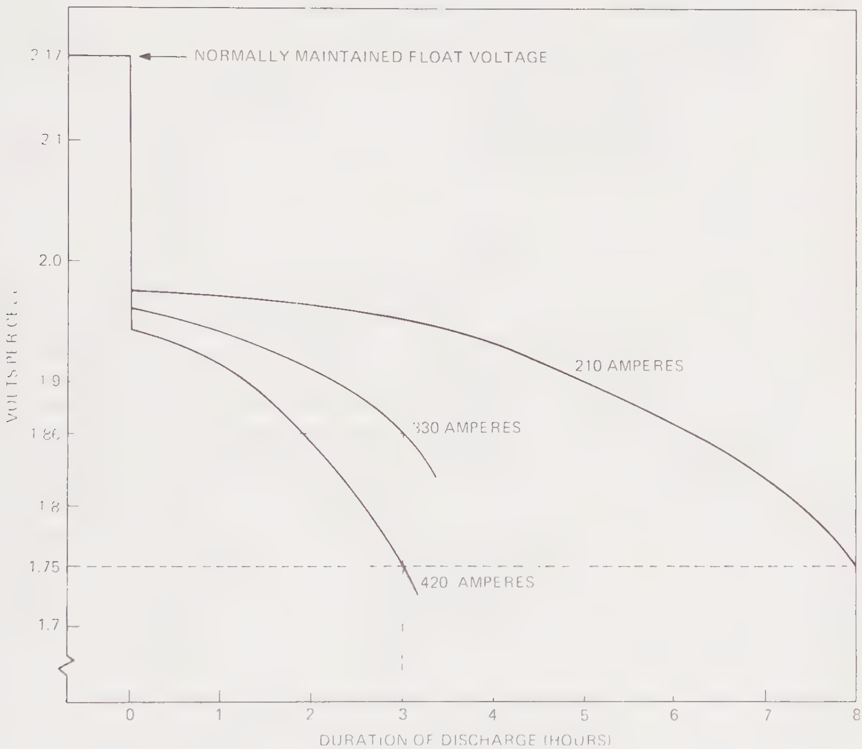

Fig. 11-2. Battery Discharge Characteristics

Since the cell voltage is normally maintained at 2.17 volts, the normal float voltage of a 24-cell battery plant is 52.08 volts. If the reserve time of this plant is based on discharging each cell to 1.75 volts, the minimum voltage at the battery will be 1.75 times 24, or 42 volts. The minimum voltage at the load would typically be about 2 volts lower because of distribution voltage drop, so the utilization equipment would be required to operate over a range of 40 to 52 volts. Many loads cannot operate satisfactorily over such a wide voltage range, so various methods are employed in the design and engineering of battery plants to restrict the voltage to a narrower range.

The simplest method is to engineer the battery so that the discharge voltage is not permitted to drop as low as 1.75 volts per cell at the end of the desired reserve time. For example, if the minimum cell voltage is held to 1.86 volts, the battery voltage will drop only to 44.6 volts at the end of the engineered reserve time. However, inspection of the cell discharge curves (Fig. 11-2) shows that the cell can supply only 330 amperes for 3 hours if the minimum voltage is 1.86 volts per cell, compared with 420 amperes if the cell can be discharged to 1.75 volts. Thus, the cells provide about 22 percent less capacity when they are used in this fashion.

Capacity curves for different cell sizes have been derived to permit selection of the proper battery to give the desired reserve time for the required load current and minimum discharge voltage.

Another technique used to restrict the voltage range of the 24-cell battery is to reduce the normal voltage supplied to the load by installing a counter-electromotive force (CEMF) cell between the battery and the load. This device maintains a more-or-less constant voltage drop over a wide range of load current, so the normal voltage seen by the load is lower than the battery float voltage by the amount of the voltage drop across the CEMF cell; this voltage drop is removed by short-circuiting the CEMF cell when the battery begins to discharge. Older CEMF cells consist of a glass jar with metal plates immersed in a solution of sodium hydroxide, with the voltage drop resulting from dissociation of water into hydrogen and oxygen. Modern cells employ a series of selenium or silicon diodes arranged in the battery plant circuit so as to develop the normal forward voltage drop when the load current flows.

A third method of controlling the output voltage of a battery plant during discharge is to switch additional cells into the circuit when the voltage drops to a preset value. The 48-volt plants that employ this method have 23 cells in the main battery and 2 groups of 2 emergency cells. The emergency cells are often called *end cells* because they are connected to the end of the main battery. During normal operation, the main rectifiers and the load are both connected in parallel with 23 cells, as shown in Fig. 11-3. In the event of an ac power failure, the main battery initially supplies the load, so the voltage starts to drop. At an appropriate voltage level, a circuit-maintaining switch operates to switch in the first group of two cells. The voltage continues to drop as the cells discharge, and the second group of two cells is switched into the circuit if the power failure is of long duration. The normal battery voltage for this plant is 23 times 2.17 volts per cell, or 49.9 volts; the minimum voltage at the battery when the cells are discharged to 1.75 volts per cell is 27 times 1.75 volts, or 47.2 volts. This type of plant thus maintains the voltage between narrow limits and obtains maximum utilization of battery capacity because the cells can be discharged to a lower voltage.

These emergency-cell plants employ a technique known as *charge-by-load* to recharge the emergency cells. When the power supply to the rectifiers is restored, the rectifiers are connected across the battery string of 27 cells, while the load is connected across 23 cells. Thus, the current supplied by the rectifiers to the load also flows through the emergency cells, recharging the cells that have been partially discharged. After the emergency cells have been

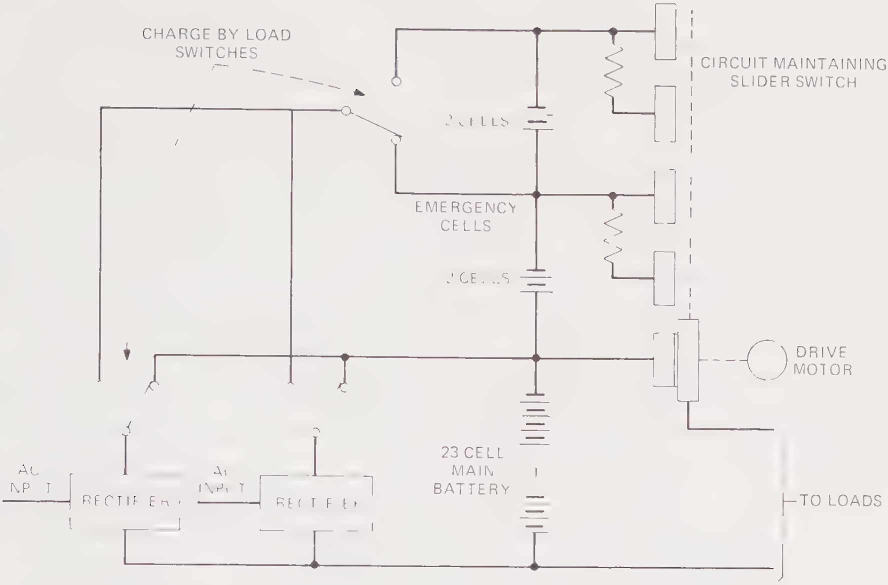

Fig. 11-3. Battery Plant With Emergency Cells

recharged, the rectifiers again are connected across the 23-cell main battery. Small trickle chargers are connected across the emergency cells to replace local losses. In the largest plants (up to 10,000 amperes) the charge-by-load feature is administered manually, whereas in smaller plants (up to 2000 amperes) this feature is fully automatic. In addition, the smaller plants are arranged for series-parallel operation of the emergency cells, in which the two groups are first connected in parallel and then switched into series if the power failure is long enough.

The plants described here are all identified as 48-volt plants, even though the normal voltage and variations during power failure are different for the various arrangements. Similar techniques are employed in 24-, 130-, and 140-volt plants, except that the number of cells connected in series is chosen to meet the desired voltage limits.

11.1.4 BATTERY CHARGING EQUIPMENT

The equipment units used in a battery plant to convert alternating current to direct current are called *battery chargers*. Actually, they perform three functions: supplying power to the loads, maintaining the battery in a fully charged state, and recharging the battery after it has been discharged. Until about 1960, ac-dc motor-generator sets were used exclusively to perform these functions in medium and large installations, and thyratron, vacuum-tube, copper-oxide, and selenium rectifiers were used in small systems. Although many of these older units are still in service in telephone power plants, the advent of semiconductor devices, such as silicon diodes and thyristors or silicon-controlled rectifiers (SCRs), has resulted in development of a wide range of modern solid-state rectifier units.

The introduction of solid-state rectifiers has permitted a change in the method of operating the power plant. Motor-generator sets were inefficient and operated poorly at light loads, so elaborate sequence-starting and stopping circuits were furnished to operate only those machines required to carry the load. Modern rectifiers, on the other hand, can be designed to have high efficiency over a wide load range and to operate satisfactorily at light loads, so they are connected to operate continuously in newer plants, thus avoiding the sequencing arrangements required with motor-generator sets.

Rectifier units are available in ratings up to 1600 amperes at 48 volts, with input voltages to match the various power service voltages in different telephone company buildings. Single-phase designs are used for power ratings up to about 5 kW, whereas 3-phase designs are used for larger sizes.

11.1.5 SPECIAL VOLTAGE SUPPLIES

Although battery plants such as those just described have provided not only the reserve source, but also the operating voltages for many telecommunications systems, the introduction of new systems and devices in the 1950s produced a need for voltages not readily obtainable from a battery plant. Voltages of several thousand volts are needed to operate coaxial cable systems, where uninterruptible power is applied to the coaxial cable at a power-feed station to energize a string of repeaters located in manholes several miles apart. Many different voltages, including some that are in the kilovolt range, are needed in microwave radio systems. Other devices need closely regulated low voltages.

The large-scale introduction of integrated circuits, many of which must operate from well-regulated supply voltages in the range of 3 to 12 volts, has accelerated the need for special power conditioning. In early systems, these voltages were supplied by regulated rectifiers which required an uninterrupted source of alternating current. Two-motor alternator sets were used to provide this ac source. (A 2-motor alternator set has an ac motor normally supplied from the electric utility, a dc motor energized from a battery plant when the ac input fails, and an ac alternator, all mounted on a common shaft.) However, the practice since the early 1960s has been to utilize dc-dc converters to provide single-step conversion from the reserve battery plant to the required dc voltages. In most applications, converters perform two functions. They furnish voltages not available from a battery plant, and they maintain better stability of the output voltage than is obtainable from a battery plant.

In its simplest form, a dc-dc converter can be viewed as a circuit that uses semiconductor devices to alternate (at a controlled frequency) the direction of flow of direct current from a battery through the primary winding of a transformer. An alternating voltage is therefore developed on the secondary winding, with the transformer performing the desired voltage conversion. The alternating current output from the transformer is then converted back to direct current by solid-state rectifiers. Transistors are employed as the switching elements in small- and medium-power converters, whereas thyristors are often used in high-power units.

Many different circuit arrangements and regulating methods are being used in present dc-dc converter designs. Some circuits do not employ a transformer as a coupling device, but instead momentarily store energy in an inductor or capacitor. When the switching elements are turned off, this stored energy is transferred to the output circuit. Most converters employ feedback circuits to regulate the output voltage or current to a closely controlled value, regardless of changes in input voltage or load current. These feedback circuits adjust the switching frequency, duty cycle, or other parameter of the switching schedule to regulate the output. Many converters are designed with monitor, alarm, shutdown, and other peripheral circuits in order to meet individual system needs.

Since the dc-dc converter interposes a major power system element between the battery plant and the load circuits, consideration must be given to the possible effect of converter failure. The most common approach is to design a converter to power a single functional unit (e.g., channel bank, radio transmitter, or memory unit) and to depend on system reliability arrangements, such as protection switching or redundancy, to maintain service in the event of converter failure. Although this avoids the need for parallel operation of converters, it may result in high costs, especially when many small functional units are required in a given installation. In these cases, parallel operation of converters, with one more converter provided than the number required to carry the load, may be more desirable. Both of the above arrangements are employed in present designs.

Since one function of the dc-dc converter is to provide close control of its output, it is essential that the converter be physically close to the load it supplies to minimize voltage drop in distribution circuits, especially in low-voltage applications. Most of the smaller units are mounted in the same frames as the loads they supply and employ similar physical design techniques. Larger converters are generally mounted in separate bays or power plants located in communication equipment rooms.

The range of converter output voltages in present systems is from 3 volts to 7500 volts, whereas power levels vary from 10 watts to 5000 watts. A large telecommunications center may have hundreds, or even thousands, of converter units of different types.

11.1.6 INVERTERS

Although most loads that require reserve power in telecommunications systems are dc-operated, certain loads, such as some motors, require alternating current. Because some ac-operated equipment is used where continuous operation is essential, dc-ac inverters are furnished to provide backup ac power. Rotating machines, with a battery-driven dc motor connected to an ac alternator, have been used for this purpose for many years. Now, however, solid-state inverters are being applied to this service. These employ transistors or thyristors to convert the dc supply from a battery plant to alternating current; filters or other waveshaping techniques are used to obtain a sinusoidal output. In most systems, the ac loads are normally powered from the electric utility supply. In the event of failure of the normal supply, they are transferred to the inverter, with only a short interruption of power.

11.1.7 REGULATORS

In some systems, although the bulk of the loads can tolerate battery plant voltage variations, certain circuits require closer control of the voltage. Dissipative series regulators employing semiconductor technology are widely used to provide precise control of the load voltage. These regulators use feedback control to adjust the voltage drop across an active element connected between the input supply and the load to maintain a fixed output voltage regardless of variations in the input supply.

In addition to minimizing the effects of slow variations in source voltage, series regulators also reduce noise. The difference between the power supplied and that consumed by the load is dissipated in the regulator. Accordingly, to avoid excessive energy loss and heat dissipation, these circuits are generally employed only when the desired load voltage is a few volts below the minimum source voltage.

In some applications, dissipative regulators are incorporated in dc-dc converter units to provide regulation, particularly where the converter has several output voltages that must be closely controlled or where an especially quiet voltage source is required.

11.1.8 RINGING AND TONES

The units that supply power to ring the customer's telephone and tones to signal to the customer the progress of the call are normally considered part of the power plant because they have been furnished traditionally by rotating machines. Modern semiconductor technology has been applied in this area to develop completely static ringing and tone plants. Power inverters, energized from a battery plant, develop 20-Hz ringing voltages, while oscillators and amplifiers provide tone voltages for use by the switching systems. Counting circuits are used to generate interruption cadences; these circuits drive semiconductor switches in order to provide interrupted ringing and tone voltages as required.

11.2 MAIN DISTRIBUTING FRAMES

A distributing frame serves as a point of termination and an interconnection interface between systems in switching offices. The main distributing frame (MDF) connects customer cable pairs to the line equipment terminals of a switching system. Similarly, the trunk distributing frame (TDF) is the interface between the switching equipment and trunks. Other distributing frames, sometimes known as intermediate distributing frames or miscellaneous equipment frames, are used to interconnect other equipment in an office.

This section describes the functions and structure of the MDF and discusses MDF-related problems, recent developments, and future trends. Other distributing frames will not be detailed here, since their functions are analogous to those of the MDF.

11.2.1 FUNCTIONS OF THE MDF

Customer pairs enter a wire center building in the form of outside plant cable pairs. Such pairs are used for special-service circuits as well as loops. Up to 2700 pairs may be contained in a single cable sheath. Each working pair must be connected to a line terminal of a switching system within the wire center or to an ongoing portion of a special-service circuit; most of the connections are to switching systems. The MDF performs this basic connecting function.

The MDF provides a flexible, semipermanent connection between a cable pair and a line terminal. The MDF allows full access, in that any cable pair may be connected to any unused line terminal. The connection remains established for a relatively long period of time, compared, for example, with the duration of a path through a switching system. Thus, the MDF performs a cross-connecting, rather than a switching, function.

The flexible cross-connecting capability of the MDF allows balancing of the traffic load on the central office equipment. Traffic should be distributed over the line terminals as uniformly as possible. Without proper load balancing, a portion of the switching equipment may become overloaded, even though the total capacity of the system has not been exceeded. The MDF provides the flexibility needed to achieve proper load balancing.

The MDF also provides protection of the switching equipment. Subscriber pairs are subject to lightning strokes and other foreign sources of electrical potential. A spurious voltage on a subscriber pair may be of sufficient magnitude to damage the switching equipment. Each subscriber pair is therefore connected to its line terminal through a protector located on the MDF. The protector normally provides a conductive path, but in the presence of a sufficiently high voltage it breaks down and electrically isolates the subscriber pair from the switching equipment.

The MDF, as well as other distributing frames, also serves as a place to terminate and connect miscellaneous items such as long-line equipment and repeaters. In addition, distributing frames serve as access points for testing. Constant rearrangement of the loop plant also has an effect on the MDF. All the above functions, and many more, contribute to a concentration of manpower at the MDF, in contrast to the rest of the largely automated central office. It is, therefore, an area that requires constant improvement in efficiency, record keeping, and maintenance.

11.2.2 STRUCTURE OF THE MAIN DISTRIBUTING FRAME

Fig. 11-4 is a schematic illustration of the MDF structure used for many years in the Bell System. A typical installation of such an MDF is shown in Fig. 11-5. The conventional MDF is a basic example of how the MDF functions may be implemented. More advanced systems will be mentioned in Section 11.2.3.

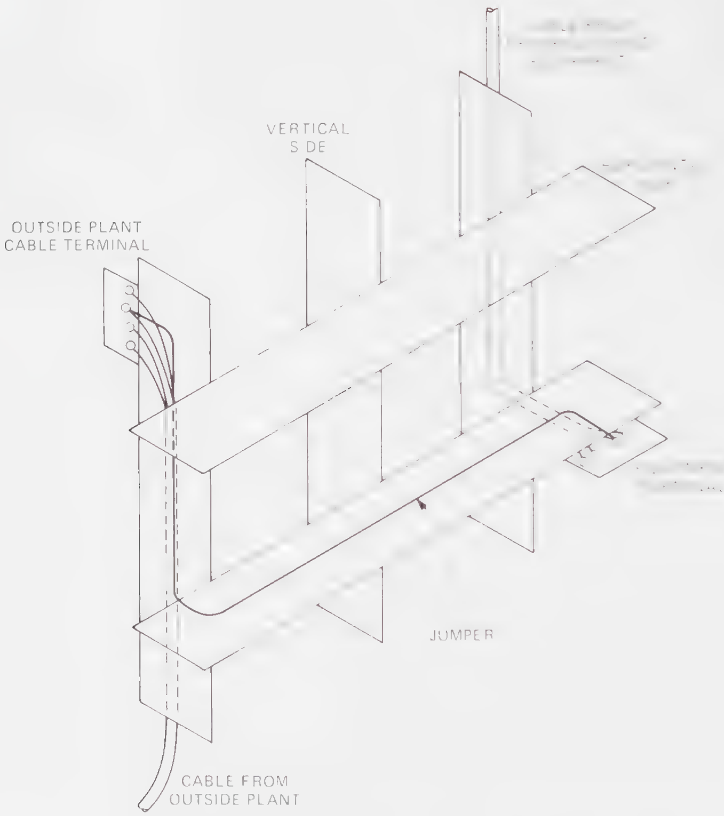

Fig. 11-4. Conventional Frame Hardware—Schematic Diagram

The MDF is generally a planar structure occupying one aisle of a wire center building. It is made up of horizontal and vertical members as shown

Fig. 11-5. Horizontal Side of Main Distributing Frame

in Fig. 11-4. Outside plant cable pairs are connected to terminals on the vertical member by means of tip cables (not to be confused with "tip and ring"), which are spliced to outside plant cables in the cable vault and brought up through the floor. Tip cables typically contain 100 cable pairs. The vertical terminal strips include the protectors. Line equipment on the office side of the MDF is connected to terminals on the horizontal member by means of cables which are routed in cable racks along the ceiling. The connection between an outside plant pair and the line equipment is made by running a jumper pair from the line equipment terminal to the cable pair terminal. Jumpers are run along the horizontal and vertical members of the frame. In this way, the horizontal members act as shelves and maintain some degree of order in the jumper array.

In most cases, the conventional structure has been capable of performing the MDF functions adequately. However, there have been serious problems with the conventional MDF in large wire centers where a number of switching systems are located. These problems have led to significant departures from the basic structure.

11.2.3 PROBLEMS AND TRENDS

Difficulties with the conventional MDF have been due to both its structure and the way it has been administered. In some cases, extreme and irreversible jumper congestion has resulted. Jumpers become physically impossible to remove, and these "dead jumpers" eventually smother the frame.

The conventional MDF is a 2-sided structure; cable pairs are terminated on one side, and switching and transmission equipment are terminated on the other side. Two framemen, one on each side of the frame, are needed to carry out most basic operations.

These problems have led to the development of new MDF hardware and administrative procedures.

A recent generation of MDF hardware, represented by the ESS frame and, more recently, the COSMIC frame (Common System Main Interconnecting frame), is characterized by one-sided operation and a separate protector frame. Outside plant cable pairs terminate on the protector frame, which is separate from the MDF. The protector frame is connected to the MDF by means of tie cables. Both outside plant and line equipment terminations appear on the same side of alternate vertical sections of the MDF. Thus, this structure has the advantages of one-sided operation as well as separation of the cross-connecting and testing functions. A COSMIC frame installation is shown in Fig. 11-6 and 11-7. The interconnecting frame is illustrated in Fig. 11-6, and Fig. 11-7 shows the protector frame.

Long jumpers and congestion are primarily the result of poor planning and administration. If a cable pair and line equipment are assigned to a customer independently on the basis of separate criteria, long jumpers may result. Thus, the concept of preferential assignment has evolved as a means of curbing jumper congestion. Under preferential assignment, line equipment is assigned so as to minimize jumper length, subject to traffic constraints. Since preferential assignment for large MDFs is difficult to implement on a manual basis, a computer-based system known as COSMOS (Computer System for Main Frame Operations) has been developed to perform preferential assignment and to keep assignment records.

The success of the operation of an MDF depends on the proper integration of planning methods, engineering techniques, hardware components, and administrative software systems. In the early 1970s, Bell Laboratories, AT&T, and Western Electric introduced a new family of MDF hardware and software systems and associated guidelines.

COSMIC Frame—A high-efficiency MDF for No. 1 ESS and electromechanical switching systems.

LPCDF (Low-Profile Conventional Distributing Frame)—Conforms to new equipment and building standards and serves as a trunk distributing frame in wire centers employing the COSMIC frame or as a combined MDF in small wire centers.

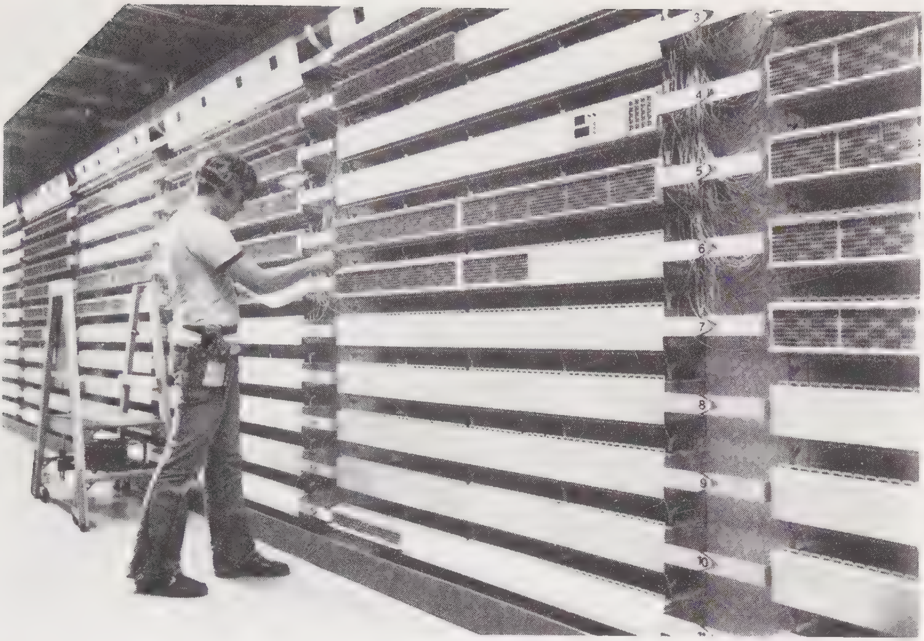

Fig. 11-6. A COSMIC Frame Installation—The Interconnection Frame

COSMOS—A minicomputer-based record keeping and MDF assignment system which is capable of administering a combination of distributing frames in a wire center.

SMFAS (Simplified Modular Frame Assignment System)—Administers both COSMIC and ESS MDFs without retaining an extensive data base. This time-shared system is designed for small to medium MDFs.

PACE (Programs for Arrangement of Cables and Equipment)—Designed for use by Western Electric for layout and engineering of COSMIC frames.

MDF Planning and Engineering Guidelines—Describes techniques for long-range planning, engineering methods, and special operational techniques.

The automation of the MDF function through a fully mechanized cross-connecting and test access system has been developed for application to very large metropolitan wire centers. Such developments, coupled with improvements in existing hardware and new planning methods, are expected to modernize and significantly reduce the expense of MDF operations in the Bell System.

Fig. 11-7. A COSMIC Frame Installation—The Protector Frame

11.3 SIGNALING IMPLEMENTATION

Signaling provides the network control functions required to set up, hold, and release connections in a traffic network, and also provides the basis for establishing charging information. The traffic network may be the public telephone network or a special private network. Refer to Fig. 6-23 for a block diagram of a connection in the public telephone network. The basic purposes of network control signaling and the signaling sequences used for call setup and release were described in Section 7.1.

The actual signaling system implementation depends on the area of application (loops, trunks, or special services) and on the type of transmission facility (wire or type of carrier). The application-oriented aspects are covered in Section 11.3.1, and the facility-related aspects are covered in Section 11.3.2. A tabular summary of signaling implementation is given in Table 11-1. Voice-frequency facility terminals, equipment configurations that incorporate transmission as well as signaling functions, are covered in Section 11.3.3.

TABLE 11-1
SIGNALING IMPLEMENTATION SUMMARY

SIGNALING FUNCTIONS

- Supervision
- Addressing

AREAS OF APPLICATION

- Station Loops
- Trunks
- Special Services (includes PBX trunks and PBX tie trunks)

SIGNALING SYSTEM INTERFACES

- Loop Signaling (may be associated with station loops, trunks, or special services)
- E&M Lead Signaling (may be associated with trunks or special services, usually those requiring 2-way origination)

FACILITY SIGNALING SYSTEMS

- DC (design and engineering depend on resistance of conductors)

  Applications are station loops, short trunks, short special-service channels, and end segments on long channels
- Out-of-Band (as on N1 Carrier)
- Digital (as on T1 Carrier)

— Facility-dependent
— Carry supervision, address, or both

- Inband Tone
  - SF (carries supervision, address, or both)
  - MF (carries address) (interoffice)
  - TT (carries address) (primarily station loop)
- CCIS (carries both supervision and address) (interoffice)

— Facility-independent

SIGNALING MODES

- Continuous
- Spurt
- Compelled

11.3.1 SIGNALING SYSTEM APPLICATIONS AND INTERFACES

For any signaling system on any type of facility, interfaces must be provided for the interchange of signaling information between the facility and the source and between the facility and the destination. In some cases, the interface is a well-defined demarcation point with specified impedances and signal levels, as described in Section 7.2. The E&M lead interface, described subsequently, is an example of this type. In other cases, a true interface may not exist, and the signaling information interchange will require careful coordination in design and, to some degree, in engineering between the source, destination, and intervening facility.

This latter concept is best illustrated by the simple example of station loop supervision. Supervision is provided between the central office (CO) and the station set by the presence or absence of direct current in the circuit formed by the two wires of the loop, the switchhook contacts in the station set, and the battery to which the loop is connected at the CO.

A current-sensing device is used at the CO to detect the station set's on-hook or off-hook signal. A standard interface in the classic sense does not exist between the customer's line and the station set or between the line and the CO, for the simple reason that it would be prohibitively expensive to condition approximately 60 million customers' lines to end in a standard impedance and signal level. Nevertheless, in signaling terminology, the technique of loop signaling just described is known as a *signaling system interface.*

There are a number of signaling system interfaces; however, only two types are used extensively: loop signaling and E&M lead signaling. All forms of loop signaling use dc changes on metallic pairs, usually without additional terminal hardware. E&M lead signaling provides two states of supervision and requires separate signaling leads at the interface. In contrast to loop signaling, E&M lead signaling always requires some form of terminal hardware for application to metallic, analog, or digital facilities. The specific interfaces used are normally associated with the three different areas of application: customer loops, interoffice trunks, and special-service circuits. These areas of application are individually discussed in the following paragraphs, and a summary is given in Table 11-2.

11.3.1.1 Station Loop Signaling

The signaling interface between a central office switching system and a customer's station terminal has a standard format known as *loop signaling.*[1] This arrangement provides for continuous application of a 48-volt battery toward the station, in conjunction with a current-sensing device to recognize the supervisory status of the station. On-hook or idle is indicated by no current flow, whereas off-hook or seizure is indicated by the flow of current in the loop. For standard supervision, the battery polarity, and hence current

1. A form of loop signaling known as *loop-reverse-battery* is used on certain types of trunks as subsequently discussed.

TABLE 11-2
SUMMARY OF SIGNALING SYSTEM APPLICATIONS AND INTERFACES

SIGNALING SYSTEM APPLICATION/INTERFACE	CHARACTERISTICS
STATION LOOP	
• Loop Signaling*	
Basic Station	DC signaling. Origination at station. Ringing from central office.
Coin Station	DC signaling. Loop-start or ground-start origination at station. Ground and simplex paths may be used in addition to the line for coin collection and return.
INTEROFFICE TRUNK	
• Loop-Reverse-Battery*	One-way call origination. Directly applicable to metallic facilities. Both current and polarity are sensed. Can be used on carrier facilities with appropriate facility signaling system.
• E&M Lead	Two-way call origination. Requires facility signaling system for all applications: *Facility* — *Facility Signaling System* Metallic — DX Analog — SF Digital — Bits in Information Stream
SPECIAL SERVICE	
• Loop Type	Standard station loop and trunk arrangements as above. Ground-start format similar to coin service for PBX-CO trunks. Automatic or ringdown for PBX nondial tie trunks.
• E&M Lead	E&M for PBX dial tie trunks. E&M for carrier system channels in special-service circuits.

* Ordinarily, no special provisions are necessary to extend the range (line resistance) over which these systems can operate. Range extenders are sometimes used in station loop signaling applications, but are rarely required for trunk signaling.

direction, is not critical and may vary with the switching system. Normally, however, negative battery is provided on the ring conductor, with ground on the tip. To avoid electrolysis problems, positive potentials are not normally provided. This format provides simple 2-state supervision from the customer toward the central office, with only minor variations introduced by the special features of different switching systems.

The customer is alerted from the central office by a ringing signal indicating the presence of an incoming call. Standard single-party ringing consists of 2-second intervals of 20-Hz energy applied between the tip and ring conductors, followed by a 4-second quiet interval. Other ringing durations and intervals, including 1 second on, 2 seconds off, are used for multiparty lines. To provide for ring tripping, which turns off ringing when the customer answers, a superimposed dc potential is generally used in association with a current detector. Following ring tripping, line potentials revert to the normal supervisory state.

For 2-party and multiparty (4-party or more) service, the ringing voltage is applied to either the tip or ring conductor with respect to ground and is superimposed on either a positive or a negative dc ring tripping potential. In this way, up to four distinct signals are provided, which, with appropriate connection of ringers in the station sets, provides full selective ringing of 2- or 4-party lines. With coded ringing durations, semiselective ringing of 8-party service can be provided. For 10-party service, additional coding is used beyond the standard one long and two short rings. Multiparty service is becoming quite rare in the Bell System.

In addition to switchhook supervision, the customer must pass the destination code of the called party to the switching office. This address information is communicated as either dial pulses from a rotary dial or as TOUCH-TONE signals. Dial pulses consist of short on-hook pulses occurring in the normal off-hook loop supervision current following the initial off-hook signal. Dial pulses are normally sent at a 10 pulse-per-second rate, with the number of on-hook or break intervals equal to the numerical digit to be sent. The ratio of break interval to total pulse cycle interval is frequently referred to as *percent break* and is typically 61 percent. Twenty-pulse-per-second dialing also is used occasionally for special applications. An example of dial pulsing the digit 3 is shown in Fig. 11-8.

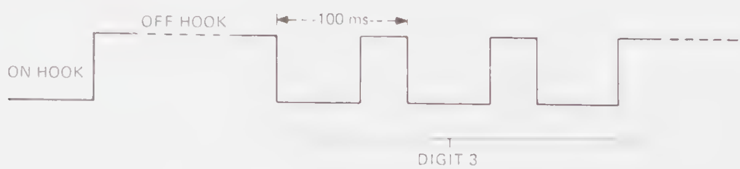

Fig. 11-8. Dial Pulsing

TOUCH-TONE address signaling consists of sending pairs of selected frequencies corresponding to the digits to be transmitted. The frequencies used are coded as shown in Fig. 11-9. They have been carefully selected to minimize the probability that a pair of high and low tones will be simulated by the human voice, thus protecting network control signaling. TOUCH-TONE signals may be transmitted over any voice circuit (providing loss and noise limitations are not exceeded). They are therefore facility-independent and are frequently used for other applications, including data transmission. Upon receipt of TOUCH-TONE address signals, the tones are decoded to indicate the called address to the central office.

Fig. 11-9. TOUCH-TONE Dialing Frequency Groups

A special case of loop supervisory signaling exists for coin stations, in which additional control signals are required for coin collection and coin return. There are two basic types: loop-start, associated with dial-tone-first service, and ground-start, associated with coin-first service. Loop-start provides ordinary loop signaling, with the addition of battery polarity reversal used for answer supervision and charging and a 130-volt dc signal applied from ground to both the tip and ring conductors for coin return.

For ground-start, seizure is accomplished by applying ground to the ring conductor at the station in response to the insertion of the proper coin. A relay circuit in the central office recognizes this ground, applies dial tone, and establishes conventional loop supervision. Coin collection and return functions are then provided as described for loop supervision.

11.3.1.2 Interoffice Trunk Signaling

There are two major per-circuit trunk signaling interfaces: loop-reverse-battery (a form of loop signaling) and E&M leads. However, numerous other standard, nonstandard, and obsolete varieties persist in use for special applications. Loop-reverse-battery is applicable only to those trunks that require call origination at only one end. These are called *one-way trunks,* although it should be recognized that it is only the call origination or trunk seizure that is one-way. Basic signaling functions are still required in both directions. An E&M lead interface also may be used on one-way trunks and is required on 2-way trunks with call origination permissible at either end.

Loop-reverse-battery, as used on metallic facility trunks, provides for application of nominal −48 volt battery on the ring conductor and ground on the tip at the terminating office end of the trunk. In addition, the terminating office has a current-sensing device and provision for polarity reversal (i.e., −48 volt battery applied to the tip conductor). At the originating office end, means are provided for closing the loop, causing current to flow as an off-hook signal. A polarity-sensing device is used to recognize the state of the terminating end (e.g., idle, disconnect, etc.). Loop-reverse-battery thus provides not only an interface with switching systems, but also an arrangement for use on metallic facilities without the need for additional signaling equipment. As will be described in Section 11.3.2, the loop-reverse-battery interface also can be used with an appropriate signaling system for applications on carrier systems.

There are numerous specialized variations of loop-reverse-battery, including use of 130-volt simplex signals (from ground to both tip and ring conductors) for operator alerting or ring-forward signals and revertive supervisory signaling associated with Panel and No. 1 Crossbar applications. (Revertive supervision provides specialized control functions and sequences associated with revertive pulsing that are beyond the scope of this text.) Other special arrangements include high-low, wet-dry, marginal or polar signaling, and PCI (panel call indicator). These arrangements, however, have very limited applications and will not be discussed here.

For 2-way trunks, that is, those that permit call origination at either end, the E&M lead interface is used. E&M leads are a true interface of the type described in Section 7.2. The E&M lead interface provides for signaling from the central office toward the facility over the M lead in the form of ground for on-hook, and -48 volt battery, through a current-limiting device, for off-hook. From the facility toward the central office, on-hook corresponds to an open E lead, whereas off-hook is ground. A summary of the signaling states is given in Table 11-3. Both the E lead and the M lead require ground return paths. A schematic representation of this basic E&M lead arrangement is shown in Fig. 11-10(a) as a type I interface. Transmission of signaling information between distant E&M lead interface points is carried out in various ways, discussed in Section 11.3.3.

TABLE 11-3
E&M LEAD SIGNALING STATES

STATE INDICATED	FROM CENTRAL OFFICE TO FACILITY (M LEAD)	FROM FACILITY TO CENTRAL OFFICE (E LEAD)
On-hook	Ground	Open
Off-hook	−48 volts	Ground

With the introduction of ESS offices, the standard E&M lead interface was modified to avoid noise problems associated with ground return paths. Two varieties of looped (paired-lead) E&M lead interfaces exist. In some ESS applications, full-looped E&M leads are used. These consist of loop closures on paired leads, both to and from the facility interface. For other ESS applications, both ground and battery return for the M lead are brought back to the facility interface as SG and SB leads. These arrangements are illustrated in Fig. 11-10(b) and 11-10(c), as type II and type III interfaces, respectively.

The loop-reverse-battery and E&M lead interfaces just described provide the supervisory interface for trunks. Destination codes are transmitted either as dial pulses (DP) applied through the same interfaces or as multifrequency (MF) pulses applied to the voice path.

As in customer loop signaling, DP trunk address signals consist of interruptions of the off-hook supervisory state of the trunk; the rate of interruption may be 10 or 20 pulses per second. DP signals can be applied directly to both loop-reverse-battery and E&M lead interfaces. Multifrequency pulsing is very similar to TOUCH-TONE signaling in that pulses of pairs of selected tones are used to represent digits; here the tones were not specifically chosen to protect against simulation by voice. In addition to the actual address digits, a keypulse (KP) tone pair is sent as a start-of-address signal to unlock the terminating-end receiver, and a start (ST) signal is sent to indicate end-of-address (start call processing).

With processor-controlled offices, a totally different signaling technique is possible for interoffice trunks. The technique is known as common channel interoffice signaling (CCIS) and requires a separate data link between processors. In such arrangements, there is no per-trunk signaling interface, but rather a single data link containing multiplexed signaling information. For economic reasons, this data link will usually go through a signal transfer point (STP). The data link will then serve multiple trunk groups from the office. Where such systems are used, neither loop-reverse-battery nor E&M leads are required, and similarly, neither DP nor MF addressing is used.

A functional description of CCIS is given in Section 7.1.4. In 1976, some No. 4A Electronic Translator Systems and No. 4 Electronic Switching Systems were equipped with CCIS. At later stages in the growth of CCIS, No. 1 ESS and TSPS may be equipped, and independent processors for other types of systems may be provided for signaling. The CCIS data terminals interface

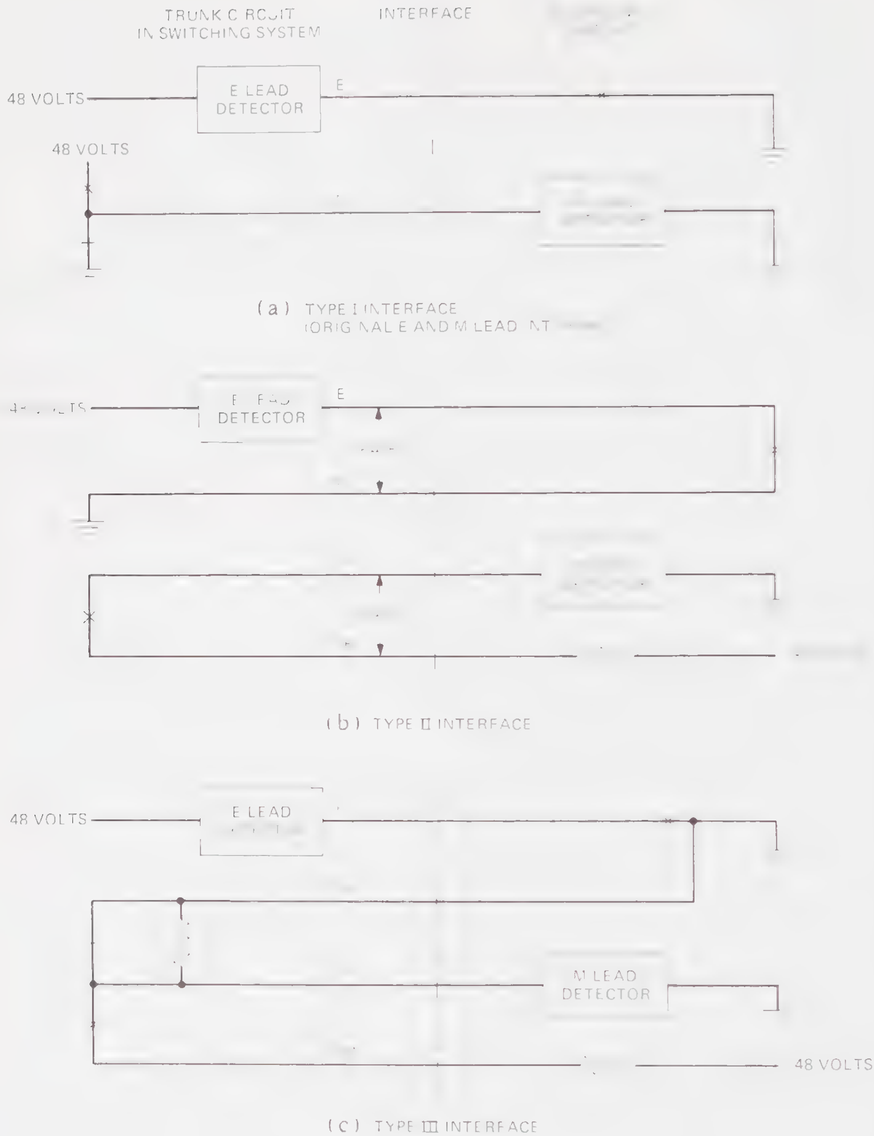

Fig. 11-10. E&M Lead Interface Arrangements

with the peripheral unit buses of the switching systems. Formatting and interpretation of the data messages are done by the processors, using software developed for CCIS. The message switching function at STPs is done by processors associated with No. 4A Electronic Translator Systems. Thus, the electronic processors for toll switching systems will be programmed to perform message origination and reception or message switching, but not both, in addition to their normal switching functions.

11.3.1.3 Special-Service Signaling

Special services frequently require special signaling arrangements. To provide these services, the standard customer loop and trunk arrangements, in addition to various modifications, have been used. It is beyond the scope of this text to consider all possible arrangements; however, a few major types will be described.

It is important to recognize that the wide variability of implementation arrangements needed for special services frequently causes problems in standardization and consolidation of signaling system equipment.

A major category of special services includes special-access lines and trunks, such as FX lines, WATS lines, and PBX-CO trunks. Special-access lines that are short normally use standard single-party customer loop signaling. Long special-access lines, such as some FX lines, use carrier transmission facilities and employ an appropriate form of signaling such as inband single-frequency (SF) signaling.

Special-access trunks may use standard loop signaling, but frequently employ a ground-start arrangement similar to that used in coin service. Special-service ground-start is used to minimize the probability of simultaneous seizures on high-usage PBX trunks. On such circuits, a PBX attendant may attempt to initiate an outgoing call at the same time an incoming call is attempting to alert the attendant. If the incoming call connection occurs during the ringing silent interval, the attendant may not be alerted to this fact for up to 4 seconds, and a misdirected outgoing call could be placed. To prevent this problem, ground-start provides for the application of ground on the tip toward the PBX as an initial connect or seizure signal even before the application of ringing. The attendant can test for this ground and, if present, avoid placing outgoing calls; the ground will make the trunk circuit busy on dial-selected trunks.

PBX tie trunks constitute another major class of special services. Tie trunks may be either dial-repeating trunks or nondial trunks. Two modes of operation for nondial trunks are automatic and ringdown.

Dial-repeating trunks are associated with those PBXs that are capable of routing tie trunk calls without attendant assistance and which therefore require DP address information. The E&M lead tie-trunk interface used is virtually identical to that used on public telephone network trunks and hence permits passing DP address information. Although address transmission is normally DP, TOUCH-TONE address transmission also is used. MF pulsing is normally not available at PBX machines.

Nondial trunks are associated with attendant-completed calls, in which address information is transmitted verbally. Automatic and ringdown nondial trunks provide only a supervision alerting function. In the case of automatic, the interface at the originating end is a loop closure. For ringdown, the originating-end interface is the application of 20-Hz ringing by the operation of a ringing key. When 20-Hz ringing is needed at the terminating end but there is an intervening facility that cannot pass the 20-Hz ringing signal, a combination of these types, known as *automatic ringdown,* is often used. The originating-end interface is a loop closure that results in the application of 20-Hz ringing at the receiving end. When the attendant answers the call, ringing is tripped.

Combinations of dial-repeating, automatic, and ringdown signaling are often used for different directions on a given tie trunk, depending on customer needs and the capability limitations of the terminating PBXs.

Private lines are another major class of special services which utilize many different types of signaling interfaces. For the simplest cases of private-line service, such as some private-line data services, the line is dedicated to a specific customer and no signaling is required; the data sets provide the alerting function. For many private-line services, however, an alerting function is necessary. This is frequently provided by automatic or ringdown operation. The signals used are very similar to those just described for tie trunks, with automatic ringdown being the most common.

Many private lines are multipoint, that is, they have from several to many stations bridged together on a common private-line network. For such applications, selective alerting is frequently desirable and can be provided by either of two systems. For simple multipoint networks with a minimum number of stations, code select may be associated with ringdown operation, or it may be combined with automatic operation in special arrangements to suit customer needs. In such an arrangement, coded ringing (one, two, three, etc., rings) may be used to alert a particular station. The ring count may be interpreted by an attendant or more typically by a code select ringing circuit in the terminating station which, with the proper input, triggers an alerting signal.

For services requiring features beyond simple alerting or for multipoint networks with many stations, a selective signaling system such as SS1 or SS3 may be used. These systems use a special combination of DP or TOUCH-TONE signaling to provide the selective ringing and control functions. Numerous other private-line signaling systems and interfaces are also in use.

11.3.2 FACILITY SIGNALING SYSTEMS

To convey signaling information from its source to its destination requires signaling transmission techniques that are compatible with the facility involved. There are basically five major types of facility signaling systems: dc, inband, out-of-band, digital, and common channel interoffice signaling (CCIS). In addition to this classification, facility signaling systems also are classified as being facility-dependent or facility-independent and as being of a continuous, spurt, or compelled variety.

Facility-dependent signaling techniques include dc signaling, out-of-band signaling, and digital carrier signaling. For each of these forms, the signaling information appears as direct current at the signaling system interfaces at the ends of the facility. Where facilities are connected in tandem[2] and at least one of the facilities at a point of connection uses facility-dependent signaling, a through connection involving this dc signal must be made. One might think of this as a simple matter of connecting interface leads, but, in the past, systems have not always been designed this way. Even if both of the facility signaling systems have E&M lead interfaces, it may be necessary to insert a signal conversion unit between the interfaces. If the type II interface (see Fig. 11-10) is used, direct interconnection is possible without a conversion unit. The new voice-frequency facility terminals (see Section 11.3.3), which combine transmission and signaling functions, provide arrangements for both facility-dependent and facility-independent signaling systems and thus serve to reduce the cost of signaling conversion.

For services built up from a combination of tandem facilities, there may be economic advantages in the use of facility-independent signaling systems. In this case, the signaling characteristics are not dependent on the particular characteristics of the transmission medium, and no hardware is needed where tandem facilities connect. Included in this category are single-frequency (SF) inband signaling and multifrequency (MF) and TOUCH-TONE pulsing. It may be noted that the facility terminal concept (Section 11.3.3) permits economical link-by-link signaling arrangements where facility-independent signaling is unattractive.

CCIS also is truly facility-independent, as it is based on a separate data link carrying multiplexed signaling information for many different circuits. The CCIS data link may be over an entirely separate facility, possibly following a different geographic route.

The three modes of signal transmission—continuous, spurt, and compelled—can be described as follows: continuous supervision requires steady-state transmission and reception of status on a per-channel basis and has no memory associated with the signaling system. This mode is restricted to dedicated, non-time-shared facilities. Spurt signals are normally associated with short-duration address information, but also may be used for supervision if the signaling system or connecting circuit provides the necessary state memory. Short-duration signals are particularly useful on time-shared facilities such as those used for CCIS. The compelled mode is a high-reliability system used for critical applications such as overseas signaling. With compelled signaling, every state change is transmitted, and its reception at the far end is

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2. "Tandem facilities" as used here refers to the interconnection of two or more facilities (wire, analog carrier, or digital carrier) to make up an interoffice trunk or a special-service circuit.

acknowledged with an appropriate signal. Following acknowledgment, the signal is normally removed, and hence state memory is required.

Each of the facility signaling systems mentioned here, dc, inband, out-of-band, digital, and CCIS, is described in more detail in the following sections.

11.3.2.1 DC Signaling

The major signaling system interfaces discussed in Section 11.3.1 included loop signaling, loop-reverse-battery, and E&M lead signaling. For each of these, there is one or more facility signaling systems for use on dc (metallic) facilities. The existing interfaces and metallic facility signaling systems came into being through an interaction of desired performance, technical possibilities, and cost; an interaction that is too complex to be treated here. In general, the main constraint is the dc resistance of the facility, and the main goal is lowest cost.

At the simplest end of the spectrum is customer station loop signaling. This uses a wire pair with no other equipment than a pair of contacts at one end and a current sensor at the other. Constrained by design and engineering rules to ensure proper operation, this arrangement is a facility signaling system. With a typical central office, it will operate with external conductor loop resistances up to 1300 ohms, a value that permits operation on the great majority of loops. Fig. 11-11 illustrates signaling range design for various gauges of cable pair.

When the station loop resistance exceeds 1300 ohms, provision is made for what is called *signaling range extension.* This is used only in exceptional cases, with the great majority of loops not requiring any such treatment. Range extension normally involves the detection and regeneration of signals in *dial long line* or similar equipment, but it may involve no more than a high battery voltage at the central office. Range extension can be applied on trunks, but is very seldom required.

Range extension equipment historically has been provided separately from voiceband transmission equipment. However, arrangements are available for range extension in the metallic facility terminal described in Section 11.3.3.

The loop-reverse-battery interface with dc signaling transmission, like basic station loop signaling, uses only the metallic conductors, but it differs in several respects. First, the metallic signaling path is separated from the voice channel by what amounts to a band-splitting filter (which may be no more than a capacitor and the inductance of a relay). The signaling band is from direct current to about 100 Hz. Second, the signaling range for a trunk can be longer than that for a station loop, since the nominal current required by the trunk circuit is less than the minimum current needed by a station set. For some of the more modern loop-reverse-battery systems, the range is up to 5000 ohms. In common with basic station loop signaling, loop-reverse-battery uses a grounded voltage supply at only one end (the terminating end of the trunk), thus avoiding problems of earth potential differences between offices.

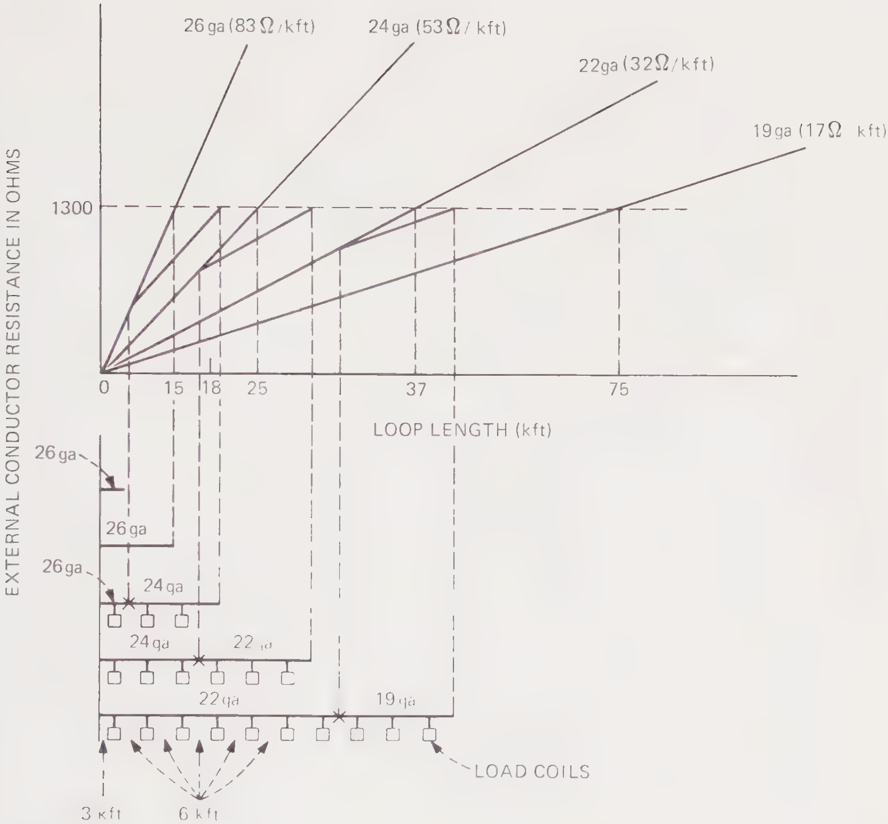

Fig. 11-11. Signaling Range Design—Resistance Design Procedure

E&M lead interfaces are used with several metallic facility signaling systems, the major one known as DX. Use of E&M leads applied directly to metallic facilities is generally ruled out because in some cases the maximum allowable resistance in an M lead path is 25 ohms. The DX metallic facility signaling system, by means of a balanced-bridge superposition technique, permits 2-way origination. As in loop-reverse-battery, the signaling band is separated from the voiceband. Grounded battery supplies are required at each end, with the balanced-bridge approach used to cancel out earth potentials. The signaling range is approximately 5000 ohms. Present systems use relays for detection, but electronic systems are being introduced.

In station loop signaling and in loop-reverse-battery signaling over metallic conductors, the relays that receive signals are generally considered part of the switching system, and so the facility signaling system design for these applications naturally has fallen to people who design switching systems. The design of range extension equipment for metallic facilities is done primarily by transmission designers.

11.3.2.2 Inband Signaling

Facilities not capable of passing dc signals must be provided with different types of facility signaling systems. This is true of all carrier systems. For analog carrier systems, a number of inband tone signaling techniques have evolved. Since these depend only on the existence of a voice channel, they are facility-independent and may be used over tandem facilities including metallic pairs and digital carrier.

Included in inband systems are single-frequency (SF), multifrequency (MF), and TOUCH-TONE signals. SF provides both supervision and, where appropriate, dial-pulse signaling and is compatible with loop-reverse-battery and E&M lead signaling interfaces. All of these systems perform their functions without the need for special signaling range extension or conversion equipment.

SF signaling provides two basic states: on-hook (normally 2600-Hz tone on) and off-hook (normally tone off). Control of the application and of the removal of tone is from the input to the dc interface; a receive tone detector provides an output signal to the dc interface. There is, of course, a mating SF unit at the distant end of the channel. A typical application is on a 4-wire carrier system, which permits full 2-way origination without the use of a second frequency. Referring to Fig. 7-5, the boxes labeled "Signaling Equipment" and the detail of the signaling interface illustrate where the functions are performed in a telephone connection.

The use of the two supervisory states is dictated by application requirements. A simple example is the use of SF to extend customer loop signals over carrier. Toward the central office, tone-off is off-hook or seizure, and tone-on is on-hook or idle. In the reverse direction, tone-off is both idle and busy, with tone-on corresponding to the application of ringing.

With SF signaling, time delays must be allocated for tone recognition to prevent false signaling by voice simulation[3] and to allow for distortion caused by facility noise or transmission degradation. These factors normally necessitate sending a tone signal of minimum duration (typically over 50 ms) independent of the input pulse. The detected signal must then be reconstructed to approximate that of the original source by a process referred to as *pulse correction*. Numerous pulse-correction schemes are in use depending on the particular service requirements of the SF application. These added requirements for SF signaling tend to make the cost of SF signaling on a digital facility higher than digital signaling (see Section 11.3.2.4) except when a digital facility is connected in tandem with one or more analog facilities that use SF signaling.

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3. This is referred to in signaling terminology as *talkoff* because a voice-produced tone with the proper characteristics can simulate an on-hook condition, causing the circuit to be dropped (the SF receiver functions as if the customer has hung up).

Many signaling system interfaces can be used with SF signaling units. In toll applications, the interface is typically E&M leads. The interface also can be loop-reverse-battery, in which case the SF unit appears to a switching system just as the metallic pair and the distant office would appear. Where a station line is quite long (as in the case of FX or some other special services), an SF unit can be used at the station, with a station loop signaling interface. On an FX line, for example, the off-hook signal from the station would remove the tone sent toward the switching office. Since special-service circuits often use various combinations of metallic and carrier facilities, it has been found desirable to provide optional interface circuitry in the SF unit for each of several signaling interfaces, with enough range capability for the majority of applications.

11.3.2.3 Out-of-Band Signaling

Analog carrier systems typically do not use the full 4-kHz voice-frequency channel slot because of channel separation filters in the channel modems. This has led to the development of out-of-band signaling systems using tones outside of the normal voiceband. Such systems are not used widely, as they are normally facility-dependent, and they are not applicable to tandem facilities without added hardware at the point of interconnection. However, one out-of-band system is often used in association with the N1 Carrier System. While out-of-band tone signaling has been considered for other systems, including A6 channel banks, the universal applicability of SF signaling has outweighed any possible economic advantages of out-of-band signaling.

The existing N1 system uses 3700 Hz as the signaling frequency in a continuous format similar to SF but restricted to E&M lead interfaces. Adaptation to other applications requires the use of external signaling conversion and/or range extension equipment.

11.3.2.4 Signaling Over Digital Facilities

A form of out-of-band signaling is used on most digital facilities. In these systems, in which transmission is provided by a digital bit stream, it is very convenient to allocate one or two bits occasionally to signaling. The bit state 1 or 0 then corresponds directly to a specific signaling state such as on- or off-hook. Signaling bits may be assigned to every encoded sample (8000 per second) or at a much lower rate consistent with the very low information transfer rate associated with per-channel signaling. Typical sample rates of about 1000 bits per second (sample interval of 1 ms) are used to simplify terminal equipment. Hence, for digital carrier, a non-tone-based signaling system is possible and is used extensively. This leads to considerably simpler terminal equipment compared with SF units and hence to much more economical arrangements. This low signaling cost, combined with the inherent low transmission cost for digital carrier, has prompted its use as an alternative to analog carrier with SF and also to wire facilities.

The precise manner in which the signaling information is digitally encoded is dictated by the particular terminal channel unit design; e.g., D1, D2, or D3 banks. A series of different channel units is provided to accommodate the various dc signaling interfaces required by different service applications. The channel unit detects the per-channel dc signaling input (e.g., the M lead) and applies the necessary control to set the corresponding state of the digital signaling bits. The digitally-encoded signaling information is then multiplexed with the voice signal for transmission over the associated digital line. At the receiving terminal, the signaling information is recovered in the demultiplexing process. The appropriate dc conditions are then applied toward the connecting circuit (e.g., the E lead).

Since most digital signaling information is transmitted at a rate of at least 1000 samples per second, the timing of the signaling information is not appreciably disturbed. For this reason, digital signaling is typically referred to as distortionless compared with SF signaling, which typically distorts or changes the timing of short-duration signals. Since it is essentially distortionless, the digital system has the potential for providing superior performance, but it is, of course, facility-dependent. Digital signals therefore cannot be extended to other facilities such as wire or analog carrier without conversion at the signaling interface. Digital facility terminals (see Section 11.3.3) provide this conversion.

11.3.2.5 Signaling Over Separate Facilities (CCIS)

The CCIS interface with electronic processors in switching systems was briefly described in Section 11.3.1.2. Transmission of signals between offices will be at a rate of 2400 bits per second on all types of facilities using voice-grade circuits.

11.3.3 VOICE-FREQUENCY FACILITY TERMINALS

Historically, signaling systems have evolved independently of voice transmission systems to meet unique needs. The dc methods evolved to meet metallic facility needs and eventually dictated the interfaces for all per-channel systems. MF and TOUCH-TONE pulsing evolved to meet a need for faster address signaling techniques to minimize the holding time of switching system common-control equipment and to speed customer service. SF systems were initially provided for supervision on long distance intertoll circuits. Because of these unique needs, signaling techniques were developed by specialized groups who concentrated on signaling, per se. As a consequence, the physical equipment configurations for signaling were separate and distinct from those associated with channel bank equipment and the miscellaneous pads, amplifiers, and equalizers needed to make up a complete trunk or special-service circuit. These different entities were packaged in separate bays and cross-connected by means of intermediate distributing frames (IDFs) to make up individual circuits as required.

In contrast to this view of signaling as a separate function, there is a strong association between particular facility signaling systems and transmission media. DC signaling system interfaces certainly evolved initially in conjunction with metallic facilities. SF systems, although facility-independent, were initially developed for use on analog carrier. Digital signaling techniques are quite facility-dependent and are integrally related to the digital transmission systems.

As a result of these associations, new equipment configurations have been developed that combine channel banks, pads, amplifiers, equalizers, and signaling equipment in a unitized arrangement. These arrangements are known as *voice-frequency facility terminals* and minimize or totally eliminate the need for IDFs. In addition to eliminating the office cable congestion associated with IDFs, unitized arrangements offer significant economic, administrative, and maintenance advantages over traditional assemblies of unifunctional equipment. The evolution from unifunctional to unitized arrangements is illustrated in Fig. 11-12 for the case of analog carrier.

As can be seen, voice-frequency terminal equipment has progressed from a system heavily dependent on distribution frames for interconnection, through several stages of integration, to the point that all functional elements have been unitized. Signaling equipment was combined with the loss-adjustment attenuators, and then SMAS (a Switched Maintenance Access System, described in Chapter 16), the voice-frequency patch jacks, and finally the channel bank were added to create a completely unitized terminal.

There are three distinct types of facility terminals, associated with metallic, analog carrier, and digital carrier facilities, respectively. Each provides the needed functions in appropriate plug-in units, whose functional combinations are engineered to best meet the characteristics of the transmission medium. In each case, two major functions are provided, transmission and signaling.

The metallic facility terminal provides all functions needed on metallic facilities including voice-frequency transmission conditioning and dc signaling functions. These two areas are virtually independent electrically, a fact which led to economical physical grouping of the signaling and transmission functions in separate plug-in units. Transmission features include items such as voice-frequency repeaters and equalization. The signaling functions include substantially all of the dc interfaces and metallic facility signaling arrangements described previously. A metallic facility terminal can be connected to a switching system or to a second metallic facility.

The analog facility terminal provides channel banks (see Section 10.4), SF facility signaling equipment, and signaling system interfaces for working with a switching system, a metallic facility, another analog facility terminal, or a digital facility terminal. Special emphasis is given to the provision of special services such as PBX-CO trunks, FX lines, WATS lines, etc. Since the channel banks, SF units, and interface units are essentially independent, these functions typically are provided by three tandem-connected plug-in units. The first provides the channel bank function and depends on the carrier type. The

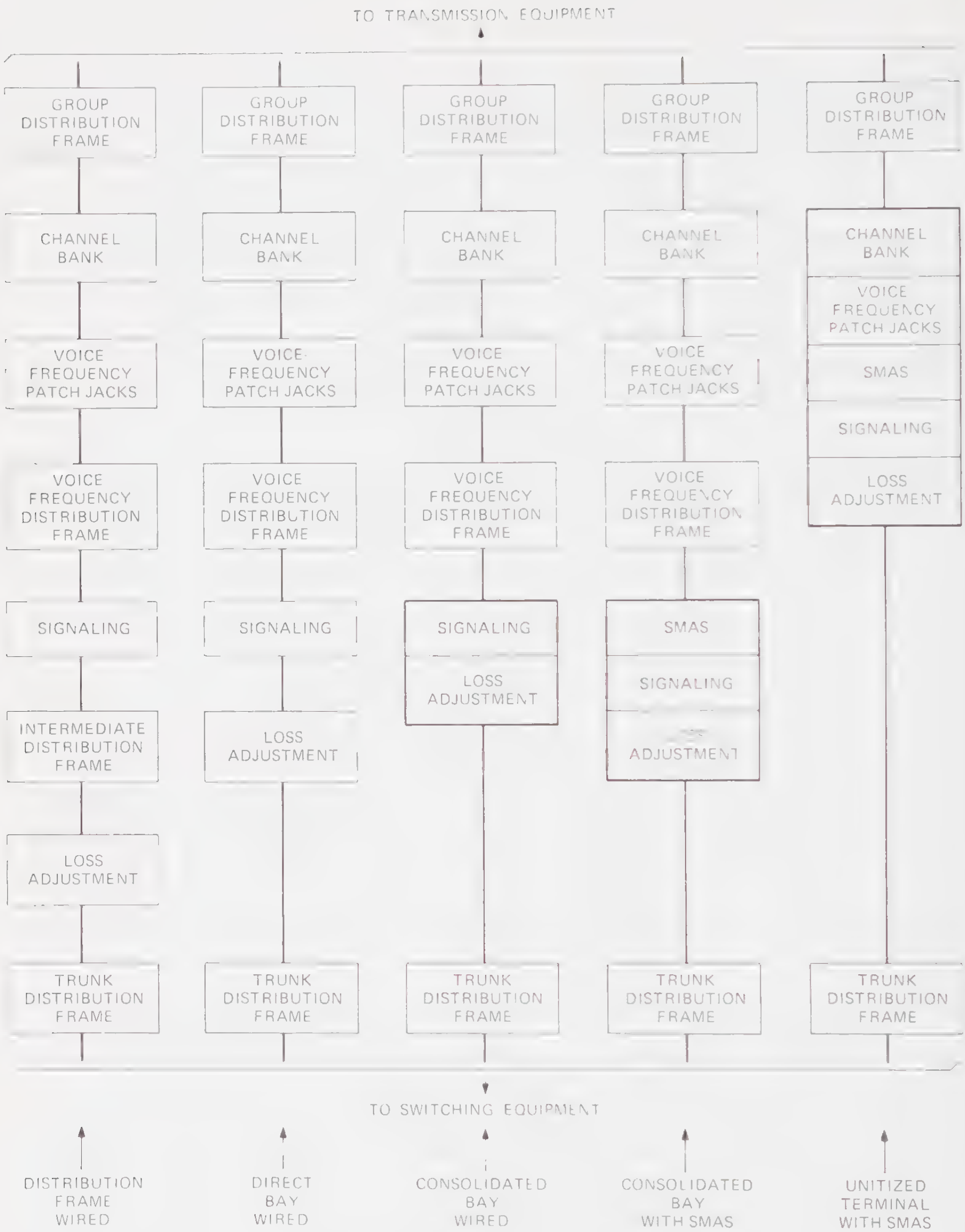

Fig. 11-12. Evolution of Unitized Terminal

second provides the standard SF function. The third provides the dc signaling and associated voice-frequency transmission interface. The latter two are often combined into what is known as *type F signaling.* A block diagram of the analog facility terminal is shown in the last column of Fig. 11-12.

The digital facility terminal is different in that signaling is intimately related to the channel bank function, and no simple logical division is appropriate. For most digital carriers, all functions—carrier interfaces, signaling, and voice-frequency interfaces—are provided in one plug-in unit of a digital facility terminal. A digital facility terminal can be connected to a switching system, to a metallic facility, to another digital facility terminal, or to an analog facility terminal.

When a digital transmission system interfaces with a digital switching system, an even simpler approach can be used. An example of this is the digroup terminal[4] (DT) which is used to terminate five T1 lines at a No. 4 ESS time-division toll switching system. The DT converts the five T1 line signals into a single digital bit stream, which is handled directly by the No. 4 ESS processor. In this process, the per-channel signaling information is extracted without ever returning to an analog voice format. This approach eliminates the need for channel banks and for dc signal conversion. A further advantage is preservation of the standard digital signaling format, resulting in compatibility with conventional digital channel bank or digital facility terminal equipment at the other end of the carrier link. The economic advantages of the DT are sufficient to make the use of digital carrier feasible on very short interoffice trunks, instead of conventional wire facilities with dc signaling. Future application of this type of signaling interface should minimize or eliminate metallic facility interfaces to No. 4 Electronic Switching Systems.

Fig. 11-13 summarizes how the three types of voice-frequency facility terminals can be used to interconnect circuits and to interconnect circuits with switching systems. Fig. 11-14 shows how voice-frequency facility terminals can be employed in assembling a complex special-service circuit. This example, a tie trunk, is contrived to include illustrations of several facility signaling systems and terminal equipment units as follows:

Facility Signaling Systems
- DX
- Single-frequency (SF)
- Digital

Voice-Frequency Facility Terminals
- Metallic facility terminal
- Analog facility terminal
- Digital facility terminal

---

4. A digroup is a digital group of 24 channels.

The sequence of transmission facilities from the first PBX to the second PBX in the tie trunk is:

Metallic loop facility
Exchange analog carrier facility
Long-haul analog carrier facility
Exchange digital carrier facility
Metallic loop facility

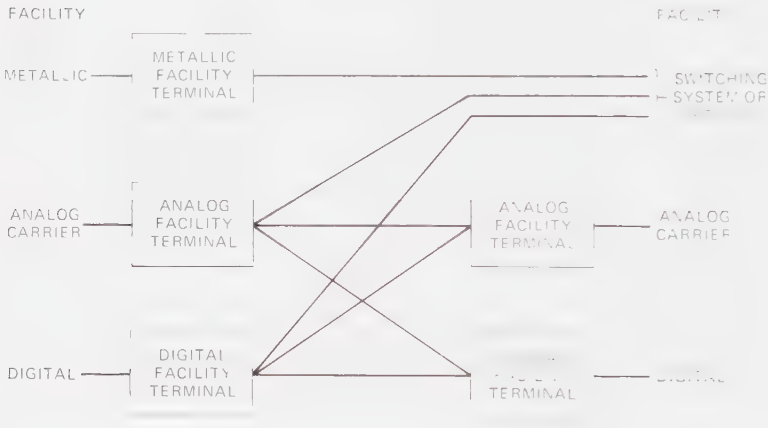

Fig. 11-13. Summary of Types of Facilities Interconnected by Voice-Frequency Facility Terminals

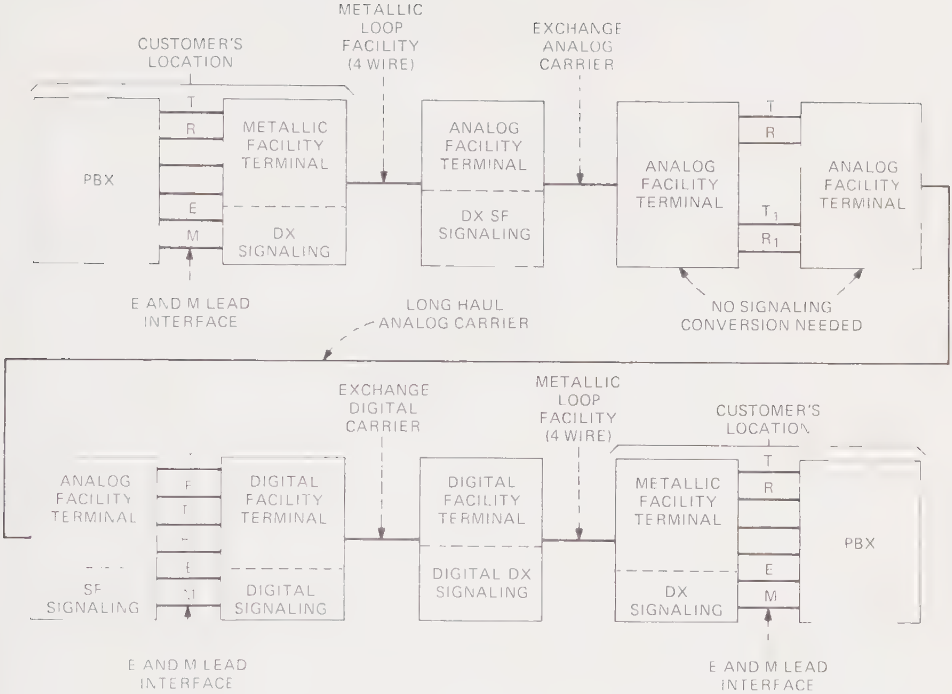

Fig. 11-14. Example of a Tie Trunk Consisting of Several Transmission Facilities and Appropriate Voice-Frequency Facility Terminals

12 Customer Services Systems

This chapter completes the description of systems that make up the facilities network. Some customer services systems are described in terms of station apparatus or equipments such as telephones, key telephones, PBXs, and data communication terminals. Others including data, mobile telephone, and visual communications are described as services and the systems that provide the services. References for supplementary reading are listed at the end of the chapter.

12.1 STATION APPARATUS FOR VOICE SERVICES

The telephone set is many things to many people. To Bell Laboratories, it is the equipment to be designed and engineered to link the customer to the network. To Western Electric, it is one of their biggest "runners"; about ten million telephones were built in 1975. To the operating companies, it is the equipment on the customer's premises—low-cost, long-lived, and reliable. To the customer, the telephone set is a communication link with the world. This section briefly discusses the telephone and its design considerations, describes some of the present offerings, and concludes with some thoughts on the next generation of telephones.

12.1.1 THE TELEPHONE[1]

The telephone has two functions: transmission and signaling. For transmission, the telephone ties the electroacoustic transducers, the transmitter and the receiver, to the 2-wire line that connects the station to the central office. For signaling, the telephone uses the switchhook to actuate central office supervision equipment to indicate origination, answer, or termination of a call; it permits dialing with a rotary or TOUCH-TONE dial and uses a bell or tone ringer for customer alerting.

The simplest telephone connection is shown in Fig. 12-1. A battery can be inserted in the line to provide a means of signaling or to add gain by allowing the use of a carbon transmitter. Most present telephones use a carbon

1. See Reference 1 for a history of the telephone from its inception to the introduction of today's rotary dial 500 set.

transmitter, which has the advantages of high output power and low cost. The carbon transmitter operates as a pressure-sensitive resistance whose value is varied by movement of the microphone diaphragm to modulate the battery-supplied line current.

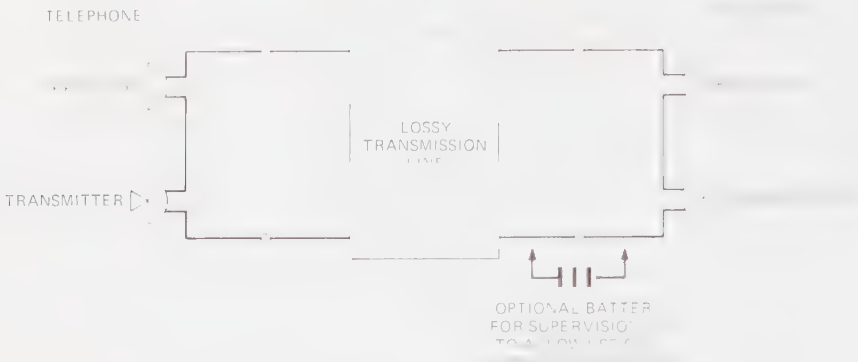

Fig. 12-1. A Simple Telephone Connection

This simple connection has a basic problem: each party hears his own voice much louder than he hears the other party because of the transmission line loss. To overcome this shortcoming, a transformer hybrid is used as a 4-wire to 2-wire converter to couple the transmitter and receiver to the line. The hybrid and its associated balance network provide compromises in sidetone amplitude and impedance match to the central office line (see Fig. 12-2). Sidetone refers to the portion of the transmitted signal that appears at the receiver of the same telephone. Sidetone is subjectively desirable because of the live quality it lends to telephone conversation. Set impedance is important because it influences return loss and hence transmission quality (see Section 6.3.1).

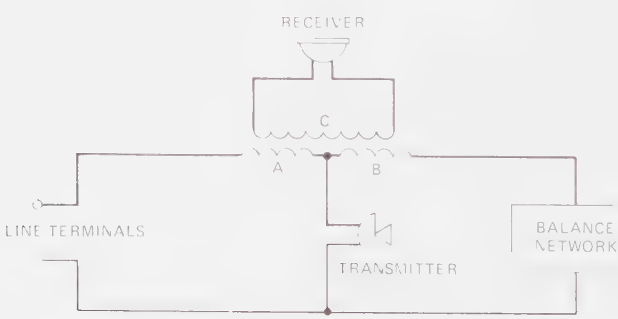

Fig. 12-2. Two-Wire Telephone With Hybrid

The transformer in Fig. 12-2 is composed of three equal windings. If the balance network, a passive impedance, approximates the line impedance, the transmitter output splits approximately equally and flows in opposite directions in windings A and B, so that only a small current is induced in the receive winding, C. In actuality, the difference between the currents in windings A and B is a function of the impedance of the telephone line. Because the likely range of line impedance is known, a compromise value for the balance network can be selected. The set is designed to produce a sidetone signal at about the same amplitude as a nominal received signal.

The circuitry used in the 500 set,[2] Fig. 12-3, has some additional features. Transmitting efficiency is improved over that of the circuit in Fig. 12-2 by using different turns ratios in the autotransformer configuration. This, combined with relatively high transducer efficiencies, gives good performance on long lines but high transmit and receive amplitudes on short lines. To reduce amplitude variations with different line lengths and cable gauges, the current-sensitive varistor, V1, is placed across the line inside the set. The high current on short lines lowers the resistance of V1, reducing the high signal levels; the low current on long lines causes V1 to remain a relatively high resistance so that long line performance is not significantly changed. A second varistor, V2, must be added in the balancing network to compensate for the impedance changes introduced by V1. The third varistor, V3, is placed across the receiver, acting as a peak clipper to protect the ear against loud noise bursts.

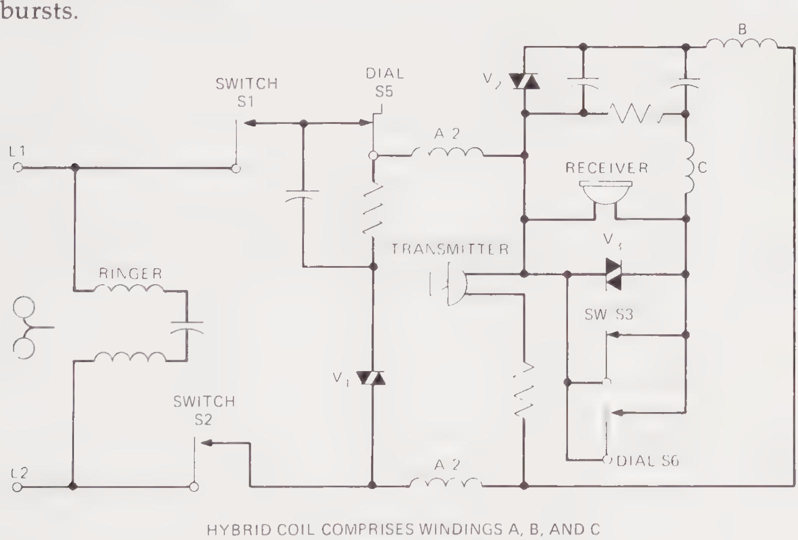

Fig. 12-3. 500 Set Speech Network

2. The term 500 set as used here refers to all the various telephones using the same basic circuitry shown in Fig. 12-3. Several examples of such sets are shown in Fig. 12-4. The rotary dial set is described in detail in Reference 2; the modifications for TOUCH-TONE dialing, in Reference 3.

12.1.2 DESIGN CONSIDERATIONS

Station equipment design must take into account many considerations in addition to cost. These added facets include system constraints, human factors, and operating company concerns related to installation, maintenance, repair, and administration.

Telephone design is indeed an economic challenge. The telephone is designed to meet functional requirements and is then cost-reduced to maximize the cost saving associated with the large production volumes; a saving of ten cents on each of the ten million telephones built each year yields a saving of one million dollars. Cost considerations are, however, not limited to manufacturing. Since operating companies own the sets, reliability, maintenance, and ease of installation are important factors in the design.

The primary electrical constraints on the telephone set are related to the need to do everything—transmission, powering, and signaling—over a single pair of wires, while remaining compatible with the existing telephone system. The available central office voltages, supervision currents, and line resistance, combined with the electrical characteristics of the set, determine the maximum size of the serving area of a central office. Addition of anything in the set that might reduce line range (for example, a polarity guard[3] with a 1.5-volt drop or active circuitry with a minimum dc voltage requirement) must justify the potential reduction in serving area it imposes on the offices or the cost of treating the long lines to retain the same serving area. The telephone is line powered, rather than locally powered, to retain the reliability associated with telephone service. The cost of providing battery backup for local powering usually cannot be justified in low-cost, general-purpose sets.

Compatibility with existing plant provides perhaps the greatest challenge. Station design changes, such as those that are required for TOUCH-TONE service, must be coordinated with necessary changes in the central office and must consider such things as whether more than one premises visit would be required.

Physically, the general-purpose telephone must be designed to operate under severe extremes, from inside a cold storage warehouse to the sunny windowsill of a humid, un-air-conditioned house in Florida. Furthermore, the set must be sufficiently rugged to withstand being shipped across country or being knocked off a table onto a concrete floor.

The fact that the station set is the interface with the customer imposes additional design constraints of a type different from those on the rest of the telephone network. The set must be easy and pleasant to use, and the design must take into account many human factors, such as the "feel" of a handset, the pleasant yet distinctive sound of a ringer, and the design of a button array to minimize dialing errors.

3. A polarity guard is an arrangement that provides correct polarity voltage to internal circuits for either polarity of line voltage.

Fig. 12-4. Several 500-Type Sets—CALL DIRECTOR®, PRINCESS, TOUCH-TONE, and TRIMLINE Telephones

The design should take into account the operating companies' problems, problems complicated by sheer numbers: more than 100 million installed stations, 100,000 installers and repair personnel, and 75,000 trucks. Without simplicity and commonality in design, the large numbers of plant personnel can lead to inefficient installation and repair of low production units. Low production for stations is still a large number; for example, a 100,000/year rate results in one new unit per year per installer.

In response to the need for greater commonality, a modular station set series has been developed which allows the installer to quickly assemble the desired type and color of telephone with the correct length cords at the customer's home. The simple change from colored to transparent mounting cords with a standard plug terminal will ultimately reduce the number of different cords stocked in every telephone truck from over 100 to 3. The added cost of using connectors in the station set is offset by reduced assembly, installation, and repair costs. For example, their use simplifies installation to the point where, for prewired homes, the customer can pick out his new telephone at a PhoneCenter or telephone store, take it home, and plug it in with savings to the customer (lower installation charge) and to the operating company (no premises visit).[4]

Design improvements to simplify handling of stations can markedly reduce costs; currently, our mobile society requires an operating company to make about six installations to add one station to the Bell System total. As a further operating company saving, those stations being repeatedly installed and removed should be designed to permit refurbishing and recycling. Today, nearly three times as many sets are refurbished by Western Electric as are built new, and a refurbished set costs about one-third as much as a new set.

12.1.3 PRESENT OFFERINGS

The mainstay of telephone service is, of course, the basic residential telephone. This is available in many colors and styles of housings, with either a rotary or TOUCH-TONE dial. For businesses, multiline key telephones are available; these sets, operating in conjunction with a small equipment unit (see Section 12.3), use button switches to select one of a number of incoming lines.[5] There are special types of station apparatus or adjuncts for many services: speakerphones for hands-free calling, repertory (automatic) dialers, the Transaction[6] telephone for credit card transactions, the portable conference telephone for use in businesses and schools, and aid-to-the-handicapped sets with hard-of-hearing handsets or loud-ringing bells. The new DESIGN LINE sets (shown in Fig. 4-2) offer telephones with stylish new housings for sale directly to the customer. The customer owns and can modify and decorate the housing; the Bell System owns and will maintain the operating internals. These and other services and systems are described more fully in Section 4.1 and subsequently in this chapter.

12.1.4 THE NEXT GENERATION—WHAT AND WHY

Today, the use of electronics in the telephone is limited to the TOUCH-TONE dial and to low-volume, special-purpose station equipment. At present,

4. Present installation charges usually cover only a faction of the operating company's installation expense.

5. Key telephones are so called because the service was originally provided by connecting two lines to a single set through an external switch similar to a toggle switch. This switch was called a key.

6. Trademark of AT&T.

electronics are too expensive to replace internals of the existing general-purpose 500 set. Electronics are expected to become part of the set when either of the following occurs:

(1) Use of electronics provides the customer a special service for which he is willing to pay (e.g., TOUCH-TONE dialing, speakerphone, or other new feature), or

(2) Use of electronics results in an overall system saving (e.g., electronic telephone set for long lines).

Many new services are expected to be introduced first in businesses rather than in the home, to take advantage of the greater willingness of businesses to pay for a service if it reduces their overall costs. As the cost of electronics decreases and as market demands increase, such services and equipment are expected to find their way into the residential market. COM KEY,[7] an example of this trend, provides speakers in each telephone to allow one-way voice signaling on intercom, supplementing the usual ringer and buzzer signaling. Voice signaling and paging have obvious applications in homes having more than one telephone.

12.2 COIN TELEPHONES AND SYSTEMS

Coin service, described in Section 4.1, is a relatively small but important and necessary part of the business; it shows continued growth in both the number of stations and revenues. Today, the more than 1-1/4 million sets in service (about one for every 200 Americans) account for about 5 percent of the total Bell System revenue. This section deals with coin service from the station standpoint, describes the station and its design considerations, and concludes with a discussion of the direction of new coin station development.

12.2.1 COIN SYSTEMS

From a station standpoint, coin service is divided into two categories, postpay and prepay, with different station configurations for each service. The older postpay service, using either modified versions of multislot (nickel, dime, and quarter) or new single-slot stations, accounts for less than 50,000 stations. This service requires a coin deposit to complete the transmission path after the called party answers; no coin refund capability is provided. This service is available only from Step-by-Step offices and is most commonly found in rural areas with low coin traffic. Although postpay service is economical from an equipment standpoint because it requires less coin control apparatus, it makes inefficient use of the network and of the toll operator's time (the called party must be on-line before money is deposited). Furthermore, it is confusing to customers familiar with the more common prepay service.

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7. Trademark of AT&T.

Prepay service requires an initial deposit before the connection is made on chargeable calls. The two divisions of prepay service are coin-first, in which the initial deposit is required to obtain the dial tone, and dial-tone-first, in which the dial tone is connected before deposit, but a chargeable call is cut through only after the correct amount has been deposited. Coin-first service can be provided from all central offices. Depositing the initial amount initiates the request for service with a ground-start supervision signal. All local calls can be dialed directly; toll calls can be dialed in areas served by TSPS. Coins are required to reach the operator and special-service codes. Coins are automatically collected on completed calls or returned on unanswered, operator, or service calls. Coin-first service is provided with both multislot or the newer single-slot coin stations.

The major advantage of prepay coin-first service is that it significantly reduces the network and operator holding time from that required for postpay service; however, it requires a coin to originate any call, including collect and other calls not resulting in coin collection, and it requires a coin to determine if the station, associated loop, and serving central office are in working order.

The newest coin system, prepay dial-tone-first, served about 100,000 lines in 1973 and can be provided from all offices except Panel. Existing offices, however, must be modified to provide this service. Dial-tone-first service also requires a modification to the coin telephone. Unlike coin-first service, the switchhook is used to initiate a call with a loop-start supervision signal. No coin is required to reach the operator or special-service codes. Dial-tone-first service provides improved transmission because the station ground is disconnected once the connection has been made.

12.2.2 THE COIN STATION

The coin telephone is essentially a conventional telephone, modified by adding components for coin handling, that operates over a conventional 2-wire line with a local ground. To understand how a coin telephone works, consider the operation of the single-slot station in a prepay coin-first system; a comparable dial-tone-first discussion is given in Reference 4.

When coins (to the value of the initial amount) are deposited, a contact is closed. This requests dial tone and states that the initial deposit has been made. A totalizer is used to count and store the initial coin deposit. On a toll call, each coin deposit initiates transmission of one to five pretimed inband tones (one for each 5 cents of coin value) to signal to the operator the value of each coin deposited. The coins are held in the hopper under control of the polarized coin relay until the call is completed or abandoned. The coins are then collected or returned, depending on the polarity of the 100- to 130-volt dc signal applied across the tip conductor to ground. Coin station long loop range is primarily limited by the ability to supply the 41 mA required to operate the coin relay.

12.2.3 DESIGN CONSIDERATIONS

Coin stations must meet the same network transmission objectives as standard station sets (see Section 12.1) and, in addition, must satisfy the primary considerations of ease of use, proper coin handling, security, and maintainability. The customer must have clear and simple instructions for both local and toll calls. The coin-handling mechanism should be reliable and easy to use, so the customer is charged fairly for the company's services. The set must be strong and rugged enough to survive a rather hostile environment of both electrical and mechanical fraud attempts. When things do go wrong, because of equipment failure, vandalism, or theft, the set must be easily and quickly repairable.

Reference 5 describes some of the improvements made by the single-slot station in meeting these objectives.

12.2.4 FUTURE COIN SERVICE

The major new effort in coin systems is automated coin toll service (ACTS). ACTS marries the TSPS to a modified station with a new coin signaling transmitter to permit automatic detection of the coin deposit signal, thereby completely automating all prepaid calls. The TSPS computer automatically determines the charge for each prepaid call, uses a computer-controlled recording to notify the caller of the required deposit, and, after determining that the coin deposit has been made, sets up the connection.

The higher cost for this system is expected to be more than compensated by the saving in labor costs for operators. The system will not completely eliminate coin service operators, as they will still be required to provide assistance and to handle other types of toll calls.

12.3 CUSTOMER SWITCHING SYSTEMS

12.3.1 CLASSES OF CUSTOMER SWITCHING SYSTEMS

Business customers, as compared to residence customers, have rather special communications needs. For example, business customers often have a need to communicate with individuals within the business, as well as with the outside world, and also often need access to several different telephone lines. In recognition of these needs, a line of switching equipment has been developed, referred to as Customer Switching Systems (CSS) or business communications systems (BCS).

Customer Switching Systems can be broadly defined as switching equipment designed to provide some form of telecommunications service to business customers. The major categories of business services, the basic functions of each service, and the main Customer Switching Systems currently offered to provide the service are shown in Table 12-1. Each of the systems listed will be described in the sections to follow.[8]

Table 12-2 gives estimated in-service and annual Western Electric shipment statistics for the various systems listed in Table 12-1.

TABLE 12-1
CUSTOMER SWITCHING SYSTEMS

SERVICE	BASIC FUNCTION	MAJOR SERVING SYSTEMS
Key Telephone Service (KTS)	Provides key-selected access at a customer station to a multiplicity of central office or other lines. Hold, intercom, and other features are available.	No. 1A, 1A1, 1A2, and COM KEY Key Telephone Systems.
Private Branch Exchange (PBX) Service	Provides a station-to-station calling capability and access to the public telephone network. Also provides for attendant handling of incoming calls on central office lines. Some systems can provide direct inward dialing to stations and automatic identification of outward dialing from stations.	No. 701, 756, 757, 770, 800, 801, 805, 101 ESS, 812, and CSS 201 Private Branch Exchanges.
Centrex Service	Provides a station-to-station calling capability, access to the public telephone network, direct inward dialing to stations, automatic identified outward dialing, and attendant services.	No. 1 ESS, No. 2 ESS, and a few No. 5 Crossbar Systems.
Automatic Call Distribution (ACD) Service	Distributes incoming calls uniformly over a grouping of answering positions in approximate order-of-arrival sequence.	No. 2A, 2B, and 3A Automatic Call Distributors, No. 4A Call Distributor, No. 1 ESS Universal Call Distribution and ACD features.
Telephone Answering Service (TAS)	Provides access by a remote TAS bureau to customer lines.	No. 551, 554, 557A, and 557B Telephone Answering Systems.

8. Special systems used by governmental groups and agencies, two examples of which were given in Section 4.1, also fall into the category of CSS. Such special systems will not be discussed further here.

TABLE 12-2
CSS STATISTICAL DATA (1972)

CUSTOMER SWITCHING SYSTEM	ESTIMATED NUMBER IN SERVICE	ESTIMATED ANNUAL SHIPMENT
Key Telephone Systems (KTS)	2.5 million systems	1.9 million lines
Private Branch Exchange (PBX) Systems	91,000 dial systems 60,000 manual systems	800,000 dial lines
Automatic Call Distributors (ACD)	1000 commercial systems	6000 positions
Telephone Answering Systems (TAS)	9000 positions at 3700 locations	600 positions

As can be seen from Fig. 12-5, about 35 percent of all Bell System revenue comes from calls over private branch exchange and key telephone systems. Automatic call distributors and telephone answering systems are included in the "Other Business" category, along with various private-line services.

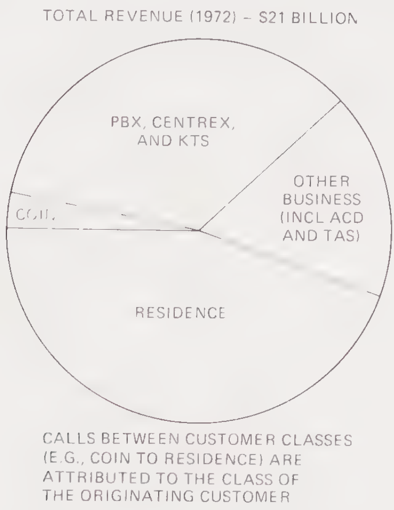

Fig. 12-5. Total Bell System Revenue by Class of Service 1972

12.3.2 KEY TELEPHONE SYSTEMS

Within a business, the need often arises for an individual to have access to several different central office lines, PBX lines, WATS access lines, FX lines, etc. Also, there often exist small communities of interest within a business that frequently desire to communicate internally as well as with parties outside the firm. Key telephone systems provide features that satisfy these and other business customer needs. The system functions are controlled in an easy-to-use manner by pushing buttons that are typically equipped with lights to indicate system status. An array of buttons is called a *keystrip*, and a telephone so equipped is called a *key telephone* or *key station*.

12.3.2.1 Key Telephone System Features

A key telephone system is a customer-controlled switching system. The basic purpose of such a system is to provide its users with the ability to pick up selectively any of several lines and to hold calls associated with any of these lines.

A typical key telephone system consists of five or six key stations which have access to some subset of four to six lines. Systems can range, however, from one to hundreds of stations or lines. Various types of station sets are used in key systems. The most common have been keysets that can handle up to 6 lines, 10- and 20-button sets, and various types of CALL DIRECTOR telephones, which can handle up to 30 lines.

Key mountings to be fitted into customer-provided housings can handle up to 120 lines; separately mounted keystrips can be associated with many types of nonkeysets to make a key station. The state of lines terminated on a station is usually indicated by lamps located under the keys on the station. The common line states and corresponding lamp indications are shown in Table 12-3.

TABLE 12-3
KEY TELEPHONE LAMP SIGNALS

LINE STATE	LAMP INDICATION
Idle	Not illuminated
Busy	Steady illumination
Ringing	Flashing (60 flashes per minute)
On Hold	Winking (120 flashes per minute)

Fig. 12-6 shows a basic key telephone system with line and station terminations at the equipment. This equipment is located in a small equipment closet or, in smaller systems, is wall-mounted in office space. This figure shows a key system working directly into a central office; about one-half of the Bell System key systems work into PBXs, which in turn connect to central offices.

In addition to the ability to pick up and hold lines, a key system can provide a variety of other features such as intercom service and conferencing.

Intercom service provides one or more dedicated channels on which stations can intercommunicate without the need for placing the call through a collocated private branch exchange or local central office. In manual inter-

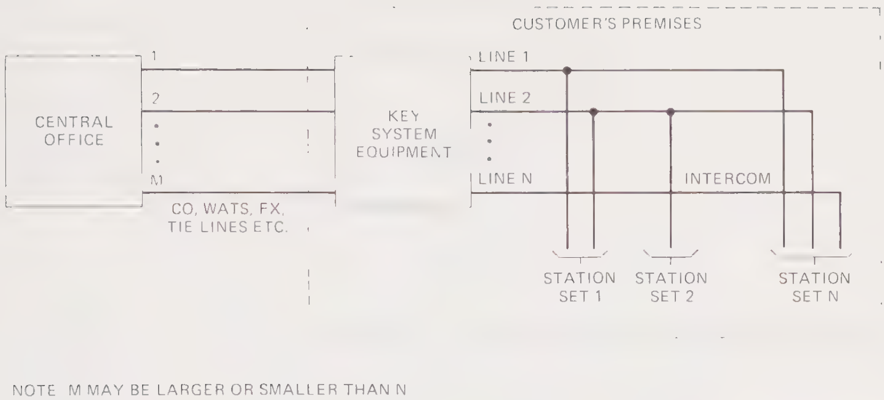

Fig. 12-6. Key Telephone System Serving Arrangement

coms, all station lines have access to a common talking path, and signaling is commonly done with a buzzer. In dial intercoms, there may be more than one talking path, and signaling is on a dial basis.

A key system conferencing arrangement allows a station user to establish a 3-way call by simultaneously using two of the lines that appear at his station.

12.3.2.2 Wiring Plans

Key telephone service was originally provided by special assemblies of lamps and keys, which were subsequently standardized and referred to as *wiring plans.*

12.3.2.3 1A KTS

The Bell System's first key telephone system was the 1A, developed in 1938. Each telephone line connected to the system required a set of control relays called key telephone units (KTUs). Other assemblies controlled the service features, which could be changed by changing the assemblies.

12.3.2.4 1A1 KTS

The 1A1 KTS was introduced in 1953 to reduce the amount of field labor required with the 1A. Commonly used functions were combined into a single KTU to allow easier installations. To further facilitate installation, key service units (KSUs), which housed several KTUs, were developed. Hence, picking appropriate KTUs and housing them in a KSU allowed offering assembled key systems tailored to meet common key telephone user requirements. Such service units avoided many of the inconveniences, much time, and the possibility of error involved in separately ordering long lists of assemblies for each customer. For equipment closet installations, KSUs serving up to 11 PBX or central office lines were provided.

12.3.2.5 1A2 KTS

The 1A2 KTS, first offered in 1963, continued the packaging concept of the KTU introduced with the 1A1. The 1A2 does not differ greatly from the 1A1 from a user's point of view. Internally, however, the 1A2 is a completely new system using solid-state components, printed wiring boards, and miniature relays to effect a saving in space requirements compared with the 1A1 system. The KTUs of the 1A2 consist of plug-in cards, whereas the 1A1 KTUs used screw-terminal wiring.

12.3.2.6 Key Telephone System Trends

Installation cost is a major component of a key telephone system's cost. A recent development, a series of modular panels for the 1A2 KTS, is aimed at curbing this expense. These modular panels combine equipment mounting and wire connecting arrangements in a single unit. The modular panel is in contrast to present key system installation techniques, in which the equipment and the cross-connecting fields for stations and central office lines are physically separate.

Two new packaged key telephone systems, called COM KEY systems, became available in 1973 and a third in 1975. These systems are prewired at the factory to offer a fixed feature package. The 7A COM KEY system provides up to 7 central office or PBX lines and 18 stations; the 14A system provides up to 14 lines and 34 stations; and the 21A provides up to 21 lines and 52 stations as well as increased flexibility and features. Modified 10- and 20-button stations are used.

The COM KEY systems provide a number of new service features. Tone signaling, replacing the conventional ringer, provides two different alerting tones to differentiate between central office and intercom calls. Voice signaling on intercom calls allows the calling party to convey a message to the called party via a loudspeaker built into the station set, even if the called party is engaged on another call. Other new features include multiline conferencing arrangements and the provision for incoming callers placed on hold to hear music, rather than silence. The economies gained by standardizing these two new systems in factory-wired packages and the new features they provide have made them attractive offerings in the competitive market.

12.3.3 PRIVATE BRANCH EXCHANGE AND CENTREX SYSTEMS

The basic function of a private branch exchange (PBX) is to connect PBX stations to each other or to trunks to the local central office. The role of the PBX in interconnecting stations and in connecting stations and trunks is similar to the role of the local central office in performing intraoffice and interoffice switching.

The PBX is typically located on the customer's premises, as shown in Fig. 12-7, although there is also an arrangement in which PBX service is provided directly from a central office with very little equipment on the customer's premises. The equipment shown in Fig. 12-7 may be rack-mounted, in which case a separate equipment room is used, or it may be in a cabinet (or cabinets) located in an office or other area of the business. All the stations served by the PBX and an attendant position (or positions) terminate at the PBX.

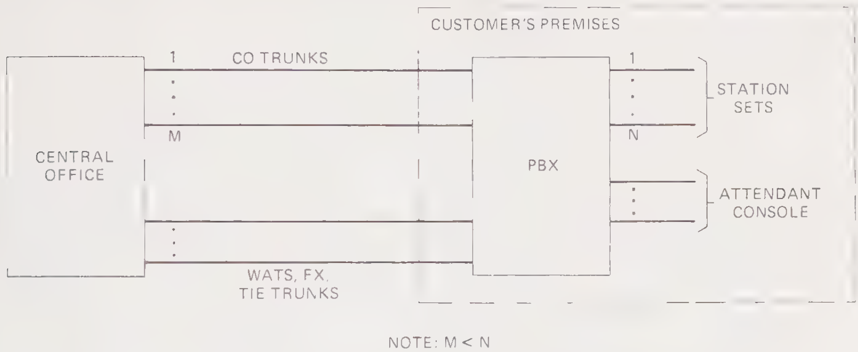

Fig. 12-7. PBX Serving Arrangement—Customer Premises (CU)

12.3.3.1 Attendant Functions

The PBX attendant, an employee of the PBX customer, answers incoming calls and interconnects these calls to the appropriate stations within the PBX. The attendant may also perform secretarial functions for the firm. The attendant usually performs the interconnecting function either by dialing the extension number of the desired station or, in some systems, by depressing a key associated with the particular station. In early manual PBXs, the attendant performed all the interconnections, incoming as well as station-to-station, at a cord switchboard. Most modern PBXs are termed *dial systems* because the interconnections are done automatically by the PBX equipment as the station user or attendant dials. The discussion here will deal only with dial PBXs.

The training of PBX attendants is a service provided to the PBX customer by the business services departments in the operating companies. "Hands-on" training is usually done on a console (or switchboard) on which simulated traffic can be presented for the training attendant to handle. During the training session, the instructor is also concerned with other aspects of the attendant's job, including phraseology, enunciation, and courtesy since the attendant answers incoming calls.

12.3.3.2 Trunks

The trunks that connect the PBX to the central office, as shown in Fig. 12-7, are fewer in number than PBX stations. The engineering of the trunk groups is done similarly to the way trunk groups in the public telephone network are engineered and is based on the fact that rarely if ever will all of the stations attempt to talk outside of the PBX at the same time (see Chapter 14). The operating company usually recommends the appropriate number of trunks; however, the customer may specify the number desired.

Besides central office trunks, a wide variety of other circuits can be connected to a PBX so as to be accessible to the PBX stations. These include WATS trunks, private lines, tie trunks, and foreign exchange trunks.

12.3.3.3 PBX Customer Sizes

PBX customers range in size from those having as few as ten stations to those having several thousand. The average PBX customer has about 100 stations, one or 2 attendants, and 15 or more central office trunks.

12.3.3.4 PBX Features and Designations

The major PBX service features were described in Section 4.1.2.1. All of the PBX systems described in this chapter provide basic dial service; several of the systems can provide direct inward dialing and automatic identified outward dialing (DID/AIOD) service.

PBX numeric designations starting with 7, such as 701, denote electromechanical systems. Those starting with 8, such as 801, denote systems using electronic common control. The new CSS 201 series denotes stored program control systems. Section 9.1 describes the basic switching concepts and hardware mentioned in the following sections.

12.3.3.5 701 PBX

One of the earliest PBXs, introduced in the late 1920s, was the 701. Today, the 701 constitutes a large part of the in-service population of dial PBXs. The 701 is a progressive, direct-control, Step-by-Step switching system, similar in appearance and operation to Step-by-Step central office equipment (see Section 9.3). Like Step-by-Step central offices, the 701 PBX can grow in size from a system capable of serving a very small number of stations to a system having several thousand stations. This characteristic of essentially unlimited growth is not shared by other present-day PBXs and has effectively forced the use of the 701 in most very large installations (over 2000 stations). (No. 2 ESS can also be used as a PBX to serve very large customers.)

The 701 switching equipment is usually located in a separate equipment room and generally consists of step-by-step switches mounted on open frames, trunk circuits on relay racks, and a power plant that furnishes battery and ringing current.

Besides providing PBX service, the 701 can provide DID/AIOD service as defined in Section 4.1.2.1.

12.3.3.6 756 and 757 PBXs

The 756 PBX was introduced in 1957 to provide a more economical vehicle than the 701 for serving small (up to 60 stations) customers.

The 756 introduced the crossbar switching network and redundant relay-type common control to PBX technology.

The 757 PBX was introduced in 1963 and is essentially an expanded version of the 756, capable of serving up to 210 stations. Both the 756 and 757 are housed in cabinets, as opposed to the open-rack design of the 701 PBX, and do not require a separate equipment room.

12.3.3.7 770A PBX

The 770A PBX was introduced in 1972 and can serve up to 400 stations. The 770A is a wired-logic, common-control, crossbar switching system housed in cabinets. This PBX was aimed at providing low-cost service with standard features. The system has found widespread use, particularly in hotel/motel applications and in other light-traffic environments.

12.3.3.8 800A and 801A PBXs

The 800A PBX, introduced in 1967, uses electronic common control of a ferreed switch network and is capable of serving up to 80 stations. In 1971, the 800A was expanded into the 801A PBX, with the capability of serving up to 270 stations. The 800A and 801A have advantages in installation, maintenance, and reconfiguration.

12.3.3.9 805A PBX

In 1971, the 805A PBX was introduced to satisfy the needs of small (up to 57 lines) customers desiring only basic dial PBX service. Housed in a single filing-cabinet-sized enclosure, the 805A uses solid-state electronic (transistor-resistor logic) common control of a crossbar switch network.

12.3.3.10 812A PBX

The 812A PBX, introduced in 1973, has a crossbar switch network and can provide service for up to 2000 stations. It is a cabinet-housed, electronic (diode-transistor logic in dual-inline packs) common-control system, aimed at providing service to medium- to large-sized customers. It serves the market above the size range of the 770A PBX with modern services at lower cost than the 701A.

12.3.3.11 101 ESS

The 101 ESS was introduced in 1963; it provides a number of special features including call hold, call pickup, call forwarding, speed calling, 3-way conference transfer, and direct inward dialing and automatic identified outward dialing. The 101 is unique in that the serving arrangement consists of a stored program control unit, located in the central office, which is capable of controlling several switch units located on the premises of different PBX customers. The control unit converses with and controls the switch units over a connecting data link.

Several different switch units are available, with the largest serving up to 4000 stations. The customer-located switch units perform the interconnection of stations to stations and stations to trunks.

The technique of time-division switching (see Section 9.1) introduced with the 101 switch units sets up a connection by periodically connecting the station and trunk terminals together for a very short period of time through high-speed solid-state switches. The modulation technique of pulse amplitude modulation (PAM) is used in this process. The relatively high cost of the 101 and the rather specialized central office/customer location environment required (i.e., several customers requiring service in the area of the central office) have limited the system's application to customers whose service needs cannot be met by other PBXs.

12.3.3.12 CSS 201 (*DIMENSION*®) PBX

The Customer Switching System (CSS) 201, with the marketing name of DIMENSION, utilizes stored program control of a time-division PAM network. It offers more features than any previous system at lower cost. The stored program design permits great flexibility to add or change features. The common design of small, medium, and large systems minimizes operating company training and inventories for installation, maintenance, and reconfiguration.

The first systems, serving up to 120 lines, were available in late 1974. Systems up to 400 lines were available in 1975, and systems larger than 2000 lines became available in 1976.

The DIMENSION PBX system makes use of an electronic console that gives the attendant improved flexibility in comparison with previous consoles. An arrangement of light and tone signals reduces the opportunity for confusion and improves the efficiency of the attendant.

Electronic telephones were introduced with the DIMENSION PBX system in late 1975. These sets, in conjunction with circuitry and software in the CSS 201, provide key telephone service and access to special features in the system by buttons on the stations. The stations are newly styled and interconnect with the PBX by 8-wire cable.

The station capacities of PBXs described are shown in Fig. 12-8.

12.3.3.13 Service From the Central Office

The PBXs already discussed (with the exception of the control unit of the 101 ESS) are designed to be located on the customer's premises. Depending on the type and size of a PBX, it can occupy the space of a standard filing cabinet (for an 805 PBX) or a large equipment room (for a multistation 701 PBX). Beginning in 1961, the logic resident in No. 5 Crossbar central offices and later in No. 1 ESS offices was exploited to provide centrex service. With centrex service, incoming calls can be dialed direct to stations, and stations can dial outward calls without going through an attendant. These features are called Direct Inward Dialing (DID) and Automatic Identified Outward Dialing (AIOD). This concept has been broadened recently with provision of PBX service directly from central offices (termed PBX-CO). With PBX-CO service, as contrasted with centrex service, all incoming and outgoing calls are routed to an attendant; however, each station is still controlled from the central office.

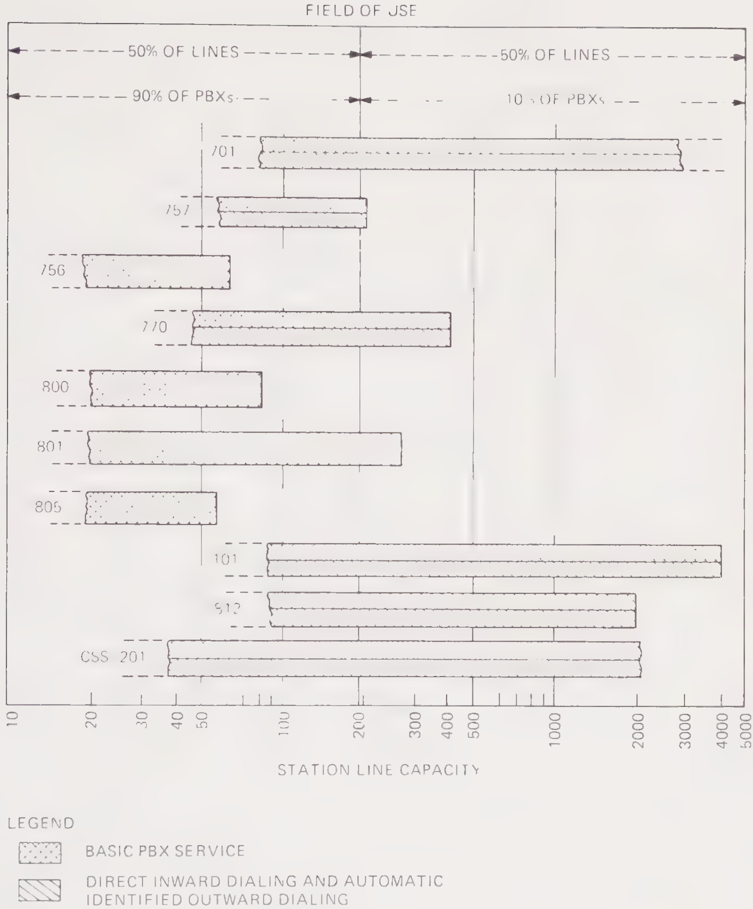

Fig. 12-8. Principal Dial PBX Systems—Field of Use

Fig. 12-9 is a diagram of the central office method of providing PBX or centrex service.

In the CO serving arrangement, all the stations are directly terminated at the central office. This involves a loop-length-dependent cost penalty compared with the CU arrangement, in which the outside plant is used more efficiently by concentrating the traffic. However, with CO service there is no switching equipment at the customer's premises; this makes maintenance more convenient and does not occupy floor space at the customer's premises. These two factors imply that, in general, CO service tends to look more attractive economically than CU service for customers with relatively few stations and who are close (i.e., have short loops) to the central office.

In CO service, the attendant console(s) is linked to the central office by a data link for large customers served from No. 1 ESS and by direct-control leads for No. 5 Crossbar or for small customers served from No. 1 ESS. Un-

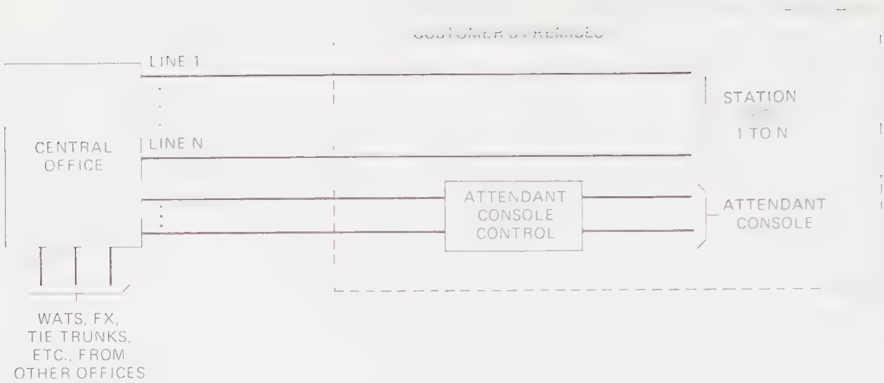

Fig. 12-9. PBX and Centrex Serving Arrangement—Central Office (CO)

like the situation in CU service, all calls, even station-to-station, are switched by the central office.

By 1974, about one million centrex lines were served from No. 5 Crossbar and over one million from No. 1 Electronic Switching Systems. Centrex service is also available in No. 2 ESS. Presently, No. 5 Crossbar and No. 1 ESS central offices can provide some PBX-CO service, although tariffs for this service do not exist in all telephone companies and for all levels of service.

12.3.3.14 PBX Trends

The market for PBXs is highly competitive, with many outside manufacturers offering a large number of different systems with a wide variety of services. The Bell System is planning to remain competitive in the PBX field in several ways. Tariffing policies were discussed in Section 4.2. The Bell System has pioneered in introducing electromechanical and electronic technology into PBXs. Continued innovation is leading to systems with more service features at lower cost.

12.3.4 AUTOMATIC CALL DISTRIBUTORS

Automatic call distributors (ACDs) are used to automatically switch large volumes of incoming calls to attendant (answering) positions. ACDs find application both in Bell System number services (delivering calls to directory assistance or intercept operator teams as described in Section 7.3) and in commercial applications such as airline reservation bureaus and department store catalog departments.

ACDs have the following characteristics:

(1) Calls on incoming trunks are served in near order-of-arrival.

(2) Calls are distributed among the attendants to maximize the efficiency of the attendant group.

ACDs range in size from those having fewer than 10 attendant positions to those having 500 or more. Approximately 70 percent of all ACD installations have fewer than 50 positions, and 90 percent have fewer than 100 positions.

As contrasted with PBX service, which is usually thought of as a means to facilitate a business's communications, the ACD is directly involved in the business operation itself. Generally, all of the personnel associated with the ACD work full time handling the incoming calls, and generally the attendants completely service the calls. In contrast with PBXs, which have concentration from station lines to trunks, ACDs typically use more trunks than active attendant positions. This permits the attendant positions to be loaded efficiently. The incoming trunks can include local central office trunks, FX lines, private lines, and INWATS lines. ACD answering positions usually consist of CALL DIRECTOR-type consoles modified for ACD use. Fig. 12-10 is a diagram of an ACD installation.

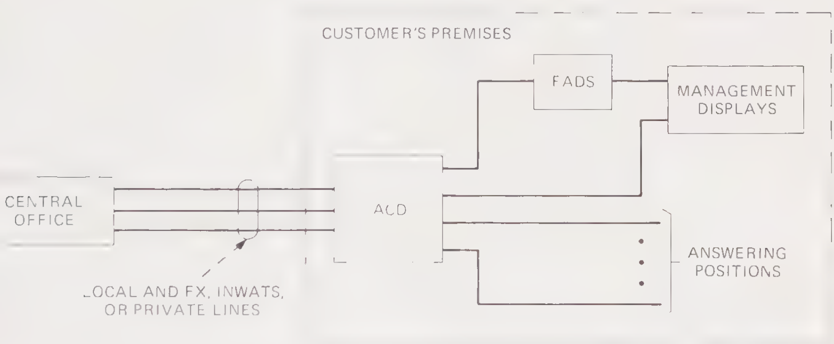

Fig. 12-10. Automatic Call Distributor Serving Arrangement

The ACD is commonly associated with key telephone and/or private branch exchange equipment to give the attendants the ability to originate and receive calls in addition to the calls received from the ACD.

Most ACDs are located on the customer's premises; however, ACD service also is provided from central offices. Bell System number service operators, repair service bureaus, and other departments that receive large volumes of incoming calls are usually served from No. 5 Crossbar ACDs. No. 1 ESS also provides ACD service.

12.3.4.1 ACD Administration

A day-to-day concern in the operation of most larger ACDs is ensuring that the ACD is being used efficiently; that is, that the incoming calls are not forced to wait excessively long to be answered and that the team of attendants is not excessively idle (see also Section 14.7). The Force Administration Data System (FADS) is an adjunct to the ACD that provides the managers of the ACD operation with certain statistical performance information. This information can be used to adjust the number of answering personnel to provide a desired grade of service to the incoming calls without having too many, or too few, manned positions.

In addition to FADS, most larger ACDs have one or more supervisory positions at which management displays (such as lamp indications of individual answering position status) appear. These displays are often provided on a special-assembly basis. Both FADS and management displays are indicated in Fig. 12-10. The newer No. 1 ESS ACD provides a large variety of management information and control features.

12.3.4.2 2A and 2B ACDs

Several systems are currently used to provide commercial (i.e., non-telephone-company application) ACD service. The 2A ACD, introduced in 1962, provides for a maximum of 56 incoming trunks and 60 attendant positions using a standard crossbar switch. The 2B ACD was made available in 1973. It provides for up to 68 incoming trunks and 70 attendant positions and utilizes a small crossbar switch. Up to three 2B ACDs can be arranged to balance the incoming load among the units. Such load balancing permits the 2B to serve up to 180 attendant positions.

The 2B can be arranged to "overflow" traffic to a distant ACD when the local ACD cannot adequately handle all of the offered load.

The 2A and 2B ACDs, as well as the 3A ACD described in the next section, can provide delay announcements to the incoming callers. These announcements, given when incoming calls are queued and waiting for service, assure the calling party that his request will be serviced if he continues to wait.

12.3.4.3 3A ACD

The 3A ACD, introduced in 1963, is a Step-by-Step ACD providing for up to 198 incoming trunks and 200 positions. Several 3A ACDs can be load-balanced to provide up to 600 positions for businesses handling very high volumes of calls.

The 3A ACD can provide for overflow trunking to a distant ACD and can be "split" to allow for several independent groups of attendant positions.

12.3.4.4 4A Call Distributor

The 4A call distributor, introduced in 1973, is intended to serve small applications. It provides for up to 20 incoming trunks and 15 attendant positions. The 4A is not an ACD in that calls are not automatically distributed, but are selected by the answering attendants on CALL DIRECTOR-type consoles by observing the flashing rates of illuminated keys.

12.3.4.5 ESS/ACD

Automatic call distribution service can also be provided from No. 1 ESS offices. A simplified form of ACD service, universal call distribution (UCD), is suitable for customers having a small number of attendant positions. ACD service with more features than can be provided from the 3A ACD became available from No. 1 ESS in mid-1975. Even more sophisticated service with an enhanced management information system became available later.

12.3.5 TELEPHONE ANSWERING SYSTEMS

The principal function of telephone answering service (TAS) is to record telephone messages for business, professional, and residential clients and to relay the messages back to the clients in accordance with a previously agreed upon plan. The Bell System does not provide TAS, but provides telephone answering systems to bureaus who do. The TAS clients' telephones can terminate at the bureau, either directly or by a method analogous to an extension telephone (a bridge tap). Direct termination implies that only the bureau can answer the call; the line does not appear at the client's premises. At the TAS bureau, for both types of terminations, each client has only one appearance; that is, the client's line is not multipled to several answering positions. TAS bureaus can have from one to 20 or even more positions; the average number of positions is 3.

Fig. 12-11 is a diagram of a typical TAS arrangement. Clients who are in the same central office as the TAS bureau are usually bridge tapped to the bureau. Also shown is the case of a non-bridge-tapped direct termination.

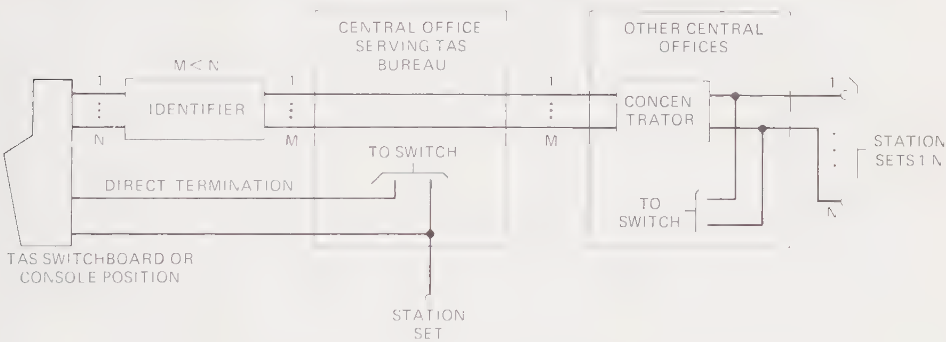

Fig. 12-11. Telephone Answering System Serving Arrangement

Clients served by central offices other than the one serving the TAS bureau are usually connected to the TAS bureau via concentrator-identifier equipment. The concentrator, located at the central office, serves to concentrate the TAS subscriber lines in that office onto a fewer number of trunks that are connected to the identifier (see also Section 9.1.1). The identifier, located at the bureau, fans out these trunks into specific customer-identified lines which are then terminated onto the answering board.

12.3.5.1 557A, 557B, 1A TAS

Two cordboards and one cordless console are presently manufactured for the TAS industry. The 557A was introduced in 1954, and is a double-cord switchboard designed for TAS applications requiring the extension (i.e., forwarding) of a bureau-answered call beyond the TAS attendant. The 557B, introduced in 1956 for use in areas where the call extension capability of the 557A is not tariffed, is a single-cord board and is the more commonly used TAS cordboard. The 1A cordless TAS console was introduced in 1965 and is not presently available for new installations, due mainly to a relatively high cost. The 1A console features pushbutton answering of incoming calls.

Some smaller TAS bureaus use key telephone equipment to pick up the clients' lines, but the majority of bureaus use either the 557A or 557B.

12.3.6 TELEPHONE COMPANY NON-WESTERN PURCHASES

Business communications systems are manufactured and sold by many companies other than Western Electric. Bell System operating companies are under no obligation to purchase from Western Electric. In fact, each company has an obligation to its customers to buy the best equipment at the lowest overall cost to meet its customers' needs. The disadvantage of a telephone company having too many different makes of systems in the field and the attendant need to have crafts personnel skilled in their maintenance and repair imply that those companies who use non-Western equipment tend to standardize on one manufacturer's equipment and to purchase relatively large quantities.

12.4 DATA

12.4.1 HISTORY OF DATA COMMUNICATIONS

Although one tends to associate data communications with modern digital computers and hence to think of it as a new field, data communications is actually much older than remote voice communications. For example, ancient man had his system of drums, gongs, smoke signals and the like, sometimes with human repeaters, which he used to send simple data messages. More recently, telegraph has been an important means of sending messages over long distances.

Telegraphy was first developed as a form of dc transmission by coded pulses over wire pairs (or one wire with ground return). The information transmission rate over long wire circuits was limited, and regenerative repeaters were needed to reconstruct the signal at intervals along a circuit because of signal distortion. The principle of regeneration has proved valuable and is used extensively in digital transmission systems today. Later, amplitude and frequency-shift modulation techniques were introduced, permitting transmission of telegraph signals over voice channels. Telegraph carrier systems were developed that multiplexed up to 17 telegraph signals in one voice channel. Telegraph circuits have been used widely for a variety of applications, the most extensive application being teletypewriter service. Speeds up to 75 bits per second (b/s) have been generally available for many years; speeds up to 150 b/s have been available since about 1965.

The need for data communications at higher than the conventional 75-b/s telegraph rate arose about 1950. One of the first applications involved transmitting radar data to antiaircraft installations and data processing centers. By the mid-1950s, the Bell System was providing 1600-b/s data links for use in the SAGE system, a system developed for the Strategic Air Command. About this time, it became clear that there was a commercial need for data communications, and in 1957 the first commercial data set, transmitting at 1000 b/s by means of frequency-shift keying, was introduced.

By the early 1960s, a whole line of DATAPHONE data sets had been developed and categorized into the following series:

100 Series—Narrowband (low-speed) Serial Data Sets
200 Series—Voiceband Serial Data Sets
300 Series—Wideband Serial Data Sets
400 Series—Voiceband Parallel Data Sets
600 Series—Voiceband Analog Data Sets.

Throughout the 1960s, there was a rapid progression of new developments, each leading to higher bit rates for a given channel bandwidth. The most dramatic increase came as a result of the development of the adaptive transversal equalizer (see Reference 6). This adaptive filter automatically compensates for the linear distortion introduced by a telephone channel. Whereas without automatic equalization, voiceband data rates had been limited to about 3000 b/s, with automatic equalization it became feasible to transmit at rates up to approximately 10,000 b/s.

Coincident with the technological change that occurred during the 1960s, a major policy change also took place regarding the interconnection of non-Bell System data sets to the switched network. From 1969 to 1975, it was permissible to connect any non-Bell modem to the switched telephone network, so long as power limitations specified in the tariff were observed and a Bell-provided connecting arrangement was used to ensure adequate network protection. Starting in 1976, a data set registered with the FCC could be connected directly to the telephone network. Use of customer-provided modems on voice bandwidth private lines had been permitted for many years before 1969. The advent of wider interconnection possibilities led to the entry into the marketplace of many new data set vendors and increased competition.

The most recent developments in data sets have been more the result of improvements in devices rather than of improvements in modulation techniques. Starting in 1972, the Bell System has been introducing a new family of data sets that exploits integrated circuit technology to achieve dramatic size reductions from their predecessors (see Reference 7). Some of the members of this new family are shown in Fig. 12-12.

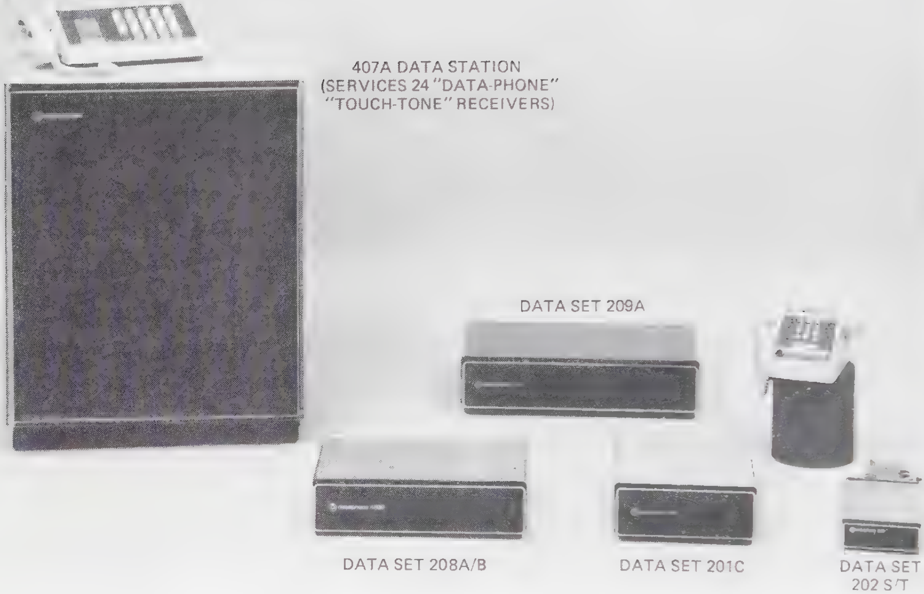

Fig. 12-12. Some of the New Family of Data Sets

12.4.2 HOW DATA TRANSMISSION HAS BEEN ACCOMPLISHED

A basic problem of data communications has been to send digital data over transmission facilities designed originally for analog voice signals. Consider some of the characteristics of such a voice channel. First of all, it can be roughly characterized as a bandpass filter with a passband between 300 and 2800 Hz. More specifically, this linear filter characteristic can be expressed in terms of amplitude and phase distortion, typical plots of which are shown in Fig. 12-13 and 12-14.

Along with linear distortion, the transmission channel introduces other impairments to data transmission. These include frequency offset, phase jitter, nonlinear distortion, and, of course, noise. Frequency offset results from sending a signal over an analog carrier facility in which the modulating and demodulating frequencies are not identical. The frequency offset, even on very long connections, is rarely more than 1 or 2 Hz, but still destroys the waveform of the signals. Phase jitter is incidental frequency modulation or phase variations introduced into signals transmitted over a telephone channel. Nonlinear distortion results from nonlinearities in the channel, such as may be introduced by nonlinear compressor-expandors (compandors), which are

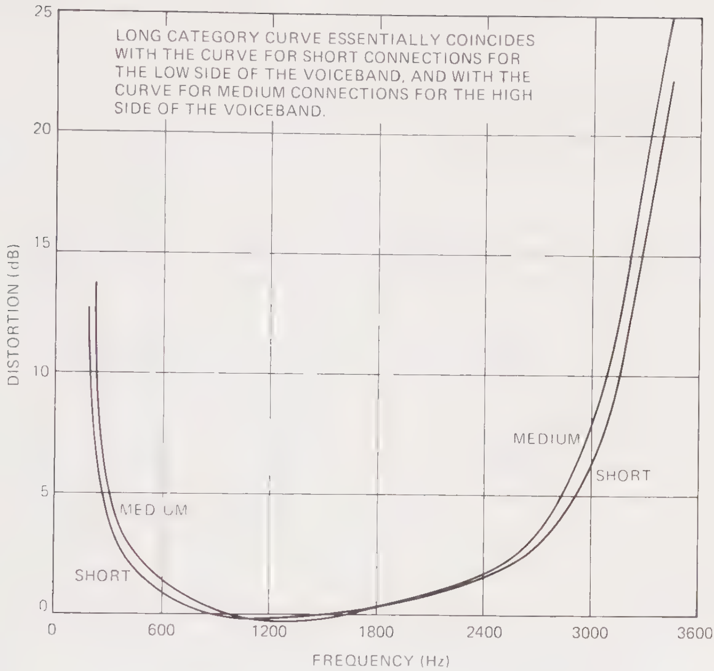

Fig. 12-13. Locus of Means for Attenuation Distortion Relative to 1000 Hz

used in some transmission facilities, particularly those using pulse code modulation (PCM), to decrease the dynamic range of the signal. If the compressor and expandor of a compandor do not track each other perfectly, nonlinear distortion results. Noise can be introduced from many sources, but, from the standpoint of data transmission, errors are most likely to result from high-amplitude noise peaks. A count of the number of these peaks exceeding a specified threshold is a good measure of the noise impairment for data transmission. One of the major sources of this noise, commonly called *impluse noise,* is the coupling into a channel of transients caused by switching systems. Some of the older switching systems, such as the Panel type (which are being replaced by Electronic Switching Systems), are so noisy that DATAPHONE service is not offered from central offices in which they are used.

The function of a data set is to convert a data signal, usually digital, into an analog signal that can be transmitted over a telephone line having all the impairments just mentioned. This conversion is accomplished by one of several modulation techniques. One of the first and still one of the most commonly used techniques is frequency-shift keying (FSK) (see technical description in Section 6.1.4). Frequency-shift keying is typically used for asynchronous data transmission; that is, transmission where the keying rate can vary and is established by the customer. Currently, FSK is used in all low-speed, 100-series data sets, as well as in the medium-speed 202-type sets. Two of the

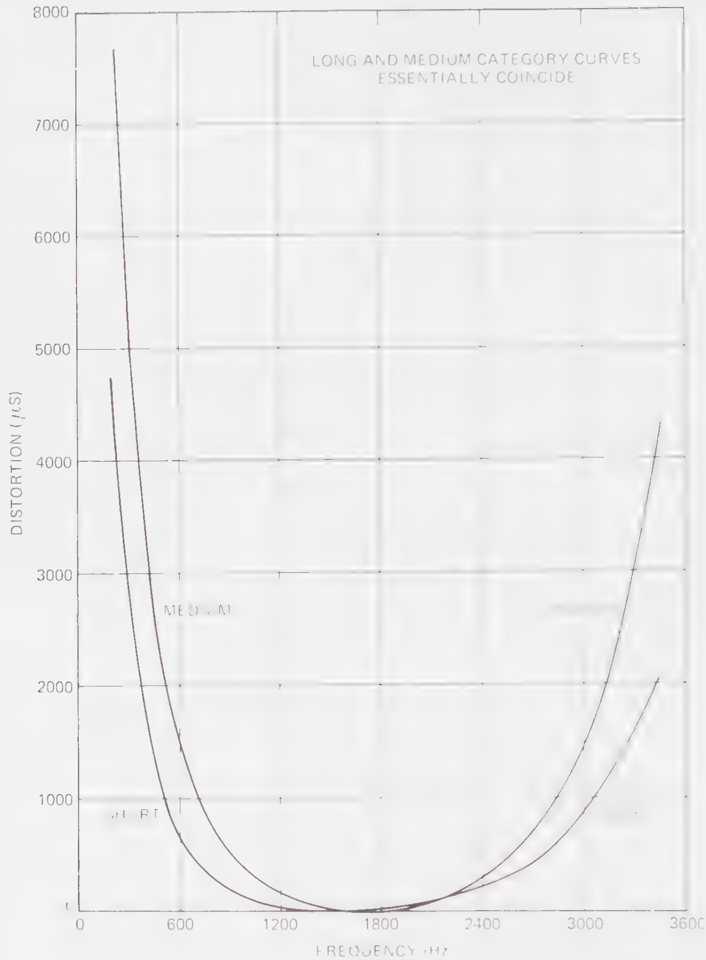

Fig. 12-14. Locus of Means for Envelope Delay Distortion Relative to 1700 Hz

recent 202-type sets are the 202T, which can be used at transmission rates up to 1800 b/s on private lines, and the 202S, which can be used for rates up to 1200 b/s on the public telephone network. Although both of these sets send and receive analog signals, their internal processing is mostly digital and is accomplished by two large-scale integrated circuits in each data set.

Another commonly used modulation technique is phase-shift keying (PSK) (see technical description in Section 6.1.4). This technique is used for synchronous data transmission; that is, transmission where the clock rate is established by the data set. Four-phase PSK is used in data sets of the 201 type, a recent version of which, the 201C, is capable of operating at the rate of 2400 b/s over either the public telephone network or private lines. Eight-phase PSK is used in data sets of the 208 type, which operate at 4800 b/s over either the public telephone network or private lines. To achieve reliable transmission at this rate over the wide variety of channel characteristics that can be encountered, an automatic equalizer is employed.

The third popular transmission technique is digital amplitude modulation. This technique can be subdivided into vestigial sideband modulation (VSB) and quadrature amplitude modulation (QAM). (See technical descriptions in Section 6.1.4.) Vestigial sideband modulation is used in data sets of the 203 type, which are recommended for synchronous transmission at data rates up to 4800 b/s on the public telephone network and 7200 b/s on private lines. Quadrature amplitude modulation is used in data sets of the 209 type. These sets achieve a transmission rate of 9600 b/s on private-line facilities. Data sets of the 203 and 209 types have automatic equalizers.

Finally, consider the performance of these data sets. The basic criterion for measuring the performance of a data set is error rate. Both the bit error rate and the block error rate are of interest. The latter is perhaps the better measure of performance for higher-speed voiceband transmission (>2000 b/s) because the information is usually transmitted in a blocked format.

To give an indication of typical error rates, consider two particular data sets. A recent survey of data transmission performance on the public telephone network (see Reference 8) indicates that a data set of the 202 type operating at 1200 b/s will achieve a bit error rate of 10^{-5} or better on 82 percent of the calls and a 1000-bit block error rate of 5×10^{-3} or better on 85 percent of the calls. A data set of the 203 type operating at 4800 b/s will achieve a bit error rate of 10^{-4} or better on 82 percent of the calls and a 1000-bit block error rate of 10^{-2} or better on about 82 percent of the calls.

12.4.3 HOW DATA WILL BE TRANSMITTED IN THE FUTURE

The previous section discussed data communication over analog transmission facilities. However, not all transmission facilities are analog. In Section 10.2, facilities were described in which the transmission is inherently digital (see also Reference 9). The number of these facilities is rapidly increasing because of their ability to provide good, economical voice communications. In addition, they have the obvious potential capability of supporting data communications in direct digital form, rather than by carrying the analog signals of a data set.

Consider the T1 Carrier System, in which voiceband signals are encoded into a 64-kb/s digital bit stream for transmission. Analog data sets could be used to transmit digital data via a T1 carrier link, but, as with any voiceband analog system, transmission rates would be limited to about 10,000 b/s per voice channel. If, on the other hand, the digital nature of the carrier system were exploited, this same voice channel could support data rates about six times as great.

The Digital Data System (DDS) makes use of these digital transmission facilities, interconnected to form a synchronous network for data communications. From the customer's viewpoint, the DDS[9] provides private-line synchronous data communications at several speeds. This service became available to several major metropolitan areas in 1974 with speeds of 2400, 4800, 9600, and 56,000 b/s. A 1.544-Mb/s speed was added in 1976. The system is expected to grow to include over 100 metropolitan areas.

Consider the facilities in a typical transmission path through the DDS. The customer's interface with the DDS is by means of either a data service unit or a channel service unit. The data service unit provides an interface very much like that of an analog data set, whereas the channel service unit is a relatively simple termination arrangement for those customers who prefer to do most of the signal processing associated with transmission in their own equipment. From these customer interface units, the signal is transmitted in bipolar digital format over a 4-wire line to a local office. There, the line is terminated at an office channel unit, which regenerates the signal and prepares it for transmission through the multiplexing hierarchy.

In the first stage of multiplexing, up to twenty 2.4-, ten 4.8-, or five 9.6-kb/s signals can be multiplexed into a single 64-kb/s T1 channel. Alternatively one 56-kb/s data signal can be put into a 64-kb/s channel. A second stage of multiplexing combines twenty-three 64-kb/s streams into a 1.544-Mb/s bit stream, which corresponds to the DS-1 signal of the TDM hierarchy (see Section 6.2).

If the customer's end-to-end connection is limited to one metropolitan area, T1 carrier and baseband facilities may be the only transmission facilities needed. However, if long-haul transmission is required, T1 carrier will be used up to a particular office in the metropolitan area. This office, called the *hub*, provides access to the long-haul digital facilities extending to other parts of the network. Generally, the office chosen to be the hub will be the one that serves the largest number of data customers. This hub office also provides test access to individual data channels, cross-connecting facilities for efficient packing of customer data signals into the various outgoing transmission facilities, and a highly stable timing source, derived from a master system clock, for the multiplexers both at this office and the local offices. These local offices, in turn, provide system clock information to individual station units on the customer's premises. A typical point-to-point DDS channel is illustrated in Fig. 12-15.

The primary long-haul transmission facility planned for use in the DDS is the 1A Radio Digital System, generally referred to as the data under voice (DUV) system, on TD/TH microwave radio. The DUV system employs a 1.544-Mb/s bit stream in the bandwidth available underneath the message channels on a message-bearing radio channel on an existing microwave route, generally without displacing any message channels. The TD/TH microwave systems have a route capacity of one DUV signal per message-bearing radio channel. Thus, the DUV system will permit economical expansion of routes

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9. Note that DDS refers to the digital data system made up of digital facilities; the service provided on that system is known as DATAPHONE digital service.

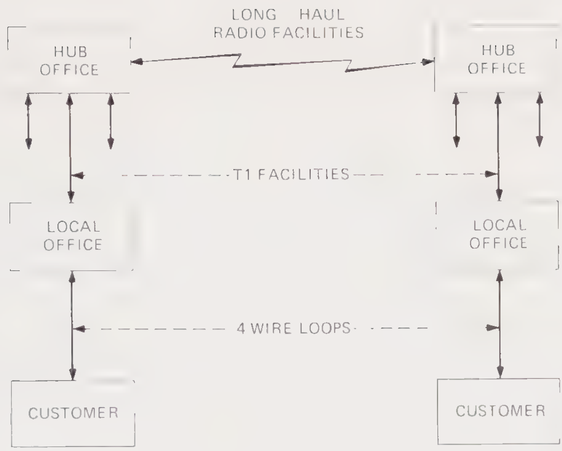

Fig. 12-15. A Typical Point-to-Point DDS Channel

having initially small cross sections, in increments well matched to the expected increases in digital channel capacity requirements during the 1970s. Alternatively, the 6.3-Mb/s T2 digital line on paired cable may be used for distances up to about 500 miles.

The DDS provides point-to-point and multipoint private-line data service. It is expected that a switched service also will be added.

What is the role in data communications expected for the DDS, as compared with that for analog data sets? These two modes of data communications are analogous to a superhighway system and a country road system, respectively. The DDS, like the superhighway system, will concentrate on providing links within and between major metropolitan centers. Just as the system of superhighways has not eliminated the need for smaller country roads, the DDS will not eliminate the need for analog data sets. Although eventually much of the long-haul data traffic is likely to end up using the DDS, there will still be many situations in which data customers, especially those who need to call many different locations, can best be served by means of data sets transmitting over the ubiquitous public telephone network. Furthermore, there also will be situations in which both data sets and DDS facilities will be used together. In these situations, the data sets will provide analog extensions of DDS to reach those customers who are outside metropolitan areas served by T1 carrier.

It is important to distinguish the Digital Data System and its potential switched version from the switched digital network (SDN) mentioned in Section 5.3.4. The DDS is a network designed specifically to handle digital data traffic in the most effective manner. The SDN, as noted in Section 5.3, is a digital facilities network imbedded within the general facilities network. As such, it will handle digital voice signals in a PCM format. It is not clear at this time if DDS traffic can flow through the SDN in an efficient manner. It is clear that the DDS and the SDN will use the same kinds of digital transmission facilities and, in many cases, will share the same carrier systems.

12.5 DATA COMMUNICATION TERMINALS

The major purpose of the data sets (modems) described in the previous section is to permit computers to communicate, over telephone lines, with one another or with data communication terminals or to permit data communication terminals to communicate with other data communication terminals. These terminals provide interfaces with computer systems so that people can insert or extract data, and they also provide a convenient way for people to exchange data directly. There are many different kinds of data communication terminals, offered by many different manufacturers. For example, one increasingly popular terminal is the electronic cash register. In most cases, these cash registers have non-Bell System modems built into them to permit the cash register to communicate over private lines with a computer.

The following discussion concentrates on Bell System terminals. There are two major classes. The first comprises telephones, of which there are both regular and special-purpose types. The second class consists of products of the Teletype Corporation, which include teletypewriters and, more recently, cathode ray tube terminals.

One of the least expensive data communication terminals is the regular TOUCH-TONE telephone. These telephones are used in digital inquiry voice answerback (DIVA) systems, some applications of which are in the fields of banking, automated ordering, credit checking, and information retrieval. The TOUCH-TONE receivers used for these data applications are data sets of the 407 type. From the standpoint of requirements, this data set is similar to the central office receiver, with the exception that it must have a much wider dynamic range because it is used for end-to-end signaling, rather than just local loop signaling.

Certain types of TOUCH-TONE telephones are particularly useful as data input devices. For example, card-reading telephones are often employed, not just to speed the dialing, but also to input frequently used data such as computer access or terminal identification codes. Similarly, any of the other automatic-dialing telephones, such as the TOUCH-A-MATIC repertory dialer, also can provide a convenient means for sending data messages.

In addition to conventional telephones, there are some telephones that are designed for specific applications. The Transaction telephone, shown in Fig. 12-16, was developed specifically for automating business transactions such as credit card sales, credit verification, check cashing, and bank deposits. This device reads magnetically encoded cards. When the connection is made to the transaction computer, the Transaction telephone transmits its terminal identification, provides any necessary computer entry codes, and sends the merchant and consumer identification numbers as read from the cards or as keyed in manually. All that the clerk must do in addition is enter the variable information, such as the transaction code and an amount of sale, using a keypad similar to the TOUCH-TONE dial. The reply is transmitted either in the form of a computer-generated audio response or as a data message used to drive an optionally provided visual display on the Transaction telephone.

Fig. 12-16. Transaction Telephone

The second major class of data terminals offered by the Bell System comprises the terminals manufactured by the Teletype Corporation, a subsidiary of Western Electric. Traditionally, these products have been used in three types of services: DATAPHONE, TWX (teletypewriter exchange), and private-line teletypewriter. As of April 1, 1971 the TWX service was sold to Western Union, leaving the remaining two as Bell System offerings.

The Teletype Corporation products can be classified as teletypewriters, higher-speed devices including tape senders and receivers and printer units, and visual display units. Some of the well known teletypewriters include the Model 33 and the heavier-duty Model 35, both of which can be used at transmission rates up to 10 characters per second, and the Model 37, which can be used at transmission rates up to 15 characters per second. These teletypewriters, which are shown in Fig. 12-17, 18, and 19, respectively, all use the ASCII[10] code, in which each character is represented by eight bits.

10. American Standard Code for Information Interchange.

Fig. 12-17. Teletype Corporation Model 33ASR

When higher transmission rates are desired, paper or magnetic tapes can be made off-line and transmitted by means of tape-to-tape machines. These machines communicate at the rate of 75 to 120 characters per second.

The Teletype Corporation's newest terminal, the DATASPEED 40, shown in Fig. 12-20, combines the versatility of a teletypewriter keyboard and printer with a cathode ray tube display. This terminal has three basic modules: a keyboard, a printer, and a display. Transmission rates up to 240 characters per second are presently available.

12.6 MOBILE TELEPHONE SYSTEMS

Today's society is a highly mobile one. In 1972, there were approximately 200 million people in the United States and 100 million registered motor vehicles. Collectively, these vehicles travelled over one trillion miles. Mobile telephone service provides a means for telephone conversations to be originated from, and terminated at, a moving vehicle or portable unit. Mobile traffic can utilize the nationwide public telephone network in the same manner as ordinary fixed-base traffic.

In 1970, there were only approximately 30,000 vehicles equipped with Bell System mobile telephones, about the same as the number of lines in one good-sized central office. One reason for this was that available offerings could serve relatively little traffic in a given city, owing to the congestion of available radio frequencies.

This section will examine past and present systems and will look briefly at a plan expected to greatly improve future mobile telephone offerings.

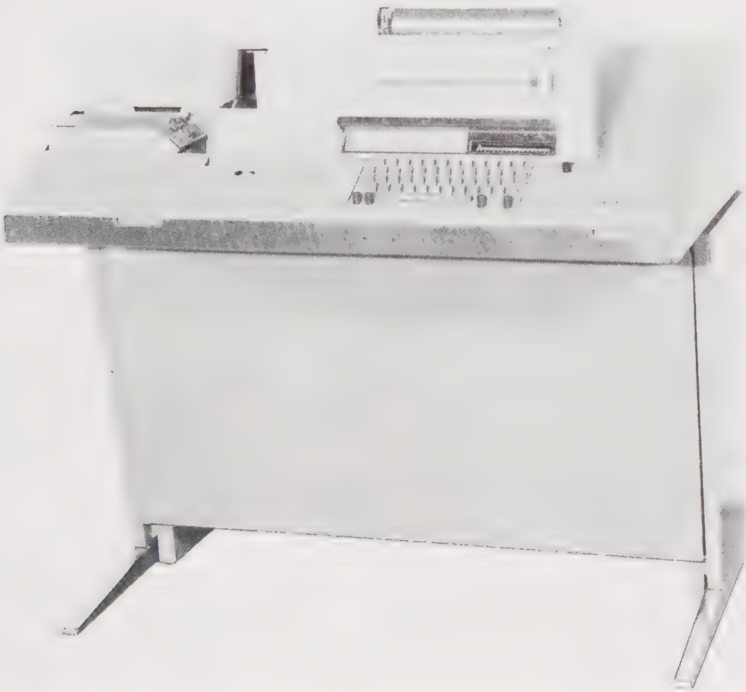

Fig. 12-18. Teletype Corporation Model 35ASR

12.6.1 PAST AND PRESENT OPERATION

12.6.1.1 Environment

Mobile telephone service uses FM radio channels as links between the mobile units and a central office equipped to provide mobile service. Since 1946, the Federal Communications Commission has allocated 33 channels for mobile telephone service: 10 in the 35-MHz band, 11 in the 150-MHz band, and 12 in the 450-MHz band. Because there are so few channels, and because they can only be reused when the serving areas are distant enough from each

Fig. 12-19. Teletype Corporation Model 37KSR

other to avoid signal overlap, there are only a very few available channels in any particular area. For example, in the New York area, the 12 channels in the 450-MHz band are assigned as follows: 6 to New York City, 3 to Newark, and 3 that are used both in Hempstead, L.I. and Morristown, N.J. Because the maximum number of simultaneous conversations is equal to the number of channels, the number of customers in an area must be limited, usually to a level less than the demand. Typically, there are between 50 and 100 customers per channel.

A present-day mobile radio system, shown in Fig. 12-21, typically consists of high-power (50- to 250-watt) FM base transmitters located at or near a central office or possibly out of town on a hilltop and wired back to the central office. There is one transmitter for each equipped channel. In addition, there are one or more receivers, scattered about the serving area. Multiple receiving stations are provided when necessary to compensate for the relatively low (20-watt) power of the mobile unit. At the central office, there are mobile service operators and special circuits to couple between the radio channels and the dial switching equipment in order to provide access into the public telephone network.

Fig. 12-20. Teletype Corporation Model 40 KDP CRT Terminal

12.6.1.2 Manual Service

Originally, mobile telephone service was on a completely manual basis. In 1972, about one-half the mobile units were in manual service areas. With this type of service, a mobile customer wishing to originate a call manually searches over the available channels in the area, hoping to find an idle one. Upon identifying an idle channel, the customer signals for the mobile operator, who dials through the central office into the public telephone network to place the call. A control terminal, shown in Fig. 12-21, interconnects the radio channels with the central office and also provides test access to the radio equipment. To signal and communicate, the mobile user must press the transmitter-control button on the handset. In modern equipment, this may be held depressed during a conversation; release to listen is not necessary. Land-originated traffic to the mobile can be signaled by the operator to the mobile on only one individually assigned "home" channel. Hence, in this arrangement, there is a possibility that a call cannot be completed even when there are idle channels and the desired mobile unit is idle.

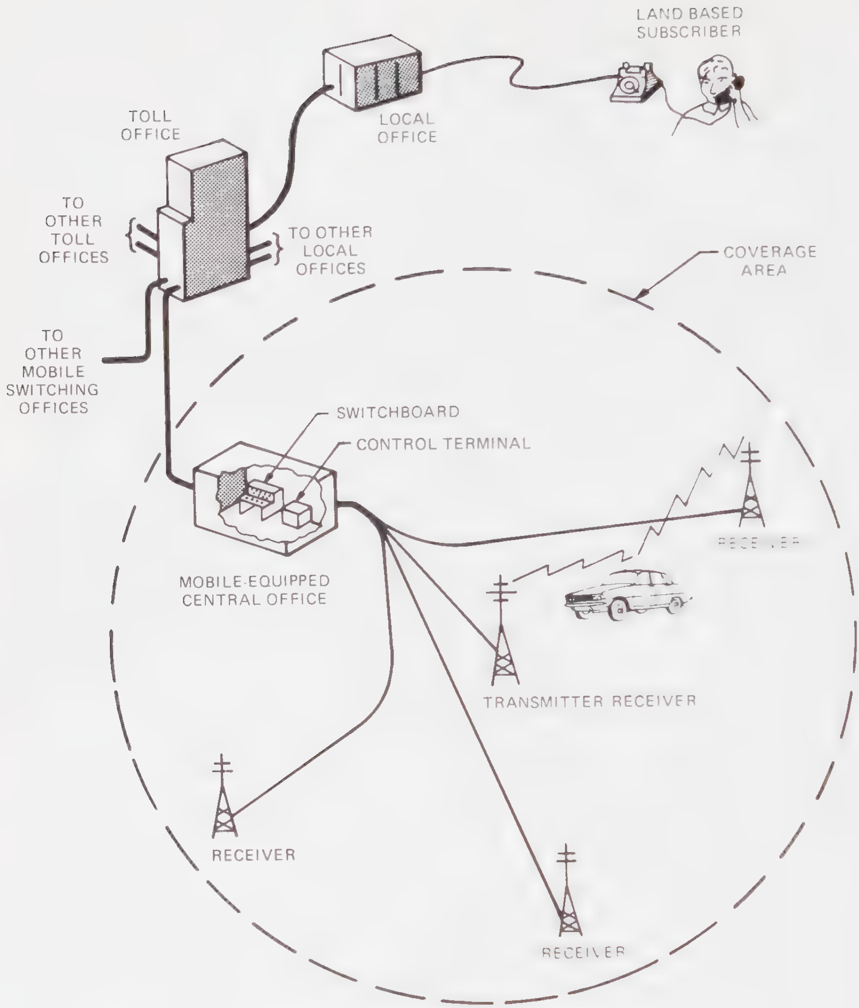

Fig. 12-21. A Manual or MJ/MK Mobile Telephone System

12.6.1.3 MJ and MK Mobile Telephone Systems

During the 1960s, two new dial systems providing improved mobile telephone service (IMTS), the MJ (see Reference 10) and MK Mobile Telephone Systems, were introduced. The MJ and MK systems are quite similar, the MJ operating in the 150-MHz band and the MK in the 450-MHz band. Both use essentially the same arrangement of facilities, shown in Fig. 12-21. The MJ and MK systems are compatible with Step-by-Step, No. 1 Crossbar, No. 5 Crossbar, and No. 1 ESS central offices. A basic feature of operation of these systems is the automatic selection of an idle radio channel for each call. All mobile units not involved in a call automatically hunt over the available channels and camp on a marked idle channel. The next call, in either direction, is then established over this channel.

When a mobile is in its home area, an MJ or MK customer may dial into the central office directly, without operator assistance. Similarly, local land-to-mobile calls are on a dial basis, the mobile being assigned a 10-digit (NPA-NNX-XXXX) telephone number distinct from any land line number assignment. Some MJ and MK systems can accept calls dialed by roamers into their areas by use of special equipment to record call details for billing. Most systems do not have this capability and, instead, use an operator for such calls. There are essentially no manual systems in the 450-MHz band; the MJ mobiles have features that permit them to be compatible in mobile areas still on a manual basis when the mobile roams from its home serving area. Another feature of MJ and MK systems is the use of full-duplex transmission, permitting simultaneous transmitting and receiving as in the land-based telephone system without the user holding down the transmitter-control button.

12.6.2 HIGH-CAPACITY MOBILE TELECOMMUNICATIONS SYSTEM

Although the MJ and MK systems clearly offered some major improvements over manual systems, the basic problem of inefficient use of available channels (because of the need for spatial separation before channel reuse was possible) still limited the number of possible customers. The proposed High-Capacity Mobile Telecommunications System (HCMTS) would overcome this problem by using a novel cellular approach. HCMTS would operate on frequencies in the 825- to 845- and 870- to 890-MHz bands made available by the FCC. The large number of channels available in the new bands has made HCMTS feasible, which it could not be with the present frequency allocations. (See Reference 11.)

12.6.2.1 How HCMTS Works

A territory to be served is partitioned into many hexagonal cells, packed together to completely cover the region. The size of each cell is based on the expected traffic density in the area, and cell sizes can range from one to several miles in radius. Channels are assigned to each cell in such a manner as to permit their regular reuse and to avoid interference between adjacent cells. In any given area, the size of the cells and the distance between cells using the same groups of channels determine the extent to which frequencies can be reused. In a system with large cells, serving only a small number of customers, frequency reuse is limited. In a dense system, however, with many small cells and many customers, one frequency could be serving customers in 20 or more cells simultaneously.

A mobile vehicle in a given cell transmits to and receives from a nearby cell site, or base station, on a channel assigned to that cell. In a mature system, these cell sites will be located at alternate corners of each of the hexagonal cells and will be connected by standard land transmission facilities to an

ESS central office equipped for HCMTS, termed a mobile telecommunications switching office (MTSO). Start-up and small city systems will utilize a somewhat different configuration with a single cell site located at the center of each cell. The mature HCMTS plan is shown in Fig. 12-22.

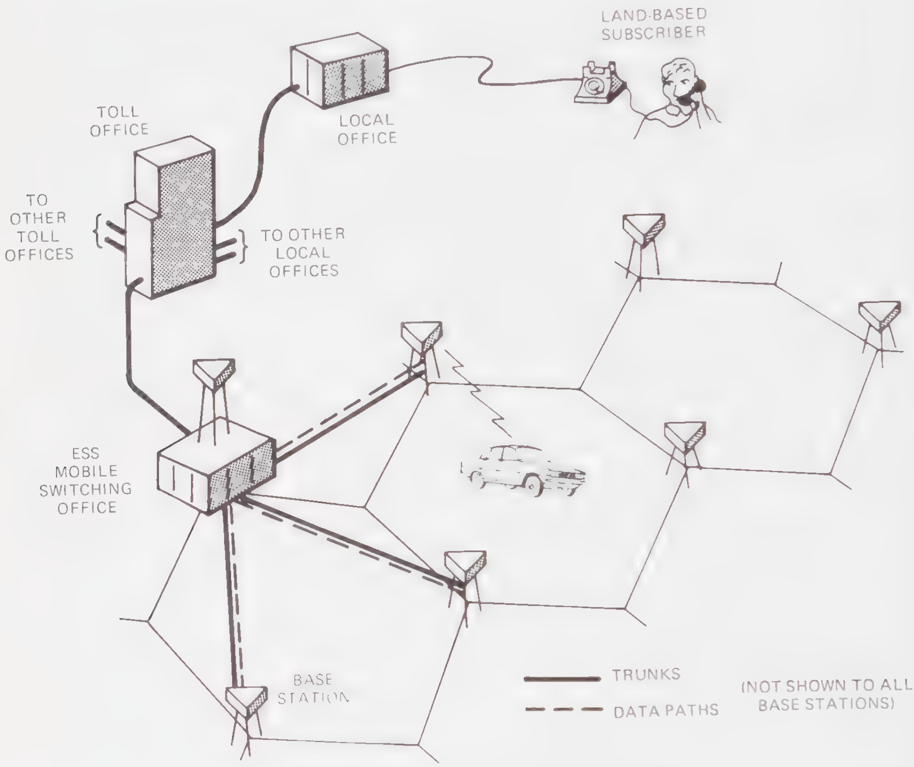

Fig. 12-22. The Proposed High-Capacity Mobile Telecommunications System (HCMTS)

When a mobile unit moves across a cell boundary, the MTSO will automatically instruct it to tune to a different frequency in the newly entered cell. The MTSO determines a change of cell by analyzing measurements of signal strength received from the mobile unit and sent to it over data channels from the controlling cell site. In addition to channel assignment, some other MTSO functions are the maintenance of a list of busy (i.e., talking) mobile units and the paging of mobile units for which incoming calls are intended. HCMTS system development, besides calling for the development of the required ESS programs and local cell sites, will include the specification of the mobile units to be used in the system. An FCC order of May 1974 prohibits the Bell System from manufacturing mobile units.

The use of the small-cell approach and the resulting efficient use of frequencies will permit HCMTS customers to enjoy a level of service almost unknown in present mobile telephone service. Grades of service of P (0.02)[11] are anticipated, compared to today's all-too-common situation of P (0.5) or worse, and the number of customers could be increased to several hundred thousand in a large city. Also, because of the stored program control of the No. 1 ESS MTSOs, service features such as conference calling and call transfer are envisioned.

12.6.2.2 HCMTS Availability

The FCC allocated a 40-MHz band for the proposed HCMTS early in 1974 and indicated additional frequency space would be made available it the demand for service warranted. Based on this FCC action, the Bell System planned a trial installation that, with FCC approval, would permit a trial to begin in 1978. After the trial has been completed, it is planned that this would become the first commercial installation. It is estimated that, 5 years after the first commercial installation, service could be available to 25 urban areas. In another 10 years, service could be extended to 100 large cities and 200 smaller areas.

12.7 VISUAL COMMUNICATION SERVICES

Experimental work at Bell Laboratories on a visual adjunct to the telephone dates back to the first demonstration of 2-way video telephony in 1930. It was not until 1970, however, that technology permitted the introduction of a commercial PICTUREPHONE service. (See Reference 12.) The slow growth of this initial service has engendered additional research in visual communications and new market exploration programs.

12.7.1 *PICTUREPHONE* SERVICE—OBJECTIVES AND VIDEO STANDARDS

Systems engineers and development engineers were faced with a formidable set of requirements for this new service, which was envisioned as a visual extension of the existing telephone system. Major objectives included:

(1) Motion and resolution capability adequate for normal visual enhancement of conversation (including lip-reading).

(2) Simplicity of use (a minimum of video controls and adjustments).

(3) Minimum switching and transmission network start-up cost.

(4) Operational compatibility with telephone service, including same-number dialing.

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11. Probability of blocking.

(5) No loss of telephone services to PICTUREPHONE users.

(6) Graphics capability, within the limitations of the resolution established by (1).

Before equipment design was begun, it was necessary to establish the basic video standards. These are listed in Table 12-4 and are based on the requirement for good transmission of live face-to-face scenes at minimum bandwidth. The technique used is exactly analogous to broadcast television, but has only one-half the horizontal and vertical resolutions of a perfectly operating standard TV system.

TABLE 12-4
VIDEO STANDARDS FOR *PICTUREPHONE* SERVICE

CHARACTERISTIC	STANDARD
Analog Bandwidth	1 MHz
Total Lines per Frame	267
Visible Lines per Frame	251
Fields per Frame	2 (2:1 interlace)
Fields per Second	59.925

These standards were initially determined through subjective testing and small-scale trials. Experience with the actual PICTUREPHONE system has confirmed their acceptability for face-to-face use.

The video standards, together with the above objectives, were applied to development of the station, transmission, and switching equipment that makes up the PICTUREPHONE system. (See References 13 and 14.)

12.7.2 *PICTUREPHONE* STATION SET

From the customer's point of view, the station set was the most important part of the PICTUREPHONE system. It had to be attractive in appearance, have simple controls, and create a reasonable simulation of face-to-face conversation.

These criteria imposed several physical constraints. The set had to be compact, and the camera had to be close to the display tube to provide good eye contact between viewers. The video display had to be large enough to produce a realistic image.

Electrically, the set had to transmit a clear picture under variable lighting conditions; it had to produce a consistent output image in the presence of interference and varying transmission characteristics.

Fig. 12-23 shows the station arrangement used for initial commercial service. It incorporated the experience gained in small trials with an earlier physical design. This set had the camera almost at eye level under normal conditions. The main unit, including the camera, display tube, and most of the electronics, was compact enough to fit on the corner of a desk. A small control pad could be placed wherever it was most convenient for the user. In addition, a remotely mounted power supply was needed. Any ordinary telephone with a TOUCH-TONE dial could be used. To maximize the naturalness of the conversation, speakerphone capability was provided.

Fig. 12-23. PICTUREPHONE Station Installation, Showing the Telephone, Display Unit, and Control Pad (Service Unit Not Shown)

12.7.3 *PICTUREPHONE* TRANSMISSION

The PICTUREPHONE video bandwidth (1 MHz) was much larger than that of any other signal that the Bell System transmits for its customers, except commercial TV. The primary consideration in designing the transmission system for a commercially viable PICTUREPHONE service was economy. The least expensive way (both in first cost and continuing maintenance) had to be found to transmit the 1-MHz signal without introducing serious impairment into the received picture. At least for initial service, this implied that existing facilities be used as much as possible.

For customer loops and short-haul trunks, a system for the transmission of baseband analog video signals on ordinary 22-, 24-, or 26-gauge paired cable was designed. Equalizers at the ends of each circuit and every 3000 to 8000 feet along the route were used to maintain an essentially flat frequency response from 1 Hz to 1 MHz. Operation of ordinary telephone pairs over a frequency range of six decades required close control of cable splices and bridged taps, as well as attention to sources of interference such as noise and video crosstalk. The cost of electronics installation and cable preparation, however, was low compared to that which would have been incurred by a dedicated cable for PICTUREPHONE transmission, at least until customer density became fairly high.

As shown in Fig. 12-24, three pairs of wires were used for each line and analog trunk. One pair carried the audio and supervision signals; the others were for video transmit and video receive.

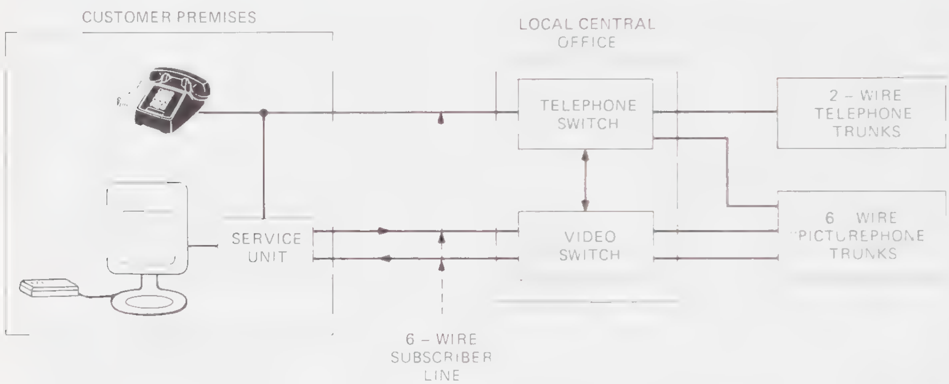

Fig. 12-24. Basic Local Arrangement

For long distance PICTUREPHONE transmission, the goal of minimizing cost remained. Again, the approach was to use existing long-haul facilities. Terminal equipment permitted digitally encoded PICTUREPHONE signals to be transmitted in L4 and L5 mastergroups and on microwave radio channels with no change to the facilities other than multiplexing equipment.

In order to eliminate signal degradation as a function of distance, digital encoding of the PICTUREPHONE signal was used for long distance transmission. Because transmission cost for a digital signal is directly proportional to bit rate, considerable development effort was spent to maximize coder efficiency. Initially, a differential PCM coder with an output rate of 6.2 Mb/s (compatible with the T2 system) was developed. By using redundancy reduction techniques, it is possible to build a coder which operates at 1.5 Mb/s (the T1 rate). Such a device compares each video frame with the preceding one and transmits only brightness information for those picture points that have changed.

12.7.4 *PICTUREPHONE* SWITCHING

Two primary objectives in designing the PICTUREPHONE switching system were compatibility with existing telephone equipment and operating procedures and maximum concentration of transmission links. The desire to use existing telephone sets and telephone numbers for controlling the video network constrained the system configuration to generally parallel that of the telephone hierarchy. Maximizing concentration was important because of the high cost of PICTUREPHONE transmission facilities; it was economically important to keep dedicated customer lines as short as possible.

The system that was chosen to meet these goals, as well as the obvious requirement of providing good transmission characteristics, consisted of four basic switching systems as shown in Fig. 12-25. A video key system (the 1P2) and a PBX adjunct (the 850A) were available for customer-premises switching. The key system provided almost all standard office calling features on both a video and an audio basis. Similarly, the PBX adjunct made PICTUREPHONE service available to customers with electromechanical PBXs.

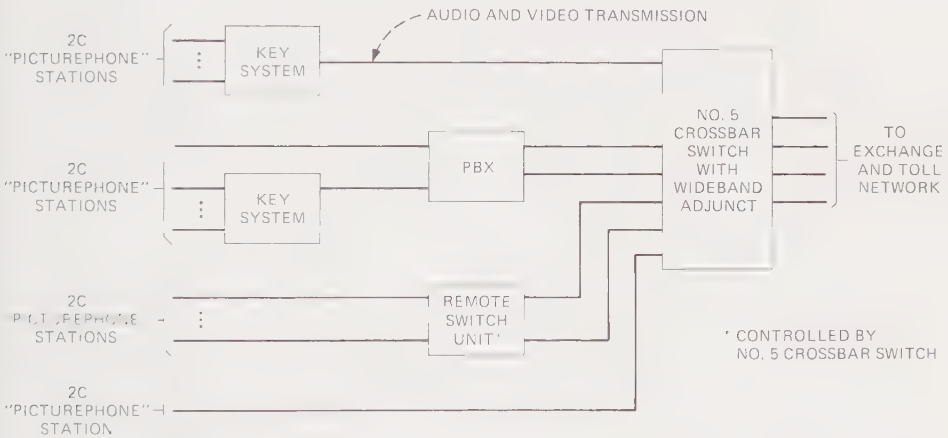

Fig. 12-25. Possible Arrangement of PICTUREPHONE Switching Equipment

Proceeding outward from the the customer's premises, the line was routed either to a PICTUREPHONE central office (if one was nearby) or to a remote switch unit (RSU). The RSU was controlled by the marker of a standard No. 5 Crossbar switching system and provided remote concentration of up to 80 PICTUREPHONE lines to 10 or fewer trunks which ran to the controlling central office.

The wideband switch, called an *adjunct*, at PICTUREPHONE central offices was controlled by a standard No. 5 Crossbar marker, which could also be handling RSUs. The audio portion of an incoming video call was switched in the standard No. 5 Crossbar System (which also handled ordinary telephone traffic), and the video transmit and receive pairs were switched in the wideband adjunct. Signaling was performed on the audio pairs.

This basic switching system had the capability of growing to a nationwide network by the development of additional types of adjuncts for ESS offices and digitized PICTUREPHONE signals.

12.7.5 NEW VISUAL SERVICES

Five years after its introduction, commercial PICTUREPHONE service was being used only in Chicago, Illinois, where there were about 400 sets in service. The slow growth of commercial service made it clear that the introduction of such a radically new means of communication presents its own set of special problems. The combination of relatively high costs and the dependence of the usefulness of the service upon the number of people having sets presented a dilemma in the start-up phase. A visual communications services marketing organization was formed in AT&T with the objectives of understanding visual communications needs and estimating the size of profitable markets. Bell Laboratories provides technical support including the design of new station apparatus.

The first generation of new video telephone apparatus was designed in 1974 to provide increased utility to the user and to overcome some of the perceived inadequacies of the PICTUREPHONE system. The basic video standard employed in the new station equipment was the 525-line commercial television standard. The nominal signal bandwidth was 4 MHz, and the equipment was compatible with outside suppliers' video adjuncts such as hard-copy machines, video tape recorders, and large-screen projectors.

In addition to a new station set, Bell Laboratories designed two video processing units to match the 4-MHz station equipment to 1-MHz PICTUREPHONE transmission equipment. One of the processors provided live transmission capability with 262-line resolution. The other processor required about 4 seconds to transmit a 525-line still picture. It was this 525-line resolution capability as well as the compatibility with commercial television equipment that was expected to increase the utility of this equipment when compared with that of PICTUREPHONE equipment.

A system plan was devised that allowed the interconnection of this equipment and the transmission of its signals. The switching vehicle employed was a modified version of an intercom switch with a video adjunct. It could handle 34 stations, 5 trunks, and a test line. Transmission facilities used in the system included Western Electric A4- and A2A-type television facilities to handle the 4-MHz signals and initial service PICTUREPHONE transmission systems to handle 1-MHz processor signals. A special "mop-up" equalizer was designed to provide an increased distance capability to the original PICTUREPHONE system.

Fig. 12-26 shows a typical arrangement of this equipment. Audio facilities were handled in standard fashion as in the PICTUREPHONE system and are not shown in the figure. It should be noted that this system was designed only for market exploration purposes.

The first step in the market exploration program effort began in 1974 in an experiment in intercity visual conferencing. Publically available group conference rooms were set up in New York, Chicago, and Washington, D. C. Initially, these rooms were equipped with PICTUREPHONE sets. As newly designed equipment became available, it was used in these rooms in place of

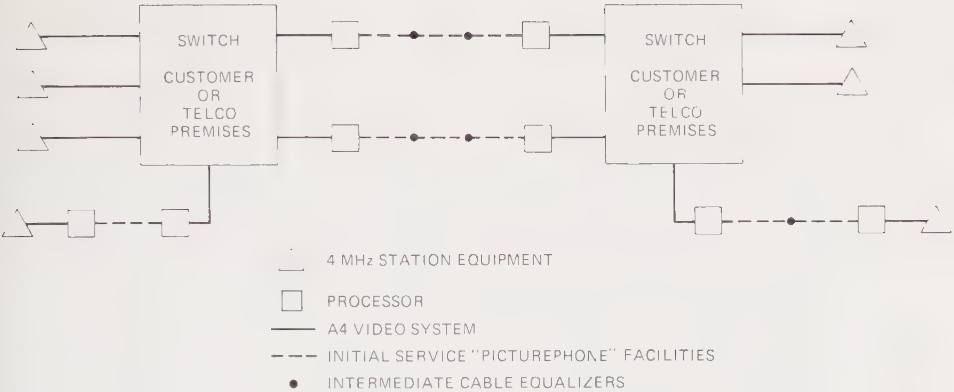

Fig. 12-26. Visual Communication Services—Typical Equipment Arrangement

the PICTUREPHONE equipment. The first specific industry trial using these newly developed concepts in visual service was held in Phoenix, Arizona, in the Criminal Justice System. In early 1975, additional trials were being considered in other fields expected to have a high need for visual communications, such as the medical, educational, and advertising fields.

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13 Other System Considerations

This chapter briefly notes three important considerations in the planning, development, and manufacture of communications systems. These are safety aspects of design, the need for new systems to be compatible with existing systems, and quality assurance of products.

13.1 DESIGNING FOR SAFETY

Most homes and offices are now equipped with telephones and associated wiring. The safety of these facilities for the customers that use them is very important. Not only terminal equipment, but all telephone equipment, including equipment not exposed to the customers such as central office equipment, must be designed with safety in mind. In addition to customers, the safety of those that manufacture, install, and maintain the equipment must be considered. Three important aspects of designing for safety will be discussed: adherence to wiring codes, Bell System design guidelines, and testing of certain types of equipment by the Underwriters' Laboratories.

13.1.1 WIRING CODES

The National Electrical Code (NEC) and National Electrical Safety Code (NESC) are nationally recognized standards of electrical wiring. The NEC covers wiring in or on buildings, and the NESC covers outside wiring. Portions of these codes cover such things as telephone wire spacings, insulation, and height above ground; protector requirements; and grounding of protectors, cables, and guy wires. Although telephone companies are exempt from the requirements of the NEC in telephone buildings, it has been the practice to adhere to these or stricter requirements. In general, the wiring code requirements are reflected in appropriate Bell System Practices.

13.1.2 DESIGN GUIDELINES

The accumulated expertise of many years of experience in equipment design has led to the formulation of design guidelines that are followed within Bell Laboratories and Western Electric in the design, manufacture, and installation of new equipment. Many of the guidelines are related to the safety of customers and employees. Protection against hazardous voltage is an important consideration; this includes protection for both internally generated voltages and spurious voltages which may result from lightning or contact between telephone and power lines. Design guidelines relating to mechanical hazards consider such things as moving parts, sharp edges, and protruding objects. Safety measures are prescribed for several types of radiation including microwave radiation, ionizing radiation (alpha, beta, gamma, X rays), and laser radiation. Excessive temperatures are considered from the viewpoints of using appropriate heat dissipating arrangements to minimize the temperature and protection to prevent human contact with hot spots. The selection of plastics that have flame-retardant properties is included. Also considered in the design guidelines are the poisonous effects that may result from mercury and toxic gases that may be encountered in manufacturing processes or that may be emitted by certain materials.

13.1.3 ROLE OF UNDERWRITERS' LABORATORIES

Underwriters' Laboratories (UL) was founded in 1894 to test products for electrical and fire hazards on behalf of insurance companies. UL continued as a testing laboratory for insurance underwriters until 1917, when it became an independent, self-supporting, safety-testing laboratory.

A UL listing implies that specimens of the equipment in question have been tested and found to meet UL specifications. To ensure continuing product integrity, the manufacturer must conduct specified examinations and tests in compliance with applicable UL requirements. UL representatives make periodic factory visits to check the efficiency of the manufacturer's own inspection program.

UL accepts no liability for the equipment it lists. In liability suits arising out of UL-listed equipment, the listing has been taken as a show of good intention on the part of the manufacturer.

The typical type of equipment submitted by the Bell System for UL listing is equipment or components that use residence power. Devices powered by central office batteries, such as the standard telephone instrument without an illuminated dial, are not submitted to UL for review. The lamp transformer for the PRINCESS telephone, an example of a line-powered device, is UL-listed. Other examples of UL-listed products include power supplies for wall-mounted key telephone equipment, most teletypewriter equipment, carbon station protectors, drop wire, coin telephone enclosures and booths, and telephone sets used in hazardous environments such as oil refineries.

13.2 PROBLEMS OF EVOLUTION

13.2.1 THE NEED TO PRESERVE OLD PLANT AND MAINTAIN COMPATIBILITY WITH IT

Telephone equipment traditionally has been designed for long life. This has influenced depreciation rates and the tariffs approved by public utility commissions. Recent tariffs have given more consideration to obsolescence. Newer equipment, offering greater economies and new services, can phase out the old. The rate of replacement, however, is much slower than the institution of new designs, so that several generations of equipment will usually be serving the field simultaneously. Fig. 13-1 shows the distribution of telephone lines over different types of switching systems from 1930 to 1973.

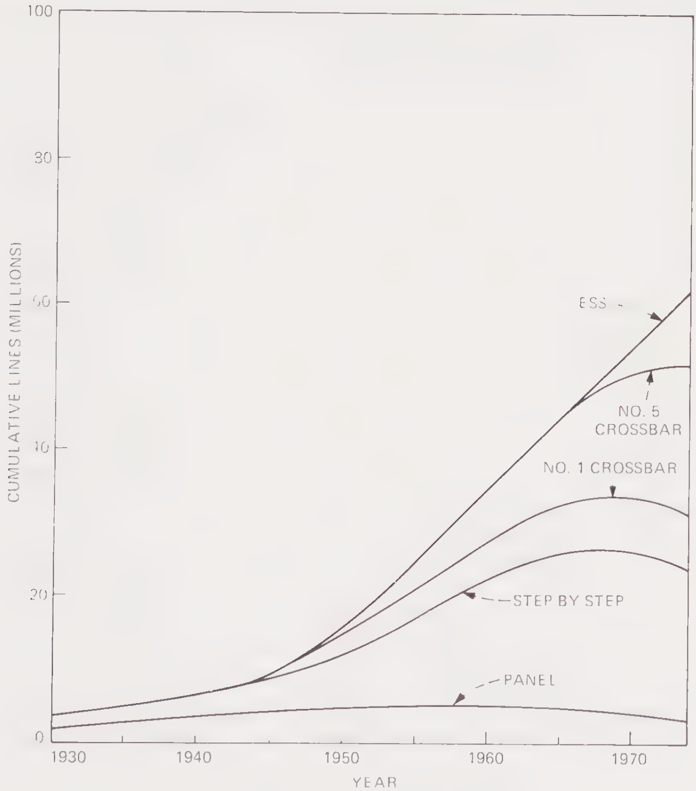

Fig. 13-1. Automatic Switching Systems Serving Bell System Lines, 1930 to 1973

Western Electric equipment designs date back to 1921 (Panel), and both No. 5 Crossbar and Step-by-Step continue to gain lines mainly through individual system growth. The continued serviceability of older equipment and limitations on capital for its replacement dictate its presence in the system for many years to come. The newest design (ESS) is used for expansion of service as well as for replacement. The ESS market will no doubt be fragmented by newer designs as time progresses.

Each new design of plant equipment must be compatible with older equipment, with the building environment, and with personnel and administrative procedures conditioned by the older equipment. Interoffice transmission systems interface with switching systems, and switching systems interface with loops and stations. Signal levels, time intervals, and sequences at the interfaces must correspond. New designs also may be restricted by building characteristics such as floor loading, frame height, temperature variations, or electrical induction. Another factor to be considered is that customers will react to any change in operating procedures. Standardization of interfaces, environments, and operations allows smooth introduction for new equipment, but by the same token, sometimes restricts the economies and service features that a new technology might realize.

Most new services must be made available in areas served by old plant as well as new and at the same price to the customer. The biggest challenge of a new service feature is to retrofit it into old plant without losing money. This section discusses the resolution of just a few of the many compatibility problems resulting from new service features or new technologies.

13.2.2 SOME PROBLEMS IN INTERFACING NEW SERVICES OR TECHNOLOGIES WITH OLDER EQUIPMENT

13.2.2.1 TOUCH-TONE Signaling

The rotary dial represents a highly successful coupling between human capability and telephone technology. For reliability and economy it has been unsurpassed since the earliest days of automatic switching; it is more reliable than the TOUCH-TONE dial. The convenience of pushbuttons, however, has been widely recognized, but until the advent of the transistor, there had been no economically feasible way to implement them. TOUCH-TONE signaling was introduced in 1963. It can be tariffed at a premium because it is a convenience to the customer. Since it is faster than rotary dialing, it will tie up registers for shorter intervals in common-control offices. It also provides more characters, which can allow additional services.

As a premium service, TOUCH-TONE dialing had to be made available on individual lines in areas that were predominantly rotary dial. It had to be possible to get service from any type of central office to avoid number changes for customers. Common-control offices that receive customer-dialed digits in register circuits had to be designed to receive TOUCH-TONE signals as well as rotary dial signals. Customers are converted from rotary dial service to TOUCH-TONE dialing by a station visit. Synchronizing the station visit with the central office change to access a TOUCH-TONE register is difficult. Therefore, registers had to be designed to accept either TOUCH-TONE or rotary dial signals. The registers can thereby accommodate party lines with a mix of

TOUCH-TONE stations and rotary dial stations or customers who mix extension telephones.

Step-by-Step switching systems use direct control of the switches from the station. Conversion to TOUCH-TONE operation is difficult and relatively expensive in Step-by-Step Systems. All TOUCH-TONE (or mixed) lines must be grouped together and new switching stages introduced so that these lines may access TOUCH-TONE registers. The TOUCH-TONE registers must then generate dial pulses to drive the succeeding switches.

When dial tone is sent to the customer, some of its energy is reflected by the station, and in early installations it reduced the sensitivity of the TOUCH-TONE receiver to the first digit dialed. It was necessary to fit a new dial tone signal, composed of frequencies that did not interfere with TOUCH-TONE operation, into all TOUCH-TONE offices. The new signal had to be similar enough to the old one to be accepted as dial tone by customers.

TOUCH-TONE signals can be the basis for many new services. They permit signaling from one station to another after the connection is set up. Applications of this type have already appeared. They work successfully in all switching systems except Step-by-Step, which usually transmits a battery reversal to the originating station after answer. For economy, the TOUCH-TONE station was designed to function with a single polarity on the loop and will not work with reversed battery. There are several ways this problem can be overcome, but none is attractive for all applications. They include:

(1) Modify Step-by-Step circuits to not send battery reversal.

(2) Equip all new TOUCH-TONE stations with a rectifying bridge.

(3) Manufacture a separate line of rectifying stations for use with Step-by-Step offices.

(4) Serve all customers who desire end-to-end signaling from non-Step-by-Step offices.

13.2.2.2 Station Ringing Signal

Station alerting is performed by a 20-Hz signal of 88 volts rms. By using combinations of tip, ring, and positive or negative polarity with 130 volts dc, this signal distinguishes between four stations on the same line on a fully selective basis. The signal level is much greater than that needed for ordinary voice communications. This has been no great burden on electromechanical crosspoints which connect ringing supplies as well as voice signals to lines. However, it has proven to be a bottleneck to the exploitation of electronic crosspoints. The thyristors and transistors used for space-division or time-division switching cannot economically handle the power levels involved in ringing existing stations. Experiments have been made with separate networks for handling the ringing signal, but they have proven to be expensive.

Another alternative, that of changing the station sets, has been explored several times. A low-level ac signal from the central office may be amplified at the station with dc loop power to generate an audible tone. Although such stations may be only slightly more expensive than existing ones, the total expense for a changeover would be substantial. A cutover strategy would be required that would assure continuity of service, and each station would require at least one field visit.

The new line of equipment would also complicate Western Electric manufacture, stocking, and repair operation. If the new system were scheduled for widespread introduction to replace older equipment, a market for reuse of the old stations would be improbable. Depreciation money is metered out carefully, and it is unlikely that it would be allotted to replace so much serviceable equipment. So far, no new switching system has been able to justify the massive turnover of station equipment necessary to avoid high-power alerting.

13.2.2.3 Compatibility of Key Telephone Systems and ESS

Key telephone systems provide for the disposition of calls from a single station set via key operation. In order to reduce central office or operator work time required to release the line circuits for reuse on calls abandoned from the central office end, rapid release of the key system's holding circuits was developed. The release signal is the interruption of the battery supply. Key telephone systems function satisfactorily with electromechanical switching systems.

In No. 1 and No. 2 ESS, normal call processing involves setting up and releasing a number of network paths between terminals during the period from call origination to answer (see Fig. 13-2). Because the reed network contacts cannot make or break current, No. 1 and No. 2 ESS are designed to remove battery from the path while changing paths. This feature is referred to as the *open switching interval* (OSI). In a basic call sequence, the OSI may range from 50 to 140 milliseconds and may exceed 150 milliseconds on a custom-calling call.

Since early key telephone systems intended to work with electromechanical switching offices were designed to release on battery interruptions of less than 140 milliseconds, there have been occurrences of undesired release of key telephone circuits during ESS call-processing cycles. There are key telephone systems having slower reaction times that will function with ESS, and the possibility of speeding up network cycling has been explored; however, for those situations in which slow key telephone systems are unavailable, auxiliary circuits are being inserted between key telephone systems and ESS. All new key telephone systems are designed for ESS compatibility. This requires that changes be made in electromechanical switching offices.

13.2.2.4 Phase Jitter and Data Transmission

Voice intelligibility is surprisingly insensitive to phase distortion. In the past, transmission carrier systems have been designed only to meet voice transmission requirements (see Section 6.3). As data transmission grew in the

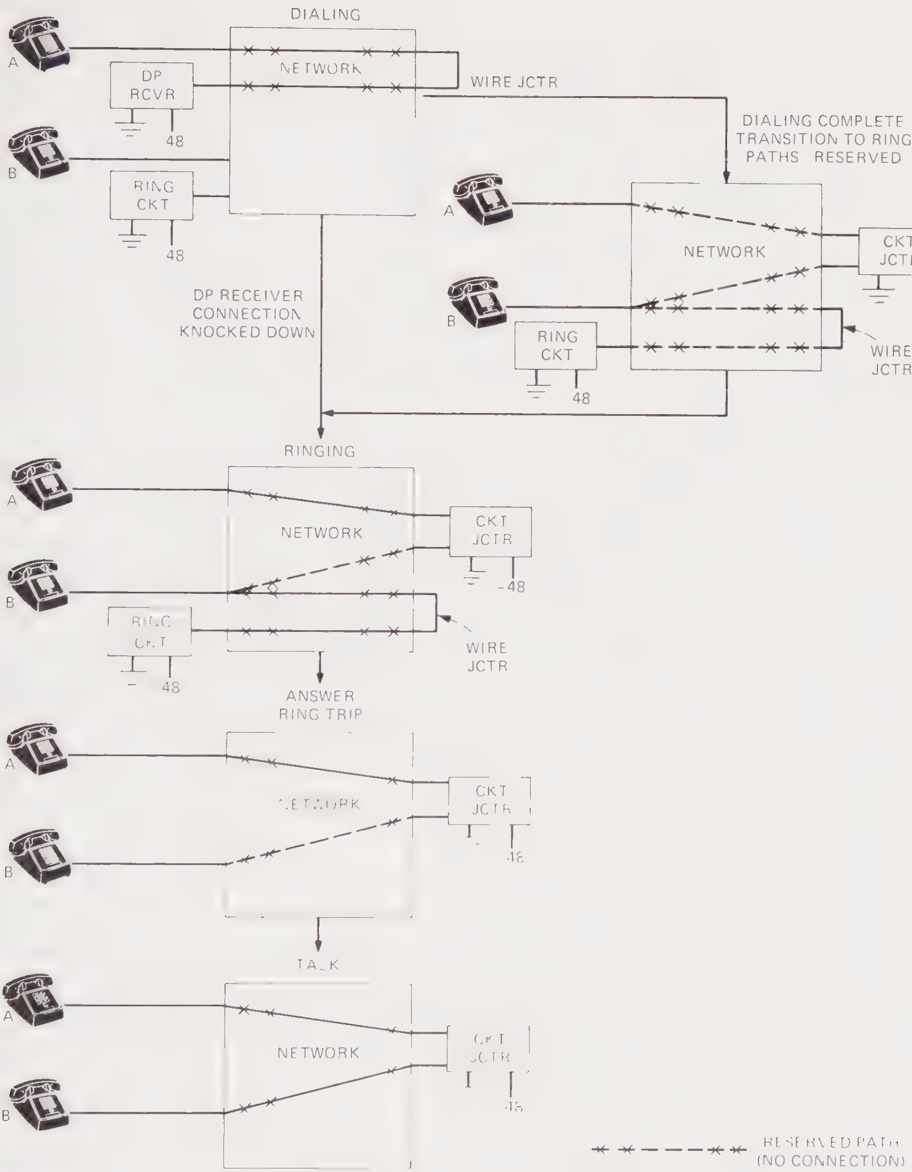

Fig. 13-2. No. 2 ESS Call Sequence

mid-1960s, some problems of high error rates arose. Upon investigation, it was found that data sets operating over 2400 bits per second were particularly sensitive to phase jitter introduced by L Carrier Systems. Noise, causing phase jitter of the multiplex frequencies, did not impair voice communication, but caused impairment to data. This was mitigated by redesign of the power supply filters. Since L Carrier Systems were widely used in the field, a retrofit program was initiated. Recent surveys show substantial improvement in data transmission over telephone facilities.

13.2.3 KEEPING OLDER SYSTEMS HEALTHY

Since older equipment will persist in the network long after newer systems have been introduced, it will continue to contribute to the overall performance of the network and to consume maintenance and administrative resources. Although telephone equipment does not deteriorate rapidly, it can, if neglected, accumulate large numbers of faults and mishandle a great deal of traffic. The situation will usually be revealed by plant and traffic statistics as described in Chapter 17. Older systems were designed in an era of manual procedures and require considerably more effort to maintain than newer ones. However, a call mutilated or congestion created by an older system is just as serious a breach in service as that in a newer system.

Under pressures of rising labor costs and a limited availability of manpower to service and troubleshoot equipment, Bell Laboratories efforts to reduce cost and improve service in older systems have received renewed attention. Automatic testing systems for transmission and switching are being extended to accommodate old as well as new systems. Tasks have been undertaken to trace and solve persistent problems with older plant. These problems are complex, often involving interactions between several systems in ways unanticipated by their designers. Chapter 16, "Testing and Maintenance," discusses some of the new measures being taken to maintain older equipment.

13.3 QUALITY ASSURANCE

13.3.1 THE ROLE OF QUALITY ASSURANCE

The quality level of products designed, built, or purchased and used in the Bell System clearly is important in determining overall costs. Optimally, the quality of a product should be chosen to minimize overall costs by balancing manufacturing ease against maintainability. The single organization that oversees quality for the entire Bell System is the Bell Laboratories Quality Assurance Center.

From the quality assurance standpoint, the relationship between Bell Laboratories, Western Electric, and the operating companies is unique. The Quality Assurance Center's activities embody a pledge to the operating companies on the part of the designer, Bell Laboratories, that the products manufactured or purchased by Western Electric will actually perform as the designer intended. This is a simple yet powerful concept, for it relieves each operating company of the need to maintain a large, highly qualified acceptance organization. This concept has been successfully implemented by giving to one company, Bell Laboratories, veto control over the output of another company, Western Electric.

Responsibility for product quality can be divided into three parts. The development organization is responsible for design, specifications, and testing; the manufacturing organization for quality production and an effective quality control system. The third part, quality assurance, has two functions: it "assures" a satisfactory product, obviating the need for operating company inspection, and it identifies both manufacturing and design problems and represents the operating companies' interests in the satisfactory resolution of these problems.

Quality assurance is a judicial function that should not be confused with quality control. Quality control is the science of providing sufficient process control over the personnel, machines, and material necessary to meet accepted quality standards consistently and economically. Quality control is an important function in the Western Electric manufacturing organizations.

The Quality Assurance (QA) organization accomplishes its tasks through two main avenues, the QA audit and QA surveillance (Fig. 13-3). The audit is conducted by Western Electric QA personnel to validate Western Electric quality control at every interface between Western Electric and the operating companies, after manufacture, after installation for Western Electric installed equipment,[1] and after repair at a Western Electric repair center. Products are continuously monitored and tested. QA exception reports, pointing out products that are significantly "out-of-spec," are sent to top-level Bell System

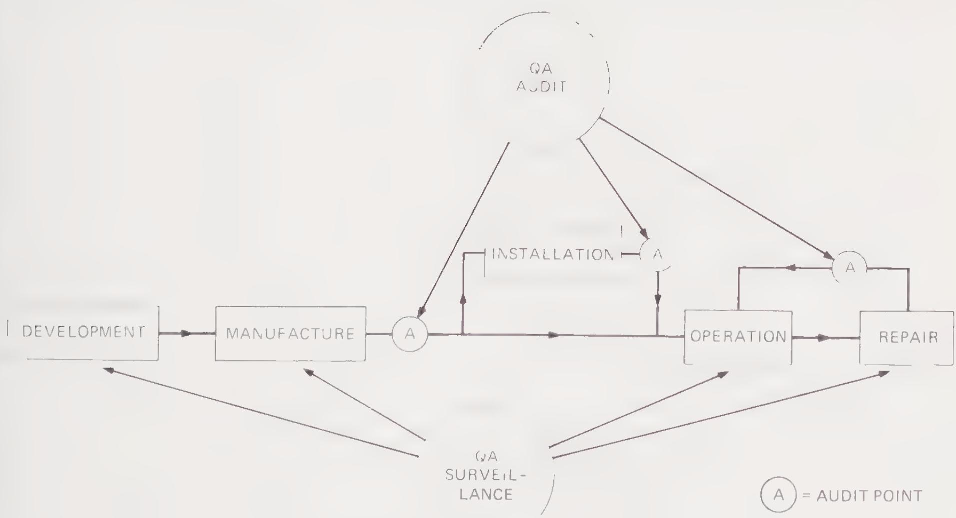

Fig. 13-3. Quality Assurance Areas of Work

1. For example, to assure central office quality, the switching system, manufactured in frames, is inspected after it is installed as a system.

management about every five weeks. The appearance of an item on these reports is usually sufficient to ensure that corrective action is taken.

Surveillance is a broad function including matters of design (such as reliability), manufacture (monitoring complex manufacturing processes), operation (analysis of problems reported by operating companies), and repair. Some aspects of surveillance are described in Section 13.3.3.

The Bell Laboratories QA Center determines quality standards and asserts a certain amount of authority to enforce them. It alone has the responsibility for determining the fate of nonconforming products (i.e., products that do not meet specifications). The QA Center is delegated to determine, for the Bell System, whether a nonconforming product is adequate and can be shipped, whether it should be reworked, or whether it should be junked.

13.3.2 QUALITY RATING

In the QA audits, quality control chart rating plans are applied to the cumulative results for a sample of each class of product for an entire rating period, which was formerly one month and is now five weeks for the audit on manufactured products. This provides a numerical rating of quality which considers all quality characteristics collectively and on which somewhat stringent limits are imposed. The parameters of the rating plans are prescribed by the QA Center which also monitors the results; the audits are conducted by Western Electric QA personnel.

Quality ratings are based on both workmanship inspections and operational tests. Workmanship rating is described subsequently in this section. It is the responsibility of the QA Center to establish standards for operational testing and to verify that the tests performed during the quality audit satisfactorily examine all phases of a unit's operation, especially the satisfaction of design intent. Generally speaking, the development laboratory specifies the tests or approves tests obtained from other sources. The primary function of any device is to operate; therefore, whenever possible, its operation is tested and appraised independently of reliability or other factors and documented in a separate index or rating. The quality rating of operational characteristics alone is particularly valuable when quality declines. Experience has shown that the ratio of operational to inspectional defects often increases greatly with worsening quality.

13.3.2.1 Demerit Rating of Quality

Each defect found in a sample during the course of a period, whether it is a failure to meet a specified operational requirement or a failure to meet some accepted standard of good workmanship, is classified as A, B, C, or D and is assigned a number of demerits, 100, 50, 10, or 1, according to its seriousness classification as given in the demerit list for the product. Class A defects are those that affect service; class B defects increase the cost of maintenance or may affect service under particular circumstances; class C defects are defects in appearance, finish, or workmanship and may affect service or increase the cost of maintenance; class D defects are minor defects in appearance, finish, or workmanship. Classes A and B are referred to as major defects, and classes C and D as minor defects.

For any class of product, the total number of demerits for the period is

$$D = 100\ d_A + 50\ d_B + 10\ d_C + d_D$$

where d_A, d_B, d_C, and d_D are the number of class A, class B, class C, and class D defects, respectively, found in the sample.

The value of demerits per unit, U, is given by

$$U = \frac{D}{n}$$

where n is the sample size for the period.

13.3.2.2 Quality Standards

The quality standard for a product is an estimate of what the quality should be at the time of shipment from the factory. Essentially, it indicates the initial degree of perfection or imperfection that QA believes will make the cost of providing adequate service the lowest for the operating company. The standard is used in the Western Electric quality control process; it is also used in the QA audit to establish an average and an acceptable range of product quality. In determining a quality standard, the quality engineer is in the unique position of not only influencing the cost of telephone service but also how it is divided between Western Electric and the operating companies.

A requirement for quality beyond normal good workmanship may add significantly to the product price. On the other hand, poor quality results in increased installation and maintenance expense as well as a shorter service life. Through the use of experience, judgment, and facts, the appropriate balance must be determined.

The quality standard has two parts: the standard demerits per unit, designated U_S, and the variance, designated C_S. A different subscript can indicate whether it is for major or minor defects or composite defects, the sum of major and minor.

There is a direct relation between the standard demerits per unit and the target number of defects per hundred units that will be considered normal in an audit. Thus, a standard can be established on the basis of a judgment of the percentage of defective units in the delivered product that will make the cost of providing adequate service the lowest for an operating company; the percentage is a function of the use and type of the product. For simplicity, consider only major defects. The relation can be expressed as

$$\text{Number of major defects/100 units} = \left(\frac{1 + R}{1 + 0.5R}\right) U_M$$

where R is the ratio of class B to class A defects and U_M is the standard demerits per unit for major defects. When better information is not available, the ratio R is generally assumed to be 0.75 for packaged electronic products and 2.0 for wired equipment.

Major defects do not necessarily mean initial failures in service. For example, an unsoldered connection is a major defect, but the connection may never fail in service. As a general rule, experience has shown that it is reasonable to assume that 40 to 50 percent of major defects in packaged electronic products and about 30 to 40 percent in wired equipment result in initial operational failures.

The variance standard, C_S, is related to the standard demerits per unit and is used to establish an acceptance range of demerits per unit to allow for normal variation in manufacture and sampling error. The acceptance range is

$$U_S \pm 3\sigma_U$$

where $\sigma_U = \sqrt{\frac{C_S}{n}}$ and n = sample size for the period. For major defects, the relation between C_M and U_M is

$$C_M = 50U_M\left(\frac{4 + R}{2 + R}\right).$$

Similarly, relations for quality standards for minor defects and for combined major and minor defects can be expressed and are used as appropriate.

13.3.2.3 Setting Quality Standards for Workmanship Inspections

There are two approaches to setting quality standards: the "equipment" approach and the "apparatus" approach. The equipment approach generally is used for a large wired unit for which the possible arrangements are too varied for a specific demerit standard. An example is an equipped bay of relay rack. On the other hand, an unequipped bay of relay rack is always the same, and its standard demerits probably would be determined by the apparatus method.

With *equipment-type standards*, the standard quality expectancies (U and C) for wired equipment are given on a count-unit basis. The individual U and C are intended to be multiplied by the number of the appropriate unit of count (e.g., soldered connections, relays, mounted apparatus) checked in the particular unit of wired equipment. For example, if 1000 soldered connections were inspected, the standard quality expectancy would be 1000 times that shown under U and C for soldering.

The *apparatus-type quality standard* gives a standard demerit and variance for each unit of production. For example, the standard demerit for a drop wire clamp is 0.05, which, if the sample were 500 clamps, would give a standard quality expectancy of 25 demerits.

There are three ways of determining apparatus standards. Although each is unique and capable of producing a useful value, it is often practical to use parts of two or more together or to use one to check another. In order of preference, these methods are:

(1) Objective method.

(2) Packaged electronic product curves.

(3) Base period reference study.

The *objective method* of determining an apparatus-type quality standard is the most basic and generally should be used whenever circumstance and time permit. The procedure is as follows:

(1) A list of defects and defect expectancy is synthesized based on experience with similar products, examination of the manufacturing processes, and engineering judgment.

(2) The defects are given demerit weighting in accordance with their effect on the product's service life.

(3) A standard demerit and a variance are derived from the defect expectancies and the demerit weightings.

(4) By methods discussed above, the percent of product with major defects is determined and appraised.

(5) The effects of the percent defective determined in (4) on installation and operation costs are estimated. If these costs are considered acceptable, the standard derived in (3) is used as the quality standard. If not, the whole process is reexamined, particularly with respect to the process capability and final requirements, to accomplish a more acceptable output.

The *packaged electronic product* approach is a method of determining a quality standard for a product consisting of interconnected discrete electronic components mechanically assembled into small functional packages, such as plug-in circuit packs. With this procedure, the standard demerits are a function of the complexity of the product as measured by the number of connections.

Curves have been derived showing standard demerits for both major and minor defects as a function of the number of connections. They have been in general use for packaged electronic products since 1963. Experience has shown that they seem to be compatible with the Western Electric Company's manufacturing capability and the customer's needs. It should be noted that subassemblies such as integrated circuits are treated as discrete components with only their external connections being counted.

The *base period reference study* depends on the assumption that Western Electric manufactures at the most economical and efficient level during a reference period. The inspection records for the reference period, six months to a year, are examined, and the average number of demerits per 5-week period per unit is used as the standard demerits.

13.3.2.4 An Example

Fig. 13-4 gives an example of the computation of demerits per units of X, Y, and Z type relays. The control chart for demerits per unit, at the bottom of Fig. 13-4, indicates quality over several months relative to the standard quality level, which is 0.52 demerits per unit. A lower control limit is shown on the chart; the upper control limit, in this case, is zero.

X, Y, AND Z TYPE RELAYS UNMOUNTED
MONTHLY DEMERIT RATE

TYPE OF DEFECT	DEMERIT WEIGHT	NO. DEFECTS			NO. DEMERITS		
		JUNE	JULY AUG	SEPT	JUNE	JULY AUG	SEPT
A	100	0	1	0	0	100	0
B	50	0	2	0	0	100	0
C	10	5	10	6	50	100	60
D	1	1	4	3	1	4	3
			TOTAL DEMERITS		51	304	63
			SAMPLE SIZE, n		232	240	165

DEMERITS PER UNIT = $\frac{\text{DEMERITS}}{\text{NO. RELAYS IN SAMPLE}}$

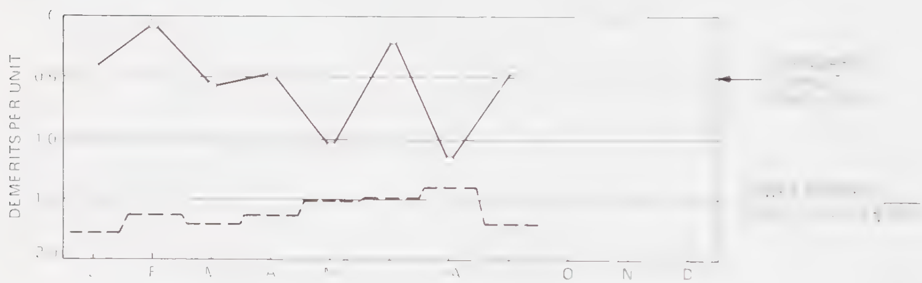

Fig. 13-4. Typical Summary of Inspection Results and Control Chart

An example of the constituents of demerits-per-unit quality standards is shown in Fig. 13-5. The allowance, in defects per unit, for each class of defect for X, Y, and Z type relays is given, as well as the computation of the standard values, U_S and C_S. The values of defects per unit might have been derived by either the objective method or by a base period reference study. The standard quality level is

$$U_S = 100u_A + 50u_B + 10u_C + 1u_D$$

where u_A, u_B, u_C, and u_D are the defects-per-unit values for class A, class B, class C, and class D defects, respectively. The computed value, rounded to two significant figures, is 0.52 demerits per unit, which is the standard quality level shown in Fig. 13-4.

The value of the standard variance factor,

$$C_S = (100)^2u_A + (50)^2u_B + (10)^2u_C + (1)^2u_D$$

X, Y, AND Z TYPE RELAYS – UNMOUNTED
QUALITY STANDARDS

DEFECTS CLASS	DEMERITS PER DEFECT, ω	CONTRIBUTIONS TO STANDARDS: DEFECTS PER UNIT, u	DEMERITS PER UNIT	(DEMERITS)^2 PER UNIT
A	100	0.0014	0.140	14.00
B	50	0.0034	0.170	8.50
C	10	0.0205	0.205	2.05
D	1	0.0097	0.010	0.01
		TOTAL	0.525	24.56
		STANDARDS: U_S = 0.52		C_S = 25

Fig. 13-5. Computation of Quality Standards U_S and C_S

is 25, when rounded. For the X, Y, and Z type relays, the control limits are

$$0.52 \pm 3\sqrt{\frac{25}{n}}.$$

13.3.2.5 Demerit Indexes

A demerits-per-unit quality rate is appropriate for a class of product when a single pair of quality standards is applicable to all types of product included in the class. An alternative quality rate is the demerit index,

$$I = \frac{D}{nU_S} \text{ or } \frac{U}{U_S}.$$

Since the demerit index is the ratio of observed demerits to expected demerits, the standard quality level is always 1. Control limits are

$$1 \pm 3\sigma_I$$

where $\sigma_I = \dfrac{\sqrt{nC_S}}{nU_S}$ or $\dfrac{\sigma_U}{U_S}$.

A demerit index chart for the X, Y, and Z type relays would look just like the demerits-per-unit chart in Fig. 13-4 except for a change in scale. The scale would be just about doubled, since $U_S = 0.52$.

Some classes of products include types that differ so much that different pairs of standard values are needed to represent the different types in the class. For those classes, a demerits-per-unit quality rate cannot be used; a demerit index is needed. The demerit index for the class is a weighted average of the indexes for the several types.

13.3.2.6 Summary

QA audits are applied primarily to products manufactured by Western Electric but also to products installed or repaired by Western Electric.

Quality ratings for the audits are based on workmanship inspections and operational tests.

A shortcoming is called a defect and is measured in terms of demerits.

Target values for demerits per unit or demerit index are established so as to minimize overall Bell System costs. More specifically, both the nominal target value and the permissible range are established. Actual values are plotted on control charts.

Whether the demerit rating for a class of product is in terms of demerits per unit or demerit index, a point falling below the lower control limit gives the basis for stating that the class of product is "significantly below standard" for the period. This condition also serves as a basis for corrective action on the manufacturing process. If a demerit rating falls below the control limit by a wide margin or if supplementary data indicate that the quality of a product is questionable, the product is labeled "nonconforming." In this situation, the QA Center determines whether the product can be delivered to operating companies or whether it must be reworked or junked.

13.3.3 SURVEILLANCE ACTIVITIES

The quality audit alone is not sufficient to ensure quality of the final product; hence the audit is supplemented by various quality surveillance activities. Surveillance occurs throughout all stages of the development, manufacturing, operating, and repair processes to ensure that adequate control is maintained. The responsibility for the integrity of the design by Bell Laboratories and the manufacture by Western Electric of any product continues throughout its service life. The continued responsibility is exercised by organized field quality studies that identify quality problems and check on the effectiveness of the quality audit. Limited-duration reliability studies, usually aimed at specific systems, not only identify engineering problems, but also yield component failure-rate data, an invaluable aid in design. The following examples further illustrate the diverse nature of surveillance activities.

13.3.3.1 Surveillance in Manufacturing

Surveillance of manufacturing processes usually occurs in two types of situations. In one type, a quality audit of the end product is either not appropriate or is not, by itself, an adequate measure of quality. The manufacture of cables (multipair, coaxial, or undersea) is an example in which monitoring of the manufacturing process is more appropriate than a quality audit. As technology moves into the complex area of integrated circuits, surveillance becomes increasingly significant, for without process control data, measurements based solely on the final product become of dubious value.

Another type of situation involves a product whose demerit rate obtained in the audit is significantly below the standard or which is not satisfactory as indicated by customer complaints or any other information. This situation may call for a thorough review of the design and manufacturing information and monitoring of the manufacturing process to determine what corrective action should be taken. This is usually a joint effort by Western Electric and the design and quality assurance groups of Bell Laboratories.

13.3.3.2 Product Performance Evaluations

An example of field performance surveillance is the product performance surveys of customer-premises equipment. Approximately one million telephone sets of all kinds are under continuous surveillance in one such survey. These sets are the entire in-service population of six telephone districts in six different operating companies. The districts were selected as representatives of the varied environments of telephone use, ranging from the hot, humid environment of New Orleans to the hot, arid environment of Salt Lake City and the cold environment of St. Paul.

In the districts included in the survey, telephone sets removed from the customers' premises for any purpose, service order removal, failure, etc., or any removed components are placed in special plastic bags which, together with a tag filled out by the installer or repairman, are sent to the local service center. There the sets are diagnosed by a resident analyst who is part of the Western Electric quality assurance organization. The results of the analysis together with the tag information are transmitted to the Bell Laboratories Holmdel Computer Center. The data form part of a data base, which is used in several ways. National and regional trouble rates are estimated by set type to track performance and to provide early warning of significant changes in performance. When indications of excessive trouble rates are found, additional information is brought to bear. The trouble rates are broken down by components of the sets, such as bell, cord, etc., by defect type, and by manufacture date stamp. The relative contribution of each component to the excessive failure rate is assessed, the mode of the failures is determined, and the vintage of sets displaying degraded performance is identified. In this way, the extent of the problem can be determined. By associating the cost of a repairman visit with each trouble, the incremental annual maintenance cost to the telephone companies incurred because of each type of trouble can be determined. Then, using standard engineering economic principles, the estimated capital equivalent of these maintenance costs is determined. This is the amount of capital dollars Western Electric may spend to eliminate the cause of the failures. A solution to the problem with capital costs less than this breakeven amount will reduce the cost of service for the Bell System. Such results are then reviewed with the development laboratory and with Western Electric to point the way toward quality improvements.

Product performance evaluations, initially limited to station apparatus, are being extended to PBX and central office equipment because of their value in rapidly identifying problems and in leading to improved designs and maintenance strategies.

13.3.3.3 The Field Representatives

The success of the quality assurance program is enhanced by the presence throughout the country of Bell Laboratories field representatives. These senior engineers, acting as Bell Laboratories ambassadors and technical consultants to each operating company, are the eyes and ears of the Quality Assurance

Center. When engineering complaints arise concerning the performance of equipment in the field, they conduct on-the-spot investigations to validate the complaints and forward design problems to Bell Laboratories and manufacturing problems to Western Electric for resolution. This ready feedback from the field continually reminds both designer and manufacturer of their ultimate responsibility; it accounts for continuing redesign and modification of design in accordance with the actual needs of the customer. In a strict sense, the design of equipment is never really complete. The field engineer pinpoints those areas where improvements can be made or where entirely new designs may be appropriate.

Part Five Operations

The goals of Part Five are (1) to convey an appreciation for those operating company activities that are not directly involved in carrying messages, but provide the network that allows people and machines to communicate and (2) to describe a representative subset of the activities carried on in Bell Laboratories to support telephone network planning, engineering, administration, management, and maintenance.

Chapter 14, "Traffic", deals with the sharing of common equipment to give an acceptable quality of service at a minimum cost. Traffic engineering is an important function in determining how a network grows.

Chapter 15, "Service Provisioning", begins by tracing a telephone service order initiated by a call to the business office of an operating company. The basic functions performed in processing the service order are described. Service-provisioning functions for trunks and special-service circuits are then discussed; these are a broad set of functions including forecasting, resource provision, inventory management, and maintenance in addition to assigning circuits in response to orders. Computer-based systems developed to mechanize parts of the service-provisioning process are described. These include systems that handle massive record-keeping functions and computer programs used in planning and engineering facilities.

Testing and maintenance are discussed in Chapter 16. The major topics of this chapter are operating company maintenance activities and the growth of automated testing systems.

Chapter 17, "Evaluation of Services and Operations", discusses how the operating companies, AT&T, and Bell Laboratories assess the quality of customer services and the effectiveness of certain operating company activities. Evaluation provides important feedback to the engineering and operating processes so that shortcomings can be identified and corrected.

14 Traffic

Important economies are achieved in shared uses of trunks, control equipment in switching systems, and operators through application of the principles of probability and statistics to the flow of traffic. The compromise between quality of service and amount of sharing and the nature of service objectives are first examined. Mathematical models are presented and applications are described. Dependence on an adequate data base of traffic measurements is emphasized. Traffic-related operating company activities including network management, network administration, and administration of the operator force are discussed.

14.1 COST VERSUS QUALITY OF SERVICE

Every really large communication network is organized around the principle of sharing common equipment. Here we are referring to sharing through sequential use rather than the kind of sharing that takes place when many conversations are carried simultaneously by a carrier transmission system. Examples of such sharing include the use by more than one family of a coin telephone and even of an ordinary station set if it happens to be located in a boarding house. Loops also, especially if long, may be used for multiparty service. In the central office, paths through the connecting network are shared by all the customers served.

Central offices exist because complete direct interconnection of all customers in an exchange area would be impractical. Similarly, on a higher level, pairs of central offices are connected by direct circuits (full or high-usage trunk groups) only where this can be justified by the volume of traffic between them. Normally, end offices are homed on tandem offices in metropolitan networks, with traffic from one central office to other central offices passing through a tandem. Extension of this principle leads to the five levels of the toll hierarchy described in Section 5.2.1.2. The trunks in these arrangements are shared by the many pairs of customers whose calls they carry.

In a similar way, many equipment items that perform logical and ancillary functions are shared. The examples cited above refer to sharing of voice-path circuits, but there is also sharing of such common-control equipment as markers, registers, and senders. In Electronic Switching Systems, some common-control functions are represented by software routines or portions of memory rather than by hardware, but the principle of sharing is the same. Operator positions are also shared, as is signaling and charging equipment such as ringing-current generators, reorder trunks, and identifiers and outpulsers for automatic number identification. All of these, with the possible exception of the operator positions, are typically used for a time that is much shorter than the average length of a conversation.

When any shared equipment is provided in an insufficient quantity, either generally or in a particular location, customers whose communication needs require the use of this equipment will have to wait or will have to try again later. Service thus is poor. Conversely, overly generous provision of such items, to the extent that some are idle even in the presence of unusually heavy loads, would be wasteful. The cost of such an unnecessary investment would have to be borne by the customers. Clearly, there must be a proper quantity of each type of shared equipment, based on existing traffic loads, a quantity that represents a reasonable balance between cost on the one hand and availability to provide good service on the other.

In practice, this balance is implemented through service objectives or service criteria. A typical service objective is a statement that a particular quality or grade of service is to be provided with a stated frequency or degree of assurance. For example, no more than 1.5 percent of customers should have to wait longer than 3 seconds for dial tone after going off-hook during the busy hour of an average business day during the busy season. However, when the load equals the average of the busy-hour loads for the ten busiest days of the year, the proportion of customers having to wait over 3 seconds is allowed to be as high as 8 percent.

Service objectives can take many forms. One class, including the example just given, is stated in terms of delay criteria. In the case of dial tone delay this is natural, because under ordinary circumstances dial tone is either given almost instantly or the customer is willing to wait the few seconds necessary to obtain it when a burst of call attempts causes a delay. (Actually, nearly half the customers fail to listen for the dial tone and dial whether it is provided or not. The central office may therefore not receive all the dialed digits when dial tone is delayed.)

Another major class of service objectives is phrased in terms of blocking criteria. For example, the fraction of calls blocked in the busy hour on a final trunk group should not exceed 1 percent. Blocking, in this context, refers to the situation in which a call finds all trunks busy in the final group, and the calling party receives a reorder tone or announcement indicating all circuits are busy. The equipment is not arranged to allow the call to succeed later if the customer remains off-hook, and so the customer must hang up and, if so motivated, try again later.

Blocked calls, then, disappear when they cannot be served and have no further effect on the telephone system (unless they are redialed at a later time), whereas calls are said to be delayed when they can remain in a queue and ultimately receive service.[1] A successful call that is answered by the called party constitutes a message.

In the preceding discussion, the notion of a peak load, defined in terms of its frequency of occurrence, occurs repeatedly. Generally, the term is used simply to indicate a higher-than-average quantity of traffic, which may range from an average of daily peaks to the rare flood of calls that follows a natural catastrophe such as a hurricane or earthquake.

The most commonly considered traffic peak occurs during the fixed busy hour. Suppose that the traffic is measured during each hour of a sequence of days (typically 20 weekdays). The hourly traffic volume can be expressed in terms of the average number of calls in progress (applies to conversation paths) or the number of devices in use (applies to servers or other equipment). Such a number represents the *carried load* in Erlangs. The number of calls that would have been in progress if there had been no congestion (blocking or delay) is termed the *offered load*. When the hourly loads are averaged across days for each hour of the day, the maximum of these averages defines the *fixed busy hour* (BH).

The highest load on a given day may not occur during the fixed busy hour. If the highest load is selected for each day without regard to the average across days, it is said to occur in the *bouncing busy hour*. Service objectives for trunk groups are most often expressed in terms of busy-hour performance (generally fixed rather than bouncing). Grades of service for central office equipment (COE) are specified for the high day (highest annual load in the fixed busy hour) and for the average of the ten highest days. The traffic performance of customer concentrators is described in terms of the grade of service given to the weekly peak load; that is, the load carried during the most congested hour of the week. All these peak loads may be calculated retrospectively from traffic measurements or estimated prospectively from projections of future loads.

Telephone traffic is not predictable in detail, and it fluctuates regardless of the time scale in which it is viewed. Calls offered to a central office are often represented as occurring in a stationary Poisson process. Such a process is easy to describe mathematically. It produces traffic with a unit peakedness; that is, the variance of the number of calls in progress is equal to the mean. This variability occurs even when the load is said to be constant. Load can change as a function of time, even within the hours that are the standard measurement intervals for most purposes in the Bell System (within-hour variation). Load also can vary from day to day in the same clock-hour (day-to-day variation), and indeed there is usually a cyclic pattern over the days of the week. In most places, there is seasonal variation as well. Traffic loads tend to grow from year to year at rates ranging from zero to over 20 percent.

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1. A slightly different terminology makes this distinction by referring to these two classes of calls as "blocked calls cleared" and "blocked calls delayed," respectively.

Since all these patterns of variability differ from place to place and from time to time, there are no general rules of thumb relating, for example, 10-high-day load to average business day busy-hour load. Thus, it would make little sense to specify grades of service in terms of average hourly loads, which would often be exceeded by unpredictable amounts. Conversely, service objectives for performance in the 10-year peak hour would be unworkable and extravagant. (The extravagance is obvious; the unworkability stems from difficulty in predicting quantities on the tail of the load distribution, which are more volatile than such central moments as the mean and variance.)

The reasonable balance between cost and availability that was mentioned previously can therefore be phrased in terms of the frequency of occurrence of the load for which a system is engineered; that is, the load at which the specified grade of service is supposed to occur. The proper compromise varies according to the function of the equipment in question.

Extreme variability costs money, because equipment that must be provided to handle the peaks is underutilized most of the time. This problem can be alleviated to some extent through properly chosen rate structures. Customers can be encouraged to call at less congested times in order to spread the load more equally over the week. This is done by setting the price of telephone service (for interstate toll calls, for example) at its highest for normal business hours (8 a.m. to 5 p.m.) on weekdays and at its lowest for the hours when little calling occurs (11 p.m. to 8 a.m.), with intermediate rates at other times.[2]

14.2 SETTING OBJECTIVES

The two examples of service criteria given, for dial tone delay and for the probability of blocking on a final trunk group, exemplify a general property of traffic service criteria, namely, that such criteria apply to individual groups of equipment items. For example, in No. 5 Crossbar central offices, service objectives are set for dial tone markers, originating registers, senders, and many other items of equipment, and also for incoming matching loss (IML). IML is the probability that no idle path through the switching network can be found between a given incoming trunk and the called line when the latter is idle. Objectives also are set for various types of full and final trunk groups, operator answer times, probabilities of overflow from ANI systems to operators, etc.

These objectives are intended to guarantee a satisfactory level of connection availability. Notice that end-to-end performance is not specified, only performance of components of the network. There are three reasons for this.

First, combining performance measurements for individual components of the network into a figure of merit for a route (say between two specified end offices) is an intricate calculation whose structure varies in detail for each pair of end offices. There are on the order of 10^8 such pairs. Such a figure of mer-

2. Not all telephone facilities experience their heaviest loads during normal working hours. For example, there are trunk groups, especially toll-connecting groups serving residential areas, on which the heaviest weekly loads occur in the evening rather than during business hours.

it would be the probability that a call dialed at office A would reach the specified line at office B. Its computation would typically involve hundreds of measurements (for a toll route). These would have to be combined in a way depending on the exact structure of the direct and alternate routes, including the types of switching systems encountered on each route. Furthermore, some of the quantities required cannot be found at all from presently available measurements. For example, first-routed and overflow traffic parcels sharing a common trunk group experience different levels of blocking, but in practice only the average for the two can be measured.

The second reason is that even if it were known how to combine individual measurements in such a way to evaluate end-to-end traffic performance and even if it were practical to do so (perhaps on a sampled basis), it is not feasible under present conditions to acquire the necessary data. To obtain complete, accurate traffic data even locally is not easy; doing so for synchronized measurement intervals in widely separated locations and bringing all the data together for processing would be a monumental and expensive undertaking. This situation is likely to improve rapidly as new technology and procedures are introduced in the field of performance measurement.

The third reason is that traffic measurements have a time dimension. The availability of the trunks in a group, in terms of probability that one will be idle when a call requires it, varies widely with time and depends on local traffic conditions.

Traffic service criteria always have been set by judgment in a process of gradual improvement. Truly rational methods would involve the solution of an explicit optimization problem, in which telephone company costs would be balanced against the costs of inconvenience to customers when they are blocked or delayed. No satisfactory way of quantifying the latter has yet been found. The present system works because good end-to-end service is in fact provided when all components of the network are functioning correctly and exist in sufficient quantity to meet their respective service criteria. There are a few holes in the traffic measurement plan, especially in older switching systems, which allow calls to fail in ways that are not recorded, but these are being corrected. See Section 14.8.

There is substantial variability, from time to time and from route to route, in the quality of end-to-end service. The public telephone network is designed to give acceptable service to those parcels and on those routes that experience the highest levels of blocking. Existing objectives for particular classes of network elements are made more stringent from time to time when technological or procedural improvements make it practical and economical to do so. This continuing process of improvement has, as in other aspects of our business, led the public to expect a gradual improvement in the quality of service. Since customers appear to be sensitive principally to changes in service quality rather than to its absolute level, the one thing that produces a sharp reaction is a perceptible drop in performance, in any of its aspects and in any area.

Over the years, as the flow of traffic in complex systems has been better understood, the trend has been toward greater precision in traffic service objectives, in the sense that arbitrary margins of safety have been replaced by quantitative specifications of performance under conditions of heavy load.

14.3 WHAT IS TRAFFIC?

As used here, traffic denotes the flow of messages through a communication system. It refers to an academic discipline, a set of organizations and activities in a telephone company, and a set of functions at Bell Laboratories.

The mathematical description of message flow in a communication network is called *teletraffic theory,* a part of congestion theory, which in turn is a branch of applied probability. Congestion theory as a part of applied mathematics has a number of major fields of application. Some others besides communications are vehicular traffic, inventories, and dams and reservoirs. Many problems in these areas have a structure that is best analyzed by queuing theory (the mathematical theory of waiting lines and delay).

Many simple congestion systems involving a probabilistic arrival process, a discipline that determines the order of service of calls and the fate of unserved calls, and a probabilistic service process are well understood. Probabilities of blocking, distributions of delay, and other quantities of engineering interest can be calculated. Many systems, however, are not understood quantitatively, particularly those involving a multiplicity of queues in series or in parallel. Indeed, nothing resembling a mathematical theory of networks of congestion systems can be said to exist.

The principal traffic functions in a telephone company include engineering and administration of trunks and switching equipment, provision of switchboard arrangements, management of operator forces, and determination of equipment requirements for Customer Switching Systems. To these must be added the equally important functions of traffic network planning, network management, and network performance measurement. All these functions will be discussed, with the exception of traffic aspects of Customer Switching Systems, a specialized area in which some of these considerations apply and which is mentioned in Section 12.3.

The role of the traffic effort at Bell Laboratories is to do traffic planning associated with the design of new switching systems and to assist in improving traffic methods used in the operating companies through an understanding of operating methods and problems combined with traffic theory. This activity includes research in teletraffic theory to improve the tools and understanding that form the basis for applied work. Typical outputs of Bell Laboratories' traffic effort include improved tables (or their equivalent in the form of computer algorithms) for the engineering and administration of equipment quantities. They also include improved methods and procedures for planning, engineering, administering, managing, and operating the network, and for evaluating its performance. Such work is of course performed with the cooperation and guidance of various organizations of AT&T, particularly Network Operations.

14.4 TRUNKING

This section proceeds from the simplest mathematical model of a traffic system and its application to some of the problems that arise in actually providing trunks in a rapidly growing network.

14.4.1 THE ERLANG B FORMULA

Consider first a group of n trunks (that is, channels or communication paths) that connects two points of a communication network. Assume that a call between these points can use any of these trunks if, when the call is placed, not all the trunks are busy. This trunk group will be discussed in isolation, and its behavior as a service system will be represented mathematically without regard to other elements of the network of which it is a part.

The conventional analysis of this system, which was first performed in the second decade of this century by the Danish engineer and mathematician, A. K. Erlang,[3] is based on these assumptions:

(1) Arrivals form a Poisson process. Imagine a set of arrival epochs, which can be thought of as points on a line representing the flow of time. At each of these points, a demand for service occurs. If one of these arrivals (i.e., arriving calls) finds at least one trunk idle, it seizes an idle trunk and service of the call begins. To say that these arrivals form a Poisson process is to say that the intervals between adjacent arrivals (i.e., the interarrival times) are independent random variables with identical exponential distributions.

The Poisson process may also be characterized as orderly and without aftereffect. In an orderly process, the probability that two events occur in an interval of length Δt goes to zero as $o(\Delta t)$,[4] that is, it vanishes faster than Δt. Physically, this means that batches of simultaneous events do not occur. A process without aftereffect has no memory; the numbers of events occurring in disjoint intervals are independent random variables.

A Poisson process can be time-varying, but in Erlang's analysis, the arrival process is stationary; that is, the distribution of the number of events in an interval of given length is independent of the absolute time at which that interval begins. The expected number of events per unit of time, also called the rate of the process, is denoted

3. The name of Erlang, the father of teletraffic theory, is used to denote the fundamental unit of traffic load mentioned in Section 14.1.

4. This symbol, read "little oh of Δt", denotes any function of Δt such that $\lim_{\Delta t \to 0} \frac{o(\Delta t)}{\Delta t} = 0$.

by λ. The Poisson process takes its name from the fact that the number of events occurring in an interval of length τ has a Poisson distribution, namely, exactly k events occur with probability $[(\lambda\tau)^k/k!]e^{-\lambda\tau}$. The probability that an arrival occurs in an interval of length Δt is $\lambda\Delta t + o(\Delta t)$, independent of what happens outside that interval. The probability density function of the interarrival times is $\lambda e^{-\lambda t}$; the arrival rate λ is also called the parameter of the stationary arrival process.

(2) The service times or holding times of the calls are independent and exponentially distributed with parameter μ; that is, their distribution function is $1 - e^{-\mu t}$. The parameter μ is often called the hangup rate. As implied above, the exponential distribution has no memory; given that a conversation has lasted for a time τ, the conditional distribution of its remaining length is still $1 - e^{-\mu t}$. An existing conversation (a call in progress) will terminate in an interval of length Δt with probability $\mu\Delta t + o(\Delta t)$; and if j calls are in progress, some one of them will end in such an interval with probability $j\mu\Delta t + o(\Delta t)$. The probability of two hangups in such an interval vanishes as $o(\Delta t)$.

Traffic with Poisson arrivals and independent exponential holding times is called "purely random", or just "random", by telephone traffic engineers. (This does not, however, mean that traffic with any other properties is deterministic!)

(3) Blocked calls are cleared (BCC). This discipline, also called lost calls cleared, means that an arriving call that finds all n trunks busy disappears without effect. As mentioned above, a successful call occupies a previously idle trunk for a holding time whose density function is $\mu e^{-\mu t}$.

The system based on these assumptions, a full-access trunk group with Poisson arrivals, exponential holding times, and blocked calls cleared, is at every instant of time in one of $n+1$ states. The "i"th state is that in which exactly i of the n trunks are busy (occupied with calls); i ranges over the integers from 0 to n.

For a particular set of arrival times and service times, the history of the system can be represented by a graph showing the state as a function of time; the collection of these sample paths is a random (or stochastic) process. In this case, the state can only increase or decrease one unit at a time for an arrival or a departure (hangup), respectively, and the corresponding process is a birth-and-death process. In the steady state, we are interested in the fraction of time spent by the process in each state; that is, we want to find the stationary state probabilities of the system. Although the state itself changes continually, we seek the unchanging state probabilities that correspond to statistical equilibrium, in which the average rate of flow of probability into any state or group of states is zero. In other words, on the average, the system makes as many transitions per unit time into as out of any state.

Dividing the set of states into two parts by means of a boundary between states k and $k-1$, the net flow across this boundary can be equated to zero. The system can reach the upper set of states only from below, by having an arrival move it from state $k-1$ into state k. Let the probability of being in state $k-1$ be $p_{(k-1)}$. Given that the system is in state $k-1$, the probability of an upward transition during the next interval of length Δt is $\lambda \Delta t + o(\Delta t)$; in other words, upward transistions from $k-1$ occur at rate λ per unit time, when the system is in state $k-1$. Thus the unconditional rate of upward transitions from $k-1$ to k is $\lambda p_{(k-1)}$. Likewise, downward transistions from k to $k-1$ occur at rate $k\mu p_k$, owing to hangups. These net flows cancel only if

$$p_k = \frac{\lambda}{k\mu} p_{(k-1)}, \quad k = 1,2,\ldots,n. \tag{1}$$

The load or traffic intensity a is defined as λ/μ, the mean number of arrivals per average holding time; a is also the mean number of servers that could be kept fully occupied by the incoming calls if there were no blocking. Then (1) becomes $p_k = (a/k)p_{(k-1)}$ which implies that

$$p_k = \frac{a^k}{k!} p_0. \tag{2}$$

Since the sum of the state probabilities must be 1,

$$\sum_{k=0}^{n} p_k = p_0 \sum_{k=0}^{n} \frac{a^k}{k!} = 1$$

and $p_0 = \left[\sum_{k=0}^{n} \frac{a^k}{k!} \right]^{-1}$. This, together with (2), describes $\{p_k\}$ completely. In particular, the system spends in state n, with all servers busy, the fraction of time

$$p_n = \frac{a^n/n!}{\sum_{k=0}^{n} (a^k/k!)} = B(n,a) = E_{1,n}(a). \tag{3}$$

This probability is the time-congestion of the system, the probability that a new request for service cannot be honored at an arbitrary instant of time. In a system with Poisson arrivals, the time-average behavior of the system is the same as the behavior averaged over arrival epochs, because the arrival process has no memory and arrivals occur independently of each other and of the state of the system. Equation (3) therefore gives the call congestion, the probability that an arriving call is blocked by finding all trunks busy. The third member of equation (3), $B(n,a)$, is one standard symbol for this quantity and gives it its common name, the Erlang B formula. It also is called Erlang's first loss formula, $E_{1,n}(a)$.[5]

14.4.2 APPLICABILITY OF ERLANG B

The stationary Poisson process is an excellent model for call attempts made by a large number of customers (such as those served by a central office) over a period of tens of minutes. There are theoretical reasons for believing that this is due to the arrival process having arisen from the essentially independent actions of many individuals (see Reference 2). Traffic originating in a single office is probably well represented over much longer intervals by a time-varying Poisson process, though this has not been verified by the study of field data. The stationary model can be substantially in error at times of particularly rapid change in mean load, such as when evening rates become effective and even at the onset of the lunch hour on a business day.

The holding times of trunks are often distributed in a way that is very close to the exponential model. This is at first surprising because the exponential density has its mode at zero, but enough brief conversations and various kinds of incomplete and ineffective attempts occur to make up the necessary short holding times. The details of this population of calls depend on the type of customer, call, trunk, and switching system involved. The probability density of the holding times does actually drop to zero as $t \to 0$, but the model is accurate enough for the most precise calculations that are needed in traffic engineering.

The behavior of an interoffice trunk group that serves only first-routed traffic (rather than calls overflowing from another first-choice route at which they were blocked) is in fact remarkably well described by the Erlang B formula, which is actually used for engineering under certain circumstances. This statement must now be qualified in several ways, and it must be noted that random traffic generally loses its nice properties when it is filtered by being carried by, or overflowing from, a service system in which appreciable congestion exists.

One unrealistic feature of the Erlang model is its neglect of retrials, repeated attempts by customers whose calls are unsuccessful. If the trunk group in question is a full group operating near a blocking probability of 1 percent, there will be few reattempts caused by congestion on the group itself, and those few will not render the arrival process non-Poisson to a significant degree. A high-usage group may operate with blocking as high as 20 percent or even 40 percent, but if the overflowing calls are handled satisfactorily by an alternate route, the model will still be realistic. The retrials offered to an underengineered group or to a group in a generally overloaded network may,

5. These ideas are developed more fully by Feller (Reference 1) for birth-and-death processes; Khintchine (Reference 2) for point processes and the Erlang formula; and Cox and Smith (Reference 3), Cooper (Reference 4), and Kosten (Reference 5) for elementary congestion theory.

however, occur in bursts following intervals when all circuits are busy, thus perturbing the memoryless character of the offered traffic and making the Erlang B formula inaccurate.

In engineering a trunk group for a fixed busy hour, one would typically use for the offered load, a, a value found by averaging hourly measurements obtained on 5, 10, or 20 days. The group would usually operate on the portion of its load-service curve where the blocking increases ever more steeply as the load increases. The average blocking $\overline{B}$, calculated by averaging the blocking values corresponding to the daily loads, would then exceed the blocking B corresponding to the average load $\underline{a}$. [This effect is illustrated in Fig. 14-1 for an average $\underline{a}$ of two daily loads a_1 and a_2, where $\overline{B} = (B_1 + B_2)/2$ and $\overline{B} > B$.] It makes sense to work with the higher blocking $\overline{B}$, which would itself be exceeded if one assigned higher weight, in the averaging process, to the heavier single-hour loads because they involve more calls.

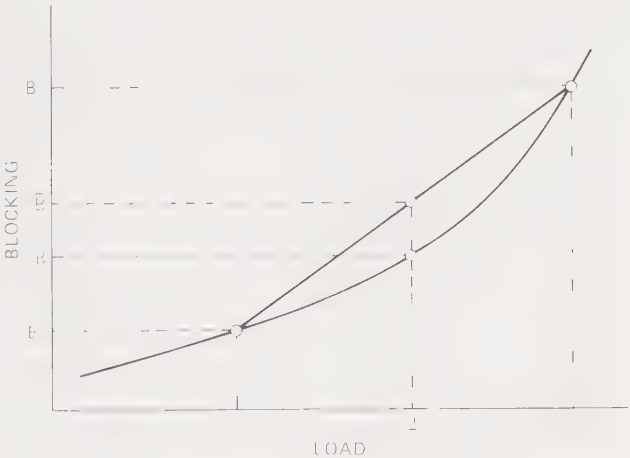

Fig. 14-1. Load-Service Curve, Showing Blocking as a Function of Load

Both retrials and day-to-day variation of busy-hour loads can cause the Erlang blocking B to underestimate the true congestion corresponding to an average load $\underline{a}$. For many years, these two effects (principally the latter) were taken into account by using instead the Poisson blocking formula, which is also based on a Poisson distribution of arrivals and which for a given load predicts a level of blocking P that is greater than $B(n,a)$. This expression is

$$P_{(n,a)} = e^{-a} \sum_{k=n}^{\infty} (a^k/k!) \tag{4}$$

which is seen to exceed $B(n,a)$ because it can be obtained by adding the quantity

$$\sum_{k=n+1}^{\infty} (a^k/k!)$$

to both numerator and denominator of the latter. Equation (4) is usually derived from the same assumptions that led to (3), except that the discipline is changed to one termed blocked calls held (BCH). In this model, every arriving call remains in the system for an exponentially distributed time, regardless of whether or when it receives service. One may imagine an unbounded number of positions, of which n are for service and the rest for waiting. If a server is free, it serves an arriving call, which otherwise occupies a waiting position until its turn comes to occupy a vacated server for the remainder (if any) of its time in the system. The formula $P(n,a)$ then represents the probability of finding n or more calls in the system, that is, of not being served immediately upon arrival.

The discipline of the blocked-calls-held model is not to be taken as describing an actual physical process. The Poisson formula is useful because it happens to give about the right answer. It also happens to interpolate appropriately between Erlang B and yet another congestion formula known as Erlang C. The latter describes an n-server system in which arriving calls wait in line until they can be served in the order of their arrival. The Erlang C expression, $C(n,a)$, gives the probability that an arriving call suffers at least some delay before being served. The existence of a queue of waiting calls makes $C(n,a) > B(n,a)$. The two Erlang models are realistic descriptions of certain simple congestion systems. The Poisson formula merely accounts roughly, and somewhat accidentally, for effects not represented in the Erlang B model.

Modern methods of collecting, storing, and processing traffic data are making it possible to find not only the mean a but also the variance of a collection of daily single-hour loads a_i. The preferred value, $\bar{B}$, can then be estimated by numerical integration or from prepared tables, making it unnecessary to rely on the rule-of-thumb correction to B that is embodied in the Poisson formula. Explicit corrections for the effects of retrials, also based on local traffic characteristics, are coming into use also where appropriate.

14.4.3 OTHER MATHEMATICAL MODELS

One aspect of the Erlang B model was barely mentioned in Section 14.4.1, namely, that the discipline specified full access to the trunk group. This feature was first stated in this form: an arriving call can seize any free trunk. Such is not always the case. The Strowger switch, which forms the basic element of Step-by-Step switching systems (see Section 9.3.1), allows a given call access to only 10 of up to 45 trunks in a group. This limitation gives rise to configurations known as gradings or graded multiples (see Reference 6), whose traffic capacities must be studied in terms of a model involving partial access of calls to idle servers, but which is otherwise like the Erlang B model. Partial access implies, of course, that a call can sometimes fail to be served even when some trunk is idle.

An enormous variety of equipment configurations exists in the Bell System, so that the traffic engineer encounters a large number of arrival processes, holding-time distributions, and service disciplines. Independence assumptions do not always hold, and service systems that are in series or in parallel interact in complicated ways. Some of the resulting phenomena of traffic flow are well understood, some can be adequately approximated, others can be studied by numerical techniques well enough for practical purposes, and still others lie on the forefront of research or will turn up as unwelcome surprises in system performance.

Further discussion of traffic formulas would be out of place here, but the next section covers an important engineering problem in which arrival processes are not Poisson.

14.4.4 ALTERNATE ROUTING

When a call can follow more than one route between its originating and terminating central offices, alternate routing is said to be involved. Traffic from one office to another, or between specified groups of offices that share routes, is called a *parcel* (sometimes a *stream*) of traffic. Since fluctuations in volume often occur independently in different parcels, one properly engineered route may be congested when another has spare capacity. Alternate routing reduces the total need for circuits by taking advantage of this.

The principle of alternate-route engineering can be illustrated by a simple example. Imagine offices A and B with a high-usage group of n trunks between them (similar to the example presented in Chapter 2) and a cost C_d for each trunk in this direct route. Suppose also that calls blocked on this group overflow to an alternate route which costs C_a per circuit; each such circuit might consist of two trunks and a path connecting them through a tandem switching system. An appropriate fraction of the switching cost would be included in C_a. The size n of the high-usage group is to be chosen so as to minimize the total cost of handling the traffic from A to B, subject to the condition that the probability of blocking on the final group (the alternate route) must not exceed 1 percent.

Let the busy-hour offered load from A to B be $\underline{a}$, and for simplicity assume Erlang B behavior on the direct route. The marginal capacity of the alternate route is γ, the additional load carried on the route per circuit added when the blocking is fixed at 1 percent. Of course, the marginal capacity is not really a constant at all; it varies from trunk to trunk as more overflow load is added to the background load that must be carried by the alternate route in any case. Furthermore, γ depends not only on the mean loads but also on the peakedness[6] of both the background and overflow loads, and the latter is a function

6. Peakedness, mentioned in Section 14.1, is defined as the variance of a stream of traffic divided by its mean and is a measure of the variability of the stream. Purely random traffic has a peakedness of 1; overflow traffic, consisting essentially of the peaks clipped off the top of a random function, tends to come in separated bunches and has a higher peakedness, commonly ranging up to about 4. The Erlang model can be extended to cover arrival processes corresponding to peaked traffic; the blocking becomes a function of n, a, and the peakedness z.

of both $\underline{a}$ and n. In practice, some or all of these functional dependencies are ignored, and γ may even be taken to be a constant independent of local conditions, typically, 26 CCS in metropolitan networks. (As mentioned in Chapter 5, the CCS is a unit of traffic load, 100 call-seconds per hour. It is used in almost all traffic engineering in the Bell System. One Erlang equals 36 CCS, or 3600 call-seconds per hour.)

The cost of handling the A-B traffic may now be written as

$$\underline{a}B(n,a)\ \frac{C_a}{\gamma} + nC_d \tag{5}$$

in which the last term is simply the cost of the high-usage group. (Strictly, B should be $\bar{B}$.) Since the fraction $B(n,a)$ of the offered load overflows to the final group, the overflow load is $\underline{a}B(n,a)$, which requires approximately $\underline{a}B(n,a)/\gamma$ trunks that cost C_a each; thus the increased cost of the final group, because it must carry the A-B overflow, is the first term in equation (5). As shown in Fig. 14-2, the direct-route cost is linear in n, and the cost of the alternate route is a nonlinear decreasing function because the Erlang formula is not linear in n; that is, each added high-usage trunk carries a smaller amount of the offered load $\underline{a}$. The total cost has a minimum at the value of n found by setting the n-derivative of expression (5) equal to zero. This yields

$$-\frac{d}{dn}\ [\underline{a}B(n,a)] = \gamma/R \tag{6}$$

where $R = C_a/C_d$ is the cost ratio, the ratio by which the cost of an alternate-route circuit exceeds that of a direct-route circuit. The left member of (6) is known as the load on the last trunk, which in this method of engineering is set equal to its economic value, γ/R. This gives rise to the name *ECCS method*, for economic CCS.

In this discussion, n_{min} has been treated as a continuous variable; in practice it is rounded off, either to the nearest integer or asymmetrically from a fractional part such as 0.2.

The economic model embodied in (5) ignores the administrative cost of a high-usage group. This cost raises the direct-route cost in Fig. 14-2 by a constant amount except at $n = 0$; the cost minimum is not shifted, but must be compared with the relatively lower cost of using only the final group. Thus, the best-sized high-usage group of n_{min} trunks may not prove economically advantageous at all. Empirical evidence suggests that this happens most often for very small groups and that the problem can be solved by the rule-of-thumb approach of adopting a minimum trunk-group size. The currently recommended values are three trunks for local networks and six for toll; smaller groups should not be built.

Such a rule fits in well with another recent development known as *modular engineering*, in which calculated Long Lines trunk-group sizes above 18 are rounded off to the nearest multiple of 12 for high-usage groups or to the next higher multiple of 12 for final groups. There are two motivations for modular

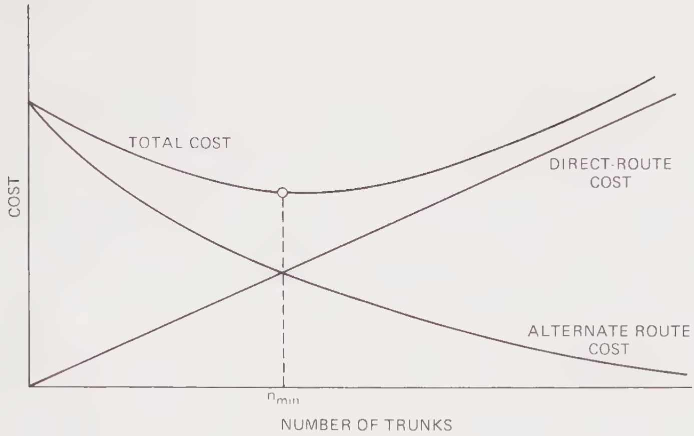

Fig. 14-2. Cost as a Function of Number of Direct-Route Trunks (Group Size)

engineering. First, transmission facilities come in channel groups of 12 circuits in long-haul carrier systems, so that administrative costs are reduced if groups of 12 trunks are treated as units from the traffic viewpoint. Second, the precision of reasonably available[7] traffic data and projections is not great enough to justify the cost of making small changes in numbers of trunks. This has long been acknowledged in the existence of minimum step-sizes of from two to four trunks for making changes in numbers of trunks in a group.

General studies of the economics and precision of the trunk-provisioning process are now in progress. It may be found that the modular and minimum-size approaches should be combined and that all group sizes should be multiples of, say, six; but there are opposing considerations too, such as the great increase in tandem-switched traffic that occurs when no small high-usage groups are built. If minimum group-size rules have a genuine economic basis, the tandem switching penalty may be illusory, yet it must be taken seriously because of the larger amounts of capital investment in switching systems, the long lead times required for their installation, and the trunking inefficiencies that exist because switching systems have not been designed with capacities as large as would be desirable from the viewpoint of network topology (see Section 5.2).

These considerations, and many others even less well quantified, relate to the question of whether traffic should be held down or forced upward in the hierarchy. An important aspect of this problem is service protection, a general concept representing the need to ensure good network performance under conditions different from those envisioned in engineering. Such conditions arise from poor forecasting and from various types of local or temporary over-

7. The phrase, "reasonably available," does not refer only to limitations of measurement technology; an annual busy season may be so short as to leave large variances in traffic estimates even when all relevant data are obtained correctly.

loads. Service protection considerations are only now beginning to be quantified and have so far been debated in general terms. One such debate has resulted in the full-group limit of 800 CCS, a rule that recommends that high-usage groups carrying more than 800 CCS be engineered to 1-percent blocking and be made into full groups by not allowing overflow to other routes. The argument is that a group large enough to carry 800 CCS (22.2 Erlangs) at 1-percent blocking (as it is called) can always serve a large amount of the traffic of the customers generating that parcel, whereas even a modest relative overload could, if overflowed to a final group, seriously increase the blocking experienced by other parcels on the final group. This full-grouping rule may well be changed when the relations between cost and service protection are better quantified.

Two different approaches to trunk forecasting are in use: the trunk-base method and the point-to-point method. The methods are distinguished by the particular data base used to generate the forecast. The trunk-base method rests upon trunk-group traffic measurements that are used to estimate first-attempt offered load for each trunk group. For the trunk groups that both originate and terminate at class 5 offices, the first-attempt offered load is projected into the future, using growth factors determined by office-growth data from the offices at both ends of the trunk group. For a class-5-to-class-4 (or 4-to-5) trunk group, the growth factor is determined by the originating (terminating) office growth. The growth factors for intertoll groups are determined by the growth rates of toll messages in the general area of the trunk group. The future trunk requirements are then determined (by using standard trunk-engineering procedures) so as to serve the projected loads at a specified grade of service.

The point-to-point method of trunk forecasting is based upon the 5-percent random sample of AMA data that is used in the Centralized Message Data System (CMDS). The data include number of messages, message holding times, and calling and called numbers. A time series of "number of NNX to NNX messages" is extrapolated in order to obtain a message forecast which is subsequently converted to a load estimate. The future trunk requirements are then determined by designing a trunk network to serve the projected point-to-point loads.

The advantage of the trunk-base method is its direct view of trunk-group loads, the quantities most immediately related to required numbers of trunks. Point-to-point data, while requiring that actual loads be inferred (because of nonbilled usage), are independent of network structure and therefore more easily used in engineering the differently configured networks of future years. Ways are being sought to combine the advantages of the two methods.

14.4.5 TRUNK PROVISIONING

The process of arranging for the proper numbers of trunks to be in the right places at the right times is lengthy and complex. For this discussion, it can be roughly divided into stages called long-range planning, trunk forecasting, and trunk servicing (see also Section 15.2).

In this context, long-range planning consists of roughly determining the configuration of a portion of the traffic network (usually a metropolitan network or an NPA) from about 5 to 20 years in the future. Note that it does not include facility planning which determines geographic routes and types of facilities to carry trunks. Based on projections of traffic loads, the topology of the network is planned first, including the numbers, types, and locations of the switching systems and the homing arrangements whereby final trunk groups are established between lower and higher levels of the hierarchy. Then the full, high-usage, and intermediate high-usage groups are approximately engineered. The resulting long-range plan embodies various routing rules, such as whether local and toll traffic will flow through the same tandems in a metropolitan network and what sequences of alternate routes are to be used. Such planning does not involve commitments to spend money; its purpose is to ensure that the long-term consequences of current decisions are foreseen and that the evolution of the network proceeds smoothly and economically.

Trunk forecasting is a more precise undertaking; it relates to the interval extending from about one to four or six years in the future. Six years is the approximate lead time required to establish a new switching location, including acquisition of land and construction of a building. Based on a careful forecast of traffic loads for each year and on increasingly detailed decisions about the functions of all the switching systems, the trunk traffic network is laid out according to a detailed set of engineering rules. (A similar process, not described here, also is carried out for special-service circuits.) The trunk forecast for each year specifies the circuits that actually will be needed for next year's busy season. This process prescribes the number of trunks required from each switching system to every other. Another set of planning methods and engineering rules, divided into its own long-range and current phases, is then used to identify the geographic routes and specific transmission facilities needed (see Section 15.5).

When the transmission facilities have been built, the appropriate trunks have been connected, and the busy season has arrived, it can hardly be expected that the network as engineered will exactly match the offered traffic. Measurements of actual usage and counts of calls offered and overflowing are therefore used to determine where to add or subtract circuits in such a way as to meet the actual demand. A few trunks are generally removed from one group and added to another in various places, so that all final groups meet their objective of 1-percent blocking. This activity is known as *trunk servicing* and is one aspect of network administration discussed in Section 14.7.

Major expenditures are involved in taking traffic measurements and in collecting, storing, and processing traffic data. Decisions based on these data are used in trunk engineering and administration. All these decisions have associated costs: the costs of building and moving trunks, the costs of unnecessary circuits where groups are overengineered, and the costs (in trouble reports, lost revenues, congestion caused by ineffective attempts, and extra calls to operators) of inadequate service where groups are underengineered. Regulatory pressures exist on both sides of the question; that is, the amount of equipment provided should be held down to minimize the rate base and hence customer charges, and at the same time enough equipment must be provided to ensure good service.

A quantitative model of the interactions among all these factors seems attainable within a few years, and it should help to answer questions about the optimum level of precision in all steps of the trunk-provisioning process, as well as to provide mechanized methods to aid planning in each of these very complicated areas. Questions about the types and quantities of data collected, about step sizes in trunk servicing, and about minimum group sizes and modular engineering can then be related to each other.

Planning, forecasting, and servicing have until recently been manual operations; now, all are being rapidly modernized by the introduction of new software tools for data management and engineering computation (see Chapter 15). These advances also will encourage quantitative studies by standardizing many phases of the operations and making possible the testing of alternatives. It appears that the stability of the trunk forecasting process can be improved through the incorporation of simple filtering in the software. This should be of great practical benefit, because it will minimize the effect of the fluctuations between successive forecasts which now plague planners in the field. When comparative studies of forecasting methods have reached such a point as to improve the credibility of forecasts, the difficult process of allocating construction money among competing demands will be rendered more effective.

14.5 SWITCHING EXAMPLES

The amount of switching equipment to be installed in an office is specified on the basis of traffic data and forecasts. Problems involved in determining the appropriate amount of equipment for initial installation in a new office are different from those encountered in the periodic review of how much additional equipment will be required for an existing office. In this section, both cases will be treated in three examples which illustrate the effect of traffic considerations on the engineering process.

14.5.1 EXAMPLE 1—ENGINEERING THE SWITCHING NETWORK

Switching networks for most switching systems are modular in nature. A basic building block in the switching network of a representative electromechanical system, the Crossbar Tandem, is the trunk link frame. As a minimum, these frames must be installed in sufficient numbers to provide terminations for all the incoming trunks and also to allow for connection of any incoming trunk to any outgoing trunk.

It is possible to provide nonblocking switching networks; that is, networks that always have a free path from every free incoming trunk to every free outgoing trunk. However, this would be very costly in a large switching system. In practice, it has been found acceptable to engineer the switching network so that it is occasionally not possible to find a free path from a particular incoming circuit to a particular outgoing circuit, provided that the probability of such an occurrence is small. The probability of not finding a free path from an incoming trunk to an outgoing trunk is called *matching loss*. The service objective used is a busy-hour matching loss, averaged over the ten high days, of 0.5 percent.

Before an office is built, the number of trunk link frames (for example) that would be required for a satisfactory matching loss can be estimated from a set of derived curves. These curves show the load per trunk link frame that would give a 0.5-percent matching loss, based on the traffic offered to the particular office.

Once an office is installed, measurements are taken of the percent matching loss versus load per trunk link frame. These measurements are used to construct a load-service curve of percent matching loss versus load per trunk link frame that applies to traffic offered to that particular office. As long as the nature of the traffic does not change, this curve can be used, together with the average busy-hour load for the ten high days, to estimate the number of additional trunk link frames needed to accommodate an increase in traffic.

14.5.2 EXAMPLE 2—SENDER ENGINEERING

In establishing a connection through some switching systems (including the Crossbar Tandem in this example), a common-control device called a sender is used to receive digit information about the called party. The sender stores this information while a conversation path is being established through the switching network and then transmits it to the following switching system. When all senders are busy serving other requests, a new call will experience a delay in sender attachment. This delay increases the time necessary to establish a talking path through the network and thus influences the service provided to the customer. It is also important to minimize this type of delay because it propagates through the network. This is discussed further in Section 14.6, "Network Management."

Since the number of arriving calls and the holding times of senders are essentially stochastic in nature, the delays may be determined statistically. The statistics of the delays will depend on the rate of incoming calls, the distribution of incoming calls, and the distribution of sender holding times, as well as on the number of servers and their rate of service.

One measure of the service provided by a group of senders is the probability of a delay[8] exceeding 3 seconds. In fact, many switching systems employ a measuring device called a sender attachment delay recorder (SADR) to estimate this measure of service. If one assumes that the incoming calls form a Poisson process (usually a good assumption for first-routed traffic) and that the sender holding times are independent and exponentially distributed, the steady-state probability of a delay exceeding T seconds is given by

$$C(n, \lambda/\mu) e^{-\mu(n-\lambda/\mu)T}; \quad \lambda/\mu < n$$

where n is the number of senders in service, $1/\mu$ is the mean holding time of a sender in seconds, λ is the mean arrival rate of calls in calls/second, and the Erlang C function $C(n,a)$ is given in terms of the Erlang B function $B(n,a)$ by

$$C(n,a) = \frac{1}{1 + \dfrac{n-a}{aB(n-1,a)}}$$

where $a = \lambda/\mu$ is the load in Erlangs into the senders.

The above relation forms the basis of tables that are commonly used in determining the number of senders to install in order to meet service objectives.[9] The tables and procedures actually used also include the effects of other factors not taken into account in this simple model.

14.5.3 EXAMPLE 3—TRAFFIC ENGINEERING OF NO. 1 ESS

As discussed in Section 9.4, switching in No. 1 ESS is unlike that in electromechanical systems in that many common-control functions are performed by a single central processor which handles the call-processing logic on a time-shared basis. Because the central processor is basically a digital computer, engineering of No. 1 ESS must be concerned not only with the number of hardware items (e.g., digit receivers) required, but also with the amount of memory necessary to keep track of the status of all calls in the system and with the processing capacity of the central processor. The necessary quantities of ESS hardware items are determined by methods similar to those described in the two examples for the Crossbar Tandem. The processing capacity is the maximum number of calls that can be processed in a given period of time subject to grade-of-service constraints. The capacity depends not only on the nature of the traffic, but also on the organization of the stored program in the central processor, the speed of the logic, and the amount of memory and hardware available. Knowledge of the system's capacity is important for net-

8. This delay should not be confused with dial tone delay; the delay in tandem switching systems results only in increased time to establish a talking path.

9. This relation also forms a basis for constructing load-service curves of sender attachment delay versus the load, a.

work planning to determine the number of trunks and lines that may be connected to the switching system.

As in other switching systems, methods for determining system capacity are different for pre- or post-installation phases. Before installation, the nature of the expected traffic must be estimated from a knowledge of the surrounding network and customer dialing patterns. After installation, the nature of the traffic can be estimated by measuring the length of time it takes for the central processor to cycle through its routines, together with the number of call attempts processed during some period of time. Computer programs are available to aid the operating companies in determining switching system capacity in both pre-installation and post-installation phases.

14.6 NETWORK MANAGEMENT

Telephone networks employing alternate routing and common-control switching systems provide efficient use of facilities. However, this efficiency carries with it an operating penalty in that heavy traffic overloads or major equipment failures may cause the network to degrade in an objectionable manner. This phenomenon is illustrated in Fig. 14-3, wherein a network engineered for 1600 Erlangs is subjected to substantial traffic overloads. The carried load matches the offered load up to the engineered capacity; beyond that, this simulated network can handle nearly 1800 Erlangs. However, as the offered load reaches 3200 Erlangs, the carried load falls to about 1300 Erlangs.

Network management is a set of procedures and equipment that keeps the network operating near maximum efficiency (as defined by completed messages per unit time) when unusual traffic patterns or equipment failures would otherwise force the network into a congested inefficient condition. Studies of congestion are a major part of the network management activities at Bell Laboratories, since an understanding of the underlying phenomena is necessary for the derivation of new and better procedures and equipment.

14.6.1 TRAFFIC NETWORK CONGESTION

14.6.1.1 Trunk Congestion

As direct routes in a network become fully occupied, calls are forced to follow alternate routes. These generally involve more trunks and switching systems per call, and hence the network operates at a lower efficiency. At higher traffic levels, as the alternate routes become occupied, more and more calls will receive a reorder tone. The switching equipment and circuits used to handle these calls up to the point where they are routed to the reorder tone have therefore, in a sense, been wasted.

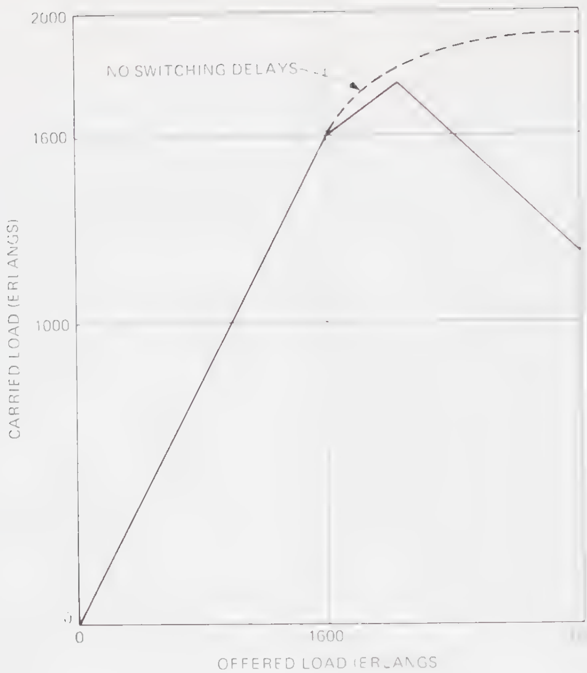

Fig. 14-3. Carried Load Versus Offered Load

14.6.1.2 Switching Congestion

A call arriving at a common-control switching system will be placed in a queue if all digit receivers (also called incoming senders) are in use. While the call is in a queue, the digit transmitter (also called an outsender) in the preceding system will be tied up until a digit receiver becomes free in the second system so that digit information can be transmitted forward. After 20 to 30 seconds, the outsender in the first system will time out and route the call to reorder tone or to a special emergency message. Thus, because of a long queue in the second system, the aborted call has used several times the normal service time on the first outsender and has twice accessed the routing equipment in the first system—once to set the call up and once to route it to reorder. If a sufficient number of calls receive this treatment, other switching systems will become congested, the switching system that originally queued incoming calls will be unable to outpulse its calls, and congestion will spread throughout the network.

14.6.1.3 Analysis of Congestion

Computer simulation techniques are ideal tools for studies of traffic network congestion. Measurements in the network itself are difficult to obtain because most congested situations cannot be predicted, the congestion patterns do not repeat themselves with enough fidelity to permit accurate comparisons,[10] and the operating companies are loath to allow experimentation with new network management techniques on revenue-producing traffic.

Computer simulations can take many forms. The program used to construct Fig. 14-3 was a call-by-call simulator; that is, each call entering the network is followed through the network. The fidelity is considered very good, but the program is limited to a network of about 50 switching systems. Fig. 14-3 shows that when the offered load exceeds the engineered load (1600 Erlangs) by more than 50 percent, the carried load falls below the engineered load. The dashed line illustrates that if switching capacity is increased so that no queues (and hence no switching delays) exist, the overload characteristics of the network improve.

The results of one simulation run are shown in Fig. 14-4 and illustrate several important principles. This figure shows the transient response of the network when a 100-percent overload (3200 Erlangs) is offered. The vertical scales show both carried load in Erlangs and ineffective attempts. The carried load is initially about 1800 Erlangs (the network was operating at engineered capacity before the overload was introduced). As the congestion builds, the attempts blocked by trunk congestion grow rapidly. Ineffective attempts caused by switching system congestion (sender time-outs) are initially small. However, the model assumes that many customers reattempt calls that are blocked. When the large number of reattempts is superimposed on the heavy initial load, the switching systems become congested, receiver queues grow, senders begin to time out, and the carried load falls. Finally, the switching system congestion dominates and results in so many time-outs, which have a relatively short trunk holding time, that the trunk congestion disappears.

Overloads such as those illustrated in Fig. 14-3 and 14-4 occur several times a year. Christmas Day, Mother's Day, and other holidays produce intertoll congestion. While the total message volume on these days is well below that of the average business day (ABD), the calling pattern is skewed or distorted, not at all like that for the ABD. Local and intrastate toll calling is light, but the long-haul interstate call attempts far exceed capacity. Skewed overloads also occur in metropolitan areas during snowstorms, when the calling between the suburbs and the center city far exceeds ABD demands.

A second type of overload, the focused overload, is typified by unusually heavy calling from many points to one point. Calling in the wake of the Los Angeles earthquake in February 1971 is a good example of a focused toll overload. During the 3-day period following the earthquake, call attempts from the rest of the network to southern California were at a level about twenty times the ABD value. In metropolitan areas, similar focused overloads occur to radio stations (responses to give-away contests), to social-service agencies

10. Christmas Day invariably results in congestion in several parts of the long distance network. However, from year to year, the problem areas and times shift according to the day of the week, as the population moves, and as new facilities are added.

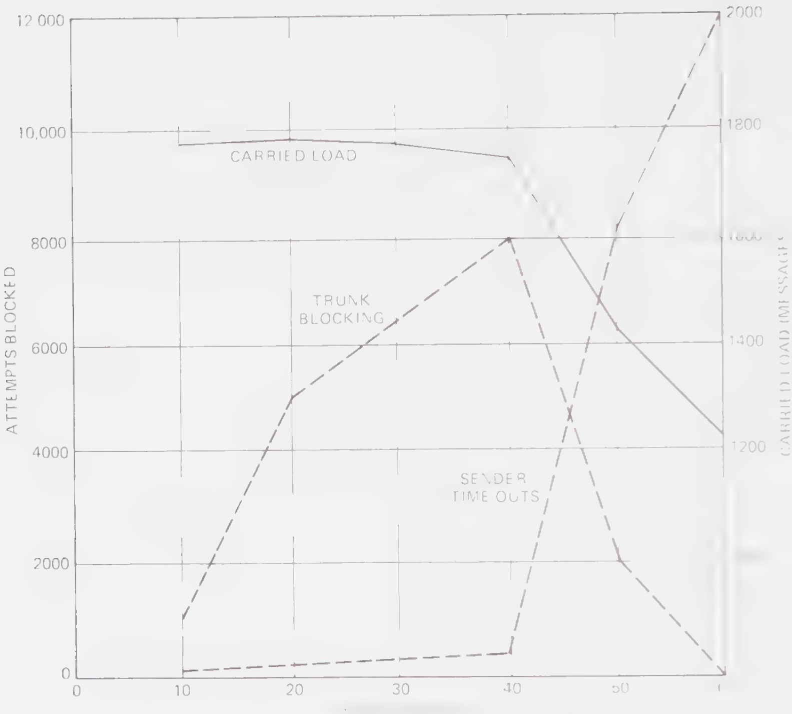

Fig. 14-4. Transient Network Congestion—100-Percent Overload

(inquiries when welfare checks are late), and to power companies (reports of power failures).

14.6.2 DATA FOR PREDICTION AND DETECTION OF CONGESTION

Network congestion is detected, and often can be predicted, by interpretation of appropriate traffic data. As shown in Fig. 14-4, overloads often begin with trunk congestion. Hence, lamps that indicate no-circuit-available status for trunk groups are provided in network management centers. In more sophisticated systems, register data in the form of trunk-group peg count (offered calls) and overflow are used to calculate attempts/circuit/hour (ACH) and connections/circuit/hour (CCH). These quantities are calculated as frequently as every 5 minutes. ACH indicates the calling pressure, and CCH indicates the holding time of the calls.

Under normal circumstances, ACH=CCH≈6 for each end of a 2-way group; that is, each circuit is handling about 12 calls per hour, and there is no overflow. If ACH is high and CCH is normal, the inference is that there is a heavy demand, but the holding times are normal, and hence most of the calls switched are completed messages. If CCH is high, the trunk holding times are unusually short, indicating that ineffective attempts are being switched and some control activity may be in order.

The most effective indicators of switching congestion are dial tone delay (for end offices) and sender attachment delay (for toll/tandem offices). Excessive dial tone delay may be due to heavy originating traffic, in which case there is very little the network manager can do. If dial tone is being affected by heavy terminating traffic (the coupling between originating congestion and terminating congestion varies widely with the type of switching system), controls can be applied to relieve terminating congestion.

If sender attachment delay becomes excessive, sender time-outs become a problem, as shown in Fig. 14-4, and the network carried load declines. As noted in Section 14.5.2, the sender attachment delay recorder measures the percentage of sender test bids that are delayed more than 3 seconds. The standard criterion is to operate controls to maintain a SADR level of less than 10 percent. At design loads, switching systems are expected to operate at a SADR level of less than 1 percent.

14.6.3 NETWORK MANAGEMENT CONTROLS

The repertoire of network management controls is outlined below, along with the problem situations in which each is commonly used.

14.6.3.1 Directionalization of Trunk Group by Making Trunks Appear Busy

This control, when operated at one switching system, reduces call pressure to a distant switching system. In the case of a 2-way group, it provides additional equivalent one-way outward trunks for the distant switching system. The control is commonly used in focused overloads to hold traffic away from the focal point.

14.6.3.2 Cancellation of Alternate Routing

This control removes alternate-routed traffic from a group and hence reduces the load on the distant switching systems. It also reduces the average number of links per call, since alternate routing is reduced. Cancellation can take two forms: CANCEL-FROM selectively cancels traffic overflowing from a high-usage to another high-usage or final group; CANCEL-TO cancels all traffic overflowing to the controlled group. These controls are usually used in peak-day overloads (such as Christmas) to increase network efficiency by reducing links per call and to control the amount of alternate-routed traffic that reaches the upper levels of the hierarchy.

14.6.3.3 Rerouting

This control routes overflow traffic to a trunk group that is not in the normal route advance sequence. This control usually is used when all normal routes are busy. For instance, the normal routes from New York to Florida may be fully occupied at 9:00 a.m. EST on Christmas Day; however, both New York and Florida would be likely to have idle circuits to the West Coast where it is 6:00 a.m. local time. Hence, some New York-to-Florida traffic will be sent to Los Angeles, which can use its available trunks to complete the calls to their destination. By this technique, the trunk layout between New York and Florida is effectively expanded.

14.6.3.4 Code Blocking

With this control, calls are blocked (routed to reorder or to a recorded message) according to destination code. The control is extremely useful in the case of focused overloads, especially if the calls can be blocked at or near their origination. The blocking need not be total unless the destination office is completely disabled through natural disaster or equipment failure. Switching systems equipped with code-blocking features typically can control 50 percent, 75 percent, or 100 percent of calls to a particular code. The controlled code may be NPA, NXX, NPA-NXX, or in sophisticated systems, NPA-NXX-XXXX, when only one specific customer is the target of a focused overload.

14.6.3.5 Dynamic Overload Control (DOC)

At best, the controls just described require manual activity at a key or switch and sometimes involve wiring changes. Hence they may be applied too slowly and are often left in effect too long.

DOC is an automatic control system that senses congestion (as measured by the number of calls waiting for a sender) at a toll or tandem office and that sends an electrical signal to subtending offices (those that home on it). The response of the subtending switching systems depends on how they have been programmed or wired. Commonly, the subtending offices cancel alternate-routed traffic or make trunks busy. When DOC is properly deployed, about 40 percent of the subtending traffic will be controlled, and a control action may last only about 10 seconds. DOC controls are much preferred over manual controls because they are activated as soon as congestion appears and are removed as soon as the need disappears.

14.6.3.6 Selective Dynamic Overload Controls (SDOC)

The DOC system described has a serious drawback in that it treats all controlled traffic uniformly. It does not discriminate between traffic that has a high completion probability and that which has a low completion probability. When code blocking is combined with DOC to form selective DOC, a very effective control system results. In operation, the subtending offices either calculate or receive completion statistics by code, and if the control office encounters congestion, the subtending offices respond to a DOC signal by canceling alternate routing for hard-to-reach codes or by making trunks appear busy for these codes.

A comparison of DOC and SDOC control schemes is shown in Fig. 14-5, which presents simulation results for a peak-day overload.

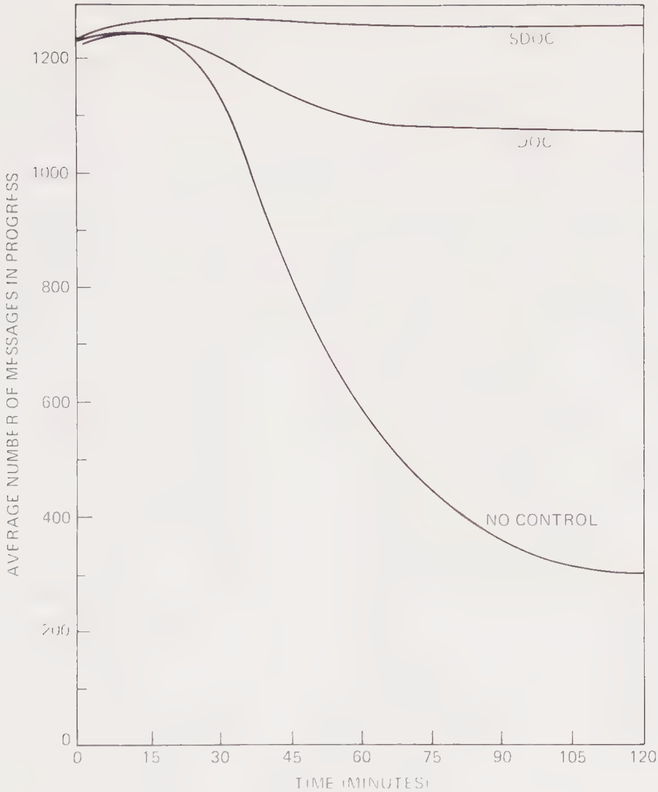

Fig. 14-5. Peak-Day Overload

14.6.4 CURRENT OPERATING ENVIRONMENT

As currently organized, network management responsibility very closely follows the switching hierarchy. A National Control Center (NCC), located at AT&T Long Lines headquarters and administered by the headquarters staff, coordinates activities among the regional switching centers in North America. The NCC has access to high-speed telemetry data on trunk group and switching system congestion at these regional centers. All regional centers are connected with the NCC through a full-period voice circuit. Each regional center, in turn, coordinates activities among its subtending sectional centers. The response to a congestion problem that involves sectional centers in two different regions would be coordinated through the respective regional centers and the NCC.

All regional centers collect real-time telemetry data from their subtending sectional centers, which also are connected with their regional centers through a full-period voice circuit. Below the regional level, the incidence of telemetry systems and full-period circuits is lower, with voice circuits more prevalent than telemetry systems.

All regional centers have dynamic overload control on their subtending finals. DOC at the sectional level is quite rare. Almost all toll switching systems have a capability to cancel alternate routing by manual key control. Code blocking is restricted to No. 4A/ETS and later versions of No. 1 ESS. Controls at end offices, other than No. 1 ESS, almost always require wiring changes. SDOC will not be available until No. 4 ESS is in the field.

Note that the basic purpose of the control measures, which are designed to suppress some of the traffic, is to maximize the amount of traffic that can pass through the network during a heavy overload.

14.7 NETWORK ADMINISTRATION

14.7.1 ITS ROLE IN THE OPERATING COMPANY

The concept of network administration is relatively new in the operating companies; it replaces the role of dial administration. The companies currently have widely varying organizational structures with different degrees of centralized responsibility, particularly in the administrative areas.

Historically, the dial administration responsibilities rested with the district traffic manager in the traditional traffic department. The responsibilities appeared to be in the proper department because the traffic department's charge was to manage the flow of communications over the network. Now, because telephone service really depends on point-to-point network completions, the concept of network administration is supplanting the treatment of traffic administration in several independent roles. It is now strongly felt that while specific administrative functions may in fact be spread among several groups, there does exist one consistent primary role: that of responsibility for the overall quality of service given by a particular network. This is the role of the network administrator. It involves striving for the most efficient overall functioning of switching systems and interconnecting trunk groups, within the constraints of existing equipment and trunk-group sizes.

Organizationally, there are varying structures within which the network administration job is presently being performed. There is a trend, however, toward combining administration functions with maintenance functions because of their highly interrelated and interdependent nature.

A typical operating company organization for network administration in a metropolitan area is shown in Fig. 14-6. The administration and maintenance functions are shown in Fig. 14-6 reporting to a common district network manager. The concept of functionalized district managers for each of the functions reporting to a common division network manager is also seen as a viable alternative.

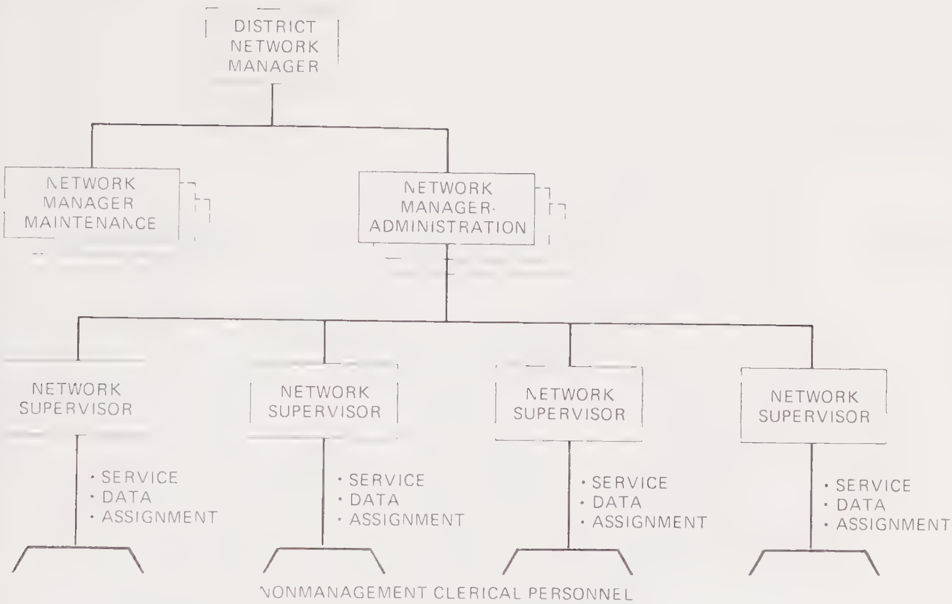

Fig. 14-6. Organization of a Metropolitan Area Network District

14.7.2 RESPONSIBILITIES

Network administration can be defined as the administration and utilization of a specific portion of the public telephone network and includes, directly or indirectly, the serving of main station demand, from a growth and usage standpoint, in accord with established service objectives.

This broad definition is expanded here to identify the specific areas of responsibility. The job responsibilities of network administration are divided among six major functional areas. The term administrator is used to identify the management supervisor who maintains responsibility for the activity or function being discussed.

14.7.2.1 Data Administration

The administrator is responsible for the scheduling, recording, posting, and validity checking of data required to properly administer, evaluate, and engineer the switching system(s). This data may be obtained using various methods, including manual register reading, recording on film, and automated data systems. Some of the specific activities are:

(1) *Traffic and Service Measuring Devices*

(a) Review installed measuring devices to determine if their features are completely utilized and if required data measurements are obtained.

(b) Develop and/or evaluate cross-connection of service, usage and peg count measurements, and storage devices.

(c) Establish controls to ensure proper operation of measuring devices.

(d) Administer trouble detection and resolution using specific measuring device routines and procedures.

(e) Review maintenance routines relating to measuring device integrity.

(f) Review the data section of a traffic order, and compare its data with actual data available for the office.

(2) *Data Collection*

(a) Identify and obtain data required for:

Network administration,
Engineering,
Trunk servicing and forecasting,
Network control,
Division of revenue,
Marketing, or
Other special requirements.

(b) Publish schedules for collection of data and measuring device operation.

(c) Administer the collection, posting, processing, and distribution of data.

(3) *Data Validation*

(a) Validate the basic taffic data before providing it to users.

(b) Coordinate with the maintenance force to resolve situations in which data do not reflect actual equipment operation and are, therefore, invalid.

(c) Reconstruct any missing or invalid data through analysis of available data following accepted guidelines and procedures.

14.7.2.2 Equipment Utilization

The network administrator is responsible for the optimum loading, balancing, and utilization of installed equipment. The administrator must use a variety of tools, such as load-balance data, forecasts, official office capacities, loading plans, administrative data analysis, etc., to service growth while maintaining objective levels of service. Provision of the required trunk network at the proper time is also a major responsibility of the network administrator. Some specific activities are:

(1) *Main Station Loading Plans*

(a) Develop detailed loading plans for use by the assignment force.

(b) Review the official office capacity, growth forecast, class of service demand, etc.

(c) Evaluate changes in growth and/or demand levels.

(d) Evaluate the load balance, present and future, considering demand by class of service, new services, capacity changes, etc.

(e) Actively participate in all committees involved in servicing regular, large job order assignments or special demands.

(2) *Line and Number Administration*

(a) Maintain accurate, up-to-date assignment records.

(b) Follow prescribed line assignment practices and procedures.

(c) Ensure adequacy of advanced assignments.

(d) Monitor ongoing assignment activity interdepartmentally.

(e) Follow up on conformity to the loading plan.

(f) Develop percent of unusable lines and numbers because of reservations, class-of-service restrictions, and in-out activity.

(3) *Equipment Operation*

(a) Evaluate current traffic data in depth (using established procedures) to ensure that installed equipment is operating properly and in the most efficient manner.

(b) Coordinate with the maintenance force in correcting instances of improper or inefficient equipment operation that are found through data analysis.

(4) *Trunk Network Administration*

(a) Determine the adequacy and integrity of the in-service trunking network as compared with routing guides, desgin trunk estimates, etc.

(b) Coordinate with the trunk servicing group and the maintenance force to ensure trunks are in service prior to the forecasted need.

(c) Maintain accurate trunk group and routing records.

(d) Assist trunk engineers and the maintenance force in overcoming roadblocks to the implementation of the required trunk network.

(e) Monitor and evaluate special announcement or mass calling arrangements, and request relief or rerouting if required.

(f) Monitor the network during periods of unexpected load caused by either natural or man-made disasters, and participate in local network control efforts.

Note: Actual forecasting, servicing, and order initiation are normally the responsibilities of a trunking group. Network administration's responsibility is limited to service-protecting surveillance.

(5) *Load Balance*

(a) Maintain a complete load-balance (line and trunk) monitoring program following prescribed practices.

(b) Evaluate the balance in terms of objectives and possible capacity loss caused by imbalance.

(c) Determine the need for and quantity of rearrangements to achieve the desired balance.

(d) Issue or arrange for transfers to correct imbalance.

(6) *Other Balance Considerations*

(a) Review and monitor the balance within and between groups of common-control equipment.

(b) Request relief or rearrangement to correct imbalances when these conditions produce or have the potential of producing a service reaction.

(c) Review future equipment orders, and evaluate proposed equipment group layouts.

14.7.2.3 Office Status Evaluation

The network administrator is responsible for daily analysis of the office status including the integrated review of measured service, load, and volume. Office and component group capacities must be determined for daily review of load versus capacity. Inherent in the evaluation of office status is protection of future service to be provided by the office. The administrator monitors growth sizing and scheduling to ensure sufficient switching capacity to meet forecast demand. Some specific activities are:

(1) *Switching System Capacity*

(a) Compute main station capacities of lines, terminals, switching paths, and each component of common equipment as required to evaluate actual performance of the switching system(s).

(b) Review official office capacities, and resolve items of disagreement with engineering, if required.

(c) Project main station capacities to exhaust of the current office using actual data and growth patterns.

(2) *Data Analysis*

(a) Maintain trends of key items of office data (CCS/main station, call rate, holding times, etc.).

(b) Test actual or projected values.

(c) Evaluate actual office capacities and office characteristics on an ongoing basis, and determine the degree of change to exhaust of the current office.

(3) *Growth and Utilization Forecasts*

(a) Assess actual growth and utilization versus the forecasted growth and load.

(b) Evaluate the impact of change in forecast or new service on the current and future capacities and/or exhaustion.

14.7.2.4 Service Problem Analysis and Correction Action

The network administrator is responsible for identification, investigation, and resolution of all service problems. Service problems are defined as any condition in which established service objectives are not met, with or without justification. This area of job responsibility is the most broad and requires proficiency in all skills and tasks associated with the network administrator's assignment. Some specific activities are:

(1) *Service*

(a) Prepare and distribute reports (or provide selected input data).

Dial-line index.
Load-balance index.
Percent Crossbar Tandem ineffective attempt report.
Specific switching system data for maintenance indexes.
All other dial-service-related company or related reports.
All other company or local reports.

(b) Monitor service daily using real-time service reports, manual or mechanized.

(2) *Diagnose Cause(s) of Service Problem*

(a) Evaluate all indications of service delay and/or blockage such as dial tone speed, incoming matching loss, overflow, tandem and end office ineffective attempts, etc., and test them against offered load and/or volume.

(b) Undertake expanded analysis as required for identification of service problems obtained from data analysis, service observations analysis, network call completion reports, customer reports and complaints, etc.

(c) Coordinate service monitoring and service problem resolution with the network service center(s).

(3) *Corrective Action*

(a) Coordinate departmentally and interdepartmentally in implementing corrective action plans.

(b) Develop and/or institute a switching system and network control plan to minimize service impact in connection with abnormal service situations, such as natural disaster, elections, telethons, strikes, etc.

(c) Frequently evaluate and update predicted service problems, such as forecasted weak spots or minor overloads, and review interim relief plans.

14.7.2.5 Transition Management

The network administrator is responsible for the analysis of plans for equipment additions, replacements, removals, and or rearrangements. The administrator must evaluate the impact this type of activity will have on service and must ensure that methods of procedure (MOP) for transition will result in desired equipment configurations with minimum equipment outages and service deterioration. Some specific activities are:

(1) *Equipment Transition and/or Additions*

(a) Participate in pretraffic order activities, and provide input on any items for consideration by the engineer during detailed job layout.

(b) Review equipment order and job specifics in detail.

(c) Input specific data and service considerations during the developmental stage of transition procedures.

(d) Determine the maximum allowable quantity of equipment (by type and group) that may be removed from service for maintenance and/or transition activity during additions or rearrangements.

(e) Evaluate the proposed transition MOP, and ensure that the desired equipment configuration is realized within allowable equipment out-of-service guidelines, with consideration for time of day, day of week, and time of year.

(f) Participate in the interdepartmental Job Contact Committee involved in acceptance and approval of installation or transition activities.

(g) Provide all translation, cross-connection, and assignment information specified as administration responsibility.

(2) *Transition Administration*

(a) Monitor customer load, service, and equipment out of service, during busy and nonbusy periods, while transitions or additions are in progress.

(b) Issue job status service reports prior to, during, and after major additions.

(c) Monitor the availability of turnover and/or acceptance tests, and maintain a complete set of related records covering new or rearranged equipment.

(d) Monitor the trunk and routing network during major transitions (office replacements, etc.) to ensure adherance to the cutover plan.

14.7.2.6 Personnel Administration

The network administrator is responsible for the coaching, developing, and evaluating of subordinates, management and nonmanagement, in the administrative and technical aspects of their jobs. The administrator determines work force requirements and training needs and administers personnel practices and policies. Some specific activities include:

(1) Apply company policies and objectives concerning personnel matters (e.g., absence, leaves of absence, disabilities, etc.).

(2) Identify subordinate job responsibilities, and jointly set objectives and targets.

(3) Review and appraise subordinates work performance on a regular basis.

(4) Recommend or administer salaries and wages.

(5) Evaluate changes that affect present and future job responsibilities of those people supervised, such as organizational changes and the introduction of new switching equipment.

(6) Participate in planning an adequate work force.

(7) Develop training programs and plans for individuals in the work group.

(8) Review and evaluate the organization for efficiency of operation.

(9) Maintain positive interdepartmental working relationships.

(10) Review and maintain safe working conditions.

14.7.3 IMPACT OF MECHANIZATION—FUTURE ROLE

Historically, most scheduled network administration tasks have been performed manually. Not only were these jobs often tedious and unrewarding, but they also have had, in many cases, detrimental effects on administrative responsibilities and objectives. New systems using minicomputer technology are being introduced to mechanize a large number of these tasks.

One major advantage of these new mechanized systems will be a dramatic improvement in the timeliness and validity of network traffic measurements (see Section 14.8). This increased accuracy in performance data, combined with improvements in forecasting, engineering, and planning (see Chapter 15) will allow more efficient loading of trunk networks and will permit the operation of switching systems closer to their design capacities.

While these increases in utilization efficiency are highly desirable in themselves, they do mean that there will be less of a service margin for load variations and/or trunk equipment problems. Similarly, switching system performance will be more sensitive to traffic and equipment irregularities as the systems operate closer to the knee of the load/service curves. It appears, therefore, that with increased efficiency, the status of the network will require closer monitoring than in the past. Since mechanization will eliminate much of the manual data manipulation effort, there should be increased freedom on the part of the network administrator to perform this active monitoring role. Also, as part of these new systems, expanded exception reporting and demand reporting will be available to the network administrator.

14.8 NETWORK MEASUREMENTS

Every day the Bell System collects large quantities of data to measure the call-completion performance of the network and the traffic loads carried by trunk groups and switching systems. These data are used to assess the quality of service and to plan the future growth of the network. A new and growing area of traffic measurements is that of providing data for network management decisions. (This topic was discussed in Section 14.6.) Measurements used to evaluate service will be discussed in Section 17.2.

This section describes provisioning measurements, discusses certain limitations in these measurements, and outlines trends in the traffic data area.

14.8.1 PROVISIONING MEASUREMENTS

One of the primary functions of a telephone company is to install equipment in a quantity that will provide satisfactory service at a reasonable cost. To accomplish this, it is necessary to measure the present traffic on the telephone network. These data then are used to plan the future growth of the network by providing the basis for predicting future load levels. In some cases, the data are used to identify pockets of substandard service for corrective action.

The three measurements commonly associated with a trunk group are *peg count, overflow,* and *usage.* Peg count is a count of all calls offered to a trunk group during the measurement interval (usually an hour). Notice that the peg count includes calls that are actually carried by the group as well as calls that find all trunks in the group busy; these latter calls are either offered to the next alternate route if the group in question is a high-usage group or receive a reorder signal if the group is a final or full trunk group. Overflow is a count of all calls offered to a trunk group during the measurement interval that find all trunks in the group busy and thus are either offered to an alternate route or receive reorder. Usage is a measure of the amount of time that the trunks are in use.

In the Bell System, usage is measured in hundred call-seconds per hour (CCS) (see Section 5.2.2.1). For example, a 10-trunk group in which each trunk was busy half the time during an hour would be said to carry 180 CCS of traffic. Usage data usually are obtained by a traffic usage recorder (TUR) which scans the trunks every 100 seconds and counts how many are busy. These counts are accumulated during the measurement interval to generate an estimate of the usage during the interval. (There is some statistical error because of the discrete scanning.) Since the TUR scans at a 100-second rate, the number of counts in an hour is a direct estimate of the usage during the hour in CCS.

For some trunk groups, these three measurements may not all be taken; for example, on a primary high-usage group, peg count and overflow may not be obtained. Also, in Step-by-Step Systems, overflow is not available, so usage and some measures peculiar to Step-by-Step are customarily employed. When a trunk is made busy for maintenance activity, the associated usage is called *maintenance usage.* For trunks, the usage measurement generally includes the maintenance usage and may be regarded as total usage. However, the sometimes inconsistent treatment of maintenance usage and its nonrandom characteristics can result in inaccuracies in the provisioning process. All the above measurements constitute the basic data for the trunk-provisioning processes and are used as described in Section 14.4.

Extensive traffic measurements are collected on switching systems because of their numerous traffic-engineered components. For the common-control portions, the usual measurements per component are carried peg count (this is frequently called simply peg count, and thus one must be careful to distinguish it from peg count in the trunking context), total usage, and maintenance usage. The traffic usage is thus directly obtainable, since it is the difference between the total usage and the maintenance usage. Since the typical holding time for a common-control item is considerably shorter than for a trunk, a 10-second scan rate is used to obtain total usage. Many other counts also are obtained, such as total originating peg count, total incoming peg count, or number of central processor cycles (in Electronic Switching Systems).

The measurement of traffic usage within the switching network of a common-control system is distinctive. Because of the large number of paths, it is not economical to measure the total usage. Rather, a sampling procedure is used, wherein the usage on a predetermined sample of the links is obtained, together with the total carried peg count and the carried peg count for the sample links. The sample usage is then scaled by the ratio of the peg counts to obtain an estimate of the total usage. These data are used as described in Section 14.5 to plan additions to a switching system or to plan the start of a new system by providing the basis for predictions of future loads.

Most equipment items in the Bell System are traffic-engineered to satisfy some objective grade of service in the component's busy-season busy hour (i.e., the fixed busy hour during the busy season when the traffic load on the component is greatest). Examples of the service objectives for trunks are described in Section 14.4 and for central-office equipment in Section 14.5. Notice that different components can have different busy hours. For example, in an office with an appropriate business-residential split, the attempt busy hour may be during the afternoon, whereas the busy hour for the switching network may be in the evening. Thus, the common-control items must be provided to meet the afternoon attempts, whereas the switching network size is determined by the evening load. The fact that different items can have different busy hours complicates the data collection function, both because of more involved data processing and because of problems associated with busy-hour determination.

In electromechanical systems, the traffic data are collected by equipment external to the system. For the peg count or overflow scorings, a recording device must sense a change of state on an appropriate lead brought out from the system. To collect usage data, leads must be brought from several circuits to the TUR; the TUR scans these leads to determine if the respective circuits are busy and indicates this information by a change of state on leads from the TUR to some recording device. Frequently, a mechanical register is used as the recording device to accumulate these changes of state (each trunk group would typically require three registers). The register does not reset itself, so a reading must be taken before and after the hour; the difference in the two readings is the traffic measurement for the hour.

To facilitate reading the registers, they are periodically photographed, and the data are transcribed manually or keypunched from the film. Currently, there is a major effort to replace these registers with electronic devices that can transmit the data over data links to a centralized minicomputer. The minicomputer records the data on magnetic tape in a format suitable for mechanized downstream processing and analysis. Savings in clerical effort and improvement in data accuracy make this approach attractive. The Engineering and Administrative Data Acquisition System (EADAS) will be the major data collecting vehicle (see Section 15.4.4) together with several outside-supplier systems similar in concept.

In ESS offices, traffic data are collected via software internal to the system and, at the appropriate time, are output on teletypewriters. The data tend to be more accurate than in electromechanical offices because physical cross-connections, which can be a source of errors, are avoided. However, the teletypewriter output presents compatibility problems for mechanized downstream processing.

14.8.2 LIMITATIONS IN CURRENT MEASUREMENTS

One limitation is the existence of "holes" in the measurements (such as the lack of an overflow count in Step-by-Step Systems) that permit overloads to go undetected. A second difficulty is the fact that certain equipment irregularities can badly distort component measurements. For example, certain trunk conditions can permit a trunk to be seized, but very soon thereafter either the customer abandons the call (perhaps because of high noise or low volume) or the trunk automatically drops the call. If such a trunk is in service, its holding time will be significantly shorter than the average holding time of a good trunk, and thus the defective trunk tends to be available to carry a disproportionate number of calls. This is called a *killer trunk*. Killer conditions can also exist in many other pieces of equipment. A killer trunk will severely reduce the overflows from a trunk group, thus distorting the measurements and possibly the future provisioning process. The impact upon customers is equally dramatic; if the killer is in a high-usage group, the group will tend not to become all busy, thus denying access to the alternate routes.

A third problem, particularly in electromechanical offices, is ensuring the proper installation and operation of the data collection equipment. The problems with open leads, cross-connections, and inoperative registers are legion.

14.8.3 FUTURE TRENDS

For provisioning measurements, the movement is quite evident toward mechanization of the data collection and data analysis operations. EADAS should improve the accuracy and response time of measurements from electromechanical offices. A variety of batch computer programs being prepared by the Bell Laboratories Business Information Systems organization will analyze the trunk data to pinpoint current deficiencies, to forecast future requirements, and to interpret the switching system measurements for use in the provisioning process.

For No. 1 ESS, an extensive time-shared computer process called PATROL is in use and being expanded. PATROL is designed to receive the switching system traffic data from the paper tape output of the No. 1 ESS and to summarize, store, and analyze the information. The difference in approach between the batch and time-shared processes is interesting, and it is not clear at present which is more effective in an operating environment.

A similar desire for mechanization exists with respect to service measurements, but progress here has not been as rapid. Exploratory study of mechanized performance measurement processes is beginning.

14.9 OPERATOR SERVICES—FACILITIES AND FORCING

This section briefly describes the methods used to engineer operator facilities and to provide the necessary number of operators at the right time, a process called *forcing*. These two functions also are performed by Bell System operating companies for PBX and ACD services in a manner similar to that described here.

14.9.1 MODEL

Operator switching systems are engineered under assumptions much like those used for local and toll switching systems. However, position and operator engineering employ a blocked-call delayed queuing model. The most adequate and readily solvable model of this class is the Erlang C model, used in Table 14-1.

TABLE 14-1
OPERATOR SERVICES QUEUEING FOR FORMULAS

$$P\{W>0\} = C(n,a) = \frac{\dfrac{a^n}{(n-1)!(n-a)}}{\displaystyle\sum_{j=0}^{n-1}\frac{a^j}{j!} + \frac{a^n}{(n-1)!(n-a)}}; \qquad 0 \leqslant a < n$$

$$P\{W>t\} = C(n,a)e^{-(n-a)\mu t}; \qquad t \geqslant 0$$

$$E\{W\} = C(n,a)/(n-a)\mu$$

where

$P\{W>0\}$ = probability of a delay of operator service

$P\{W>t\}$ = probability of a delay greater than t seconds

$E\{W\}$ = expected delay of operator service

W = waiting time or delay

$C(n,a)$ = Erlang C formula

a = offered load in Erlangs

n = number of servers (operators)

$1/\mu$ = average holding time per call

The Erlang C assumptions are that the process has:

(1) Poisson arrivals.

(2) Negative-exponential holding times.

(3) A first-come, first-served queuing discipline.

It is known that this model fails to account fully for the "real world" process. For example, some discrepancies originate with the customer. Abandonment and retrial of delayed calls violate the queuing discipline, while time-varying calling rates violate the equilibrium Poisson assumptions. Other discrepancies arise from engineering limitations, such as switching delays and only approximately full-access server groups. To counter these discrepancies, the capacity tables used for traffic engineering of positions and operators reflect quantitative adjustments to the model's assumptions and conclusions, beyond the theoretical relationships of load, service, and servers.

14.9.2 MEASUREMENT AND ERROR

Traffic measurements serve three purposes: determining the adequacy of the service given, comparing efficiency among offices, and providing engineering data to ensure good service in the future. The primary traffic service measurements for operator systems are the speed with which the customer is answered and the efficiency of serving the request. With the introduction of the Force Administration Data System (FADS) and CCS usage measurements, the Bell System is changing its measure of speed of answer (see Reference 7).

Until recently, the value measured was the probability of encountering a delay exceeding 10 seconds. This measurement of one point on the delay distribution is being replaced by the less volatile average speed of answer, which is the expected value of the customer's delay under the queuing model. The objective speed of answer is a function of the type of service and equipment and ranges from about 2 to 6 seconds.

In addition to the average speed of answer, FADS provides a measurement of how rapidly the customer is served once he has been answered; that is, the actual work time per call (AWT). These measurements are compared with Bell System standards by type of call and equipment. The other measurements available with FADS are counts of calls, total work volume usage, and operator team size. These provide the basis for operator services traffic engineering.

For engineering purposes, the newer FADS as well as earlier measurement procedures suffer from sampling variability; the value obtained is only one from an infinite possible set. Additional variability is introduced into the usage data by measuring only at discrete points in the sampling interval, rather than providing a continuous measurement over the interval. Studies have shown that with the common 100-second scanning interval employed by FADS, the variability of the load estimate caused by scanning is on the order of 10 percent of the sampling variability for most operator service applications. (See Reference 8.) The 100-second scanning interval provides relatively accurate load data at a reasonable measurement cost.

14.9.3 FACILITIES ENGINEERING

Operator services facilities engineering must provide adequate switching capacity and the proper number of operator positions to meet future demand. As in all other operating company engineering projects, the goal is to specify equipment quantities to minimize capital and installation expense while meeting service objectives. Operator positions are engineered under the modified Erlang C model with busy-season demand projected two years in the future. To avoid the provision of positions solely to meet isolated peak demands, the twenty-first high busy half-hour's projection is used, with a correction for statistical variation.

14.9.4 FORCING

Unlike facilities, which are installed once to meet busy-hour demand and then kept in service permanently, operators can be flexibly provided. Thus, forcing is a continuous job of providing enough operators to give the desired grade of service, while minimizing expense by not providing an excess number of operators (see Fig. 14-7). Operators work "tours" of from 5-1/2 to 8-1/2 hours, which, within local and union constraints, may start on the quarter-hour, have two quarter-hour reliefs, and may have a lunch period of a half-hour to an hour.

Given the volume and usage data (as from FADS), a forecast of operator requirements is made by quarter-hour for the week two weeks ahead. This demand curve is then covered using the set of available tours under an operation known as scheduling. Once the schedule has been drawn, it is allocated to the administrative units that make up the serving team. The allocated schedule tells each manager how many operators to provide by quarter-hour and which tours the operators are to work. Individual operators are then assigned to work specific tours.

The above process is basically a planning function. In addition, each day a force manager must monitor how well his planning anticipated the actual demand and must make adjustments as required. The adjustments take the form of projecting demand from intraday trends and calling out additional operators to meet unexpected demand or excusing an appropriate number of operators early if demand is low. Fine tuning is practiced by adjusting lunches and reliefs and by rescheduling training or clerical functions to counter peak or slack periods.

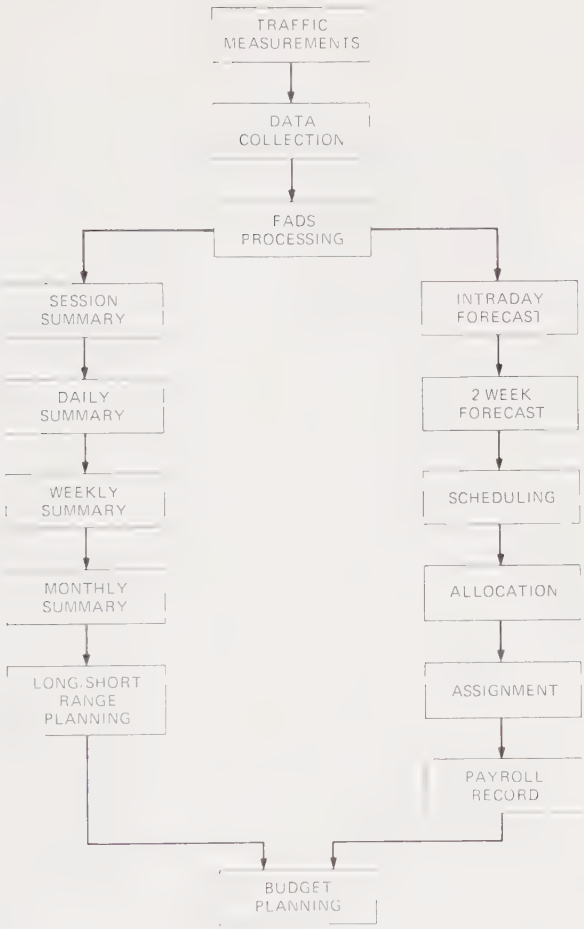

Fig. 14-7. Operator Service Information Flow

14.9.5 AUTOMATION AND OTHER IMPROVEMENTS

Three major traffic-related areas are being pursued to improve operator services. These are:

(1) Automating all or part of the operator's job to decrease the work time per call (Automatic Intercept System and Traffic Service Position System; see Section 9.6).

(2) Improving forcing techniques through automation of forecasting, scheduling, and other forcing functions (Automated Force Administration Data System).

(3) Improving service controls and measurements (provision of indications of operator overload, such as queue length or waiting time as a guide in adjusting number of operators).

Thus, traffic theory and its application and the relationships between service, demand, and servers dominate operator services; from provision of facilities two years in the future, to rescheduling the operators' next quarter-hour, to determining if the serving team has performed its function well in the period just passed.

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15 Service Provisioning

By now the reader should be familiar with the call-processing aspects of the public telephone network. But how does a prospective customer initially gain access to the network? This chapter begins by describing a customer service order and then discusses trunk provisioning for the public telephone network and special-service circuit provisioning. A number of computer-based systems for mechanizing service provisioning functions are described.

15.1 INTRODUCTION

Provisioning of service for business and residential customers includes many of the basic functions carried out in operating companies. It consists of the operations necessary to respond to service orders, trunk orders, and special-service circuit orders and to provide the resources necessary to fill these orders. Provisioning includes forecasting, planning, construction and installation of facilities, preparing and responding to the orders, and maintenance of the facilities.

Service orders are prepared in response to requests from customers for service on the public telephone network. Filling service orders requires selection of the loop plant including cable, cross-connects at terminal points in outside plant, selection and connection of central office line and number equipment, and the installation of station equipment on the customers' premises.

Trunk orders for the public telephone network are initiated by traffic engineers in the operating companies. These trunks are the interoffice circuits in the public telephone networks including interstate and intrastate circuits. A trunk consists of all the elements of the circuit from one switching system to another switching system. This includes trunk relays, traffic usage registers, tie cables, test jacks, cross-connects on trunk link frames and main frames, terminating and signaling equipment, and channels in transmission facilities. Fig. 6-23 shows several trunks used to make a customer-to-customer connection. Currently, there are over six million trunks in the Bell System.

Special-service circuit orders are prepared in response to requests from customers for special services. Special-service circuits include PBX trunks, foreign exchange lines, WATS trunks and private lines and circuits for private switched networks. Special-service circuits may include station equipment at the service points, local loop assignments, terminating and signaling equipment as required, and channels in transmission facilities. Currently, there are more than 3.5 million special-service circuits in the Bell System.

Section 15.2 focuses on customer service orders and the processing of these orders within an operating telephone company as an example of some service provisioning functions. Section 15.3 discusses the trunk and special-service circuit provisioning process. The reader should understand that there are other areas of service provisioning, for example Customer Switching Systems, that are not discussed in this chapter. Section 15.4 points out the massive and difficult challenge presented by the record-keeping aspects of service provisioning and indicates the approach taken. Computer-based systems for mechanizing parts of the service-provisioning process are discussed in Sections 15.5, 15.6, and 15.7.

15.2 SERVICE ORDERS

Processing of service orders involves the interaction of several departments within an operating company. The necessary facilities must be placed, and records must be established to provide, maintain, and account for the communication services ordered.

Suppose that Mr. Ralston has just moved into town and that he would like to have service installed in his new home. Using his neighbor's telephone, he calls the local operating company. The call is answered by a service representative who informs Mr. Ralston of the various types of telephone equipment and features that are available. A universal service order (USO) is prepared by the customer service representative. The service representative takes the name and address of the customer to be listed in the directory, the class of service (e.g., one-party residential), some billing information, and the type and color of the equipment desired.

Assume Mr. Ralston orders one-party residential service. In addition to station equipment, he requires a cable pair connecting him to his local central office and line equipment on the switching system. Thus, a copy of the service order first must be forwarded to the traffic department, for the assignment of line equipment and a telephone number, and to the plant assignment office, for assignment of a cable pair.

The traffic department maintains the records of line equipment. Available line equipment is assigned so as to maintain balanced loading of the switching equipment. The line equipment assignment for Mr. Ralston is entered on the service order as both a directory number and a line equipment number.

The plant assignment office has a record of those cable pairs to which Mr. Ralston's residence has access. A vacant pair is selected from this group and is assigned to Mr. Ralston. The cable number, pair number, and serving terminal number are entered on the service order. A cable pair color code also may be required.

Copies of the service order now are given to the frameman and to the installer. The frameman runs a jumper as specified by the cable pair and line equipment numbers. The installer places the station equipment and connects the drop wire to the cable pair near Mr. Ralston's house. If all has gone well, Mr. Ralston's telephone is now operable.

When the installer indicates that service has been established, the second phase of service-order processing is carried out. Copies of the completed service order are forwarded to various departments for the purposes of maintaining service, billing, and directory listing. The customer service department maintains records, so that if Mr. Ralston calls about his service, a service representative can retrieve the necessary information quickly. The repair service bureau must have a complete record of the connections from the central office equipment to Mr. Ralston's telephone, plus a record of the amount and type of station equipment. This is necessary in case of trouble. The accounting department must record service information in order to compute Mr. Ralston's monthly bill. Mr. Ralston's telephone number must be forwarded to the dial services group for directory listing and to the traffic department for directory assistance.

A USO consists of the following sections (some of which may not be required for a given order):

A. Control (CTL)
B. Directory (DIR)
C. Traffic (TFC)
D. Billing (BILL)
E. Service and Equipment (S&E)
F. Facilities (FACS)
G. Remarks (RMKS)
H. Assignment (ASGM)
I. Statistics (STAT)

Fig. 15-1 shows the completed service order for Mr. Ralston's service, including all the information entered by the customer service representative and the assignment information. A detailed discussion of the sections completed for Mr. Ralston's order follows.

A. *Control Section*

1. The telephone number assigned for this transaction. This telephone number will be the entry for this customer in the company telephone directories. — 464-5674

2. The customer code is used by customer record information system (CRIS) for control purposes to distinguish live and final accounts for the same telephone number. Consists of the last three digits of the order number. — 324

UNIVERSAL SERVICE ORDER

	①		②	CUS	③ CD	④ EX	⑤ APP
TN	464 5674			324	7 16 65	UNIV	7 14
ORD	N31324	CS	1FR	SS	1234	DD	7-16 W

	Line	⑥	⑦ ⑧ ⑨
①	4	ILN	RALSTON, JOHN H
◯	5	ILA	123 S PINE RD
	7	---BILL	
①	9	IPO	12345
②	10	ICC	B
③	11	ICI	SALESMAN B & B CO 4 63
	13	---S & E	
①	15	11	1FRBC
	17	---ASGN	
①	18	FA	123 S PINE RD
②	20		/ILT 30, RT 134
③	21		/RZ 13/PRQ YES
④	22	1	1FR/TN 464 5674/OE 09 31
⑤	23	F1	/CA 30/PR 68 BP 30/TEA F
	24		ELOISE, PLACE CROSS CONNECT
⑥	25	F2	/CA 3001/PR 15/BP 15/TEA R
	26		123 PINE, TERMINATE DROP
	30	---STAT	
①	31	OCB	ISY RI 1

Fig. 15-1. Example of a Service Order

3. The date the service was installed. 7-16-65

4. The exchange in which the service was installed. UNIV

5. The date the customer contacted the company for service. 7-14

6. (a) The type of order: a new connection. N

   (b) A control number. 31324

	7. The type, grade, and class of service requested: one-party, flat, residence.	1FR
	8. An identification number of the contact employee used for reference and sales purposes.	1234
	9. (a) The date service is to be installed.	7-16
	(b) The telephone company and the customer agreed on the due date.	W
B.	*Directory Section*	
	1. The name of the customer to be used for directory listing purposes and for the customer's bill.	
	2. The address for directory listing purposes, billing, and location of service.	
C.	*Traffic Section* (not completed for this order)	
D.	*Billing Section*	
	1. The post office zip code for the address in the directory section.	12345
	2. The credit classification of the customer as determined by the customer service department contact employee. Used for subsequent bill treatment when payments are delayed.	B
	3. The credit information obtained by the contact employee. Used to establish the credit classification.	Salesman
E.	*Service and Equipment Section*	
	1. The type, grade, and class of service are represented by the universal service order code 1FR. The suffix BC identifies the color and type of station equipment requested by the customer. B = black C = hand-combined telephone set	1FRBC
F.	*Facilities Section* (not completed for this order)	
G.	*Remarks Section* (not completed for this order)	
H.	*Assignment Section*	
	1. The address at which the assigned facilities should be terminated.	FA

2.	(a)	The estimated time to place the cross-connect and to terminate the drop wire.	1LT30
	(b)	The installation foreman route number for the serving terminal to assist in preparing installation work loads.	RT 134
3.	(a)	The maximum resistance of the cable pairs at the serving terminal (1300 ms).	RZ 13
	(b)	Protection is required at the facility address as cable exposure has been identified.	PRQ YES
4.	(a)	Install a one-party, flat-rate residence service.	1FR
	(b)	Telephone number assigned.	464-5674
	(c)	The line equipment assigned. The entries identify the terminals for the framemen to run a cross-connect.	09-31
5.	(a)	Identifies the first facility from the central office.	F1
	(b)	Identifies the feeder cable leaving the central office.	CA 30
	(c)	Identifies the pair within the feeder cable. The cable and pair information and the OE identifier in item 4 (c) above enable the framemen to run the MDF cross-connect and provide access to the switching network.	PR 68
	(d)	The binding post of the designated feeder cable pair at the terminal address at which a cross-connect is required.	BP 30
	(e)	The terminal address at which the installer must make a cross-connect as designated by the work instruction, "Place Cross-Connect."	TEA
6.	(a)	Identifies the second facility required from the central office. This designation is referred to as distribution cable.	F2
	(b)	Identifies the distribution cable number.	CA 3001
	(c)	Identifies the assigned pair in the distribution cable. This cable pair must be cross-connected with the feeder cable pair assigned as indicated in item 5.	PR 15

(d) The binding post of the distribution cable pair at the serving terminal identified by the next entry. — BP 15

(e) The address at which the installer will terminate the outside plant facilities that extend the central office facilities to the customer's premises, thus providing access to the switching network. Work instructions have been provided: "Terminate Drop," which implies a drop wire is in place but was opened on the prior disconnect of service. — TEA

I. *Statistics Section*

1. (a) Identifies the employee completing the installation of service. — OCB ISY

   (b) Indicates that the installer installed one telephone set that was disbursed from field stock. The existing wiring, drop and inside, was on the premises and reused. — RI 1

15.3 TRUNKS AND SPECIAL-SERVICE CIRCUITS PROVISIONING

In addition to customer service orders, the operating company interconnects equipment and facilities to provide trunks and special-service circuits. The five basic processes for provisioning of trunks and special-service circuits are illustrated in Fig. 15-2. The five processes include forecasting, resource provision, circuit provision, inventory management, and service upkeep.

The process of trunk forecasting produces an estimate of the traffic load to be carried at specific future dates by each trunk group. This estimate of the future load combined with network service objectives and the routing pattern is used to determine the number of trunks required. Special-service forecasts are based on special-service circuit historical records that group the various services and predict future demand based on past trends.

The resource provision process includes the fundamental and current planning needed to determine the equipment and facility additions to the network to satisfy the forecasted load. Fundamental planning determines the broad long-range requirements for switching and transmission facility relief in the 5- to 20-year time frame. Current planning determines specific facility and equipment additions, removals, and rearrangements over a 5-year period to support the forecasted load. Given the fundamental and current plans, the detailed engineering is carried out and work orders and requisitions for the installation of the appropriate equipment and facilities are issued. The equipment and facilities are installed, cross-connected, tested, and made available for service in the installation process.

The circuit provision process includes trunk servicing, circuit design and assignment, and installation. Servicing the trunk network is a continuous

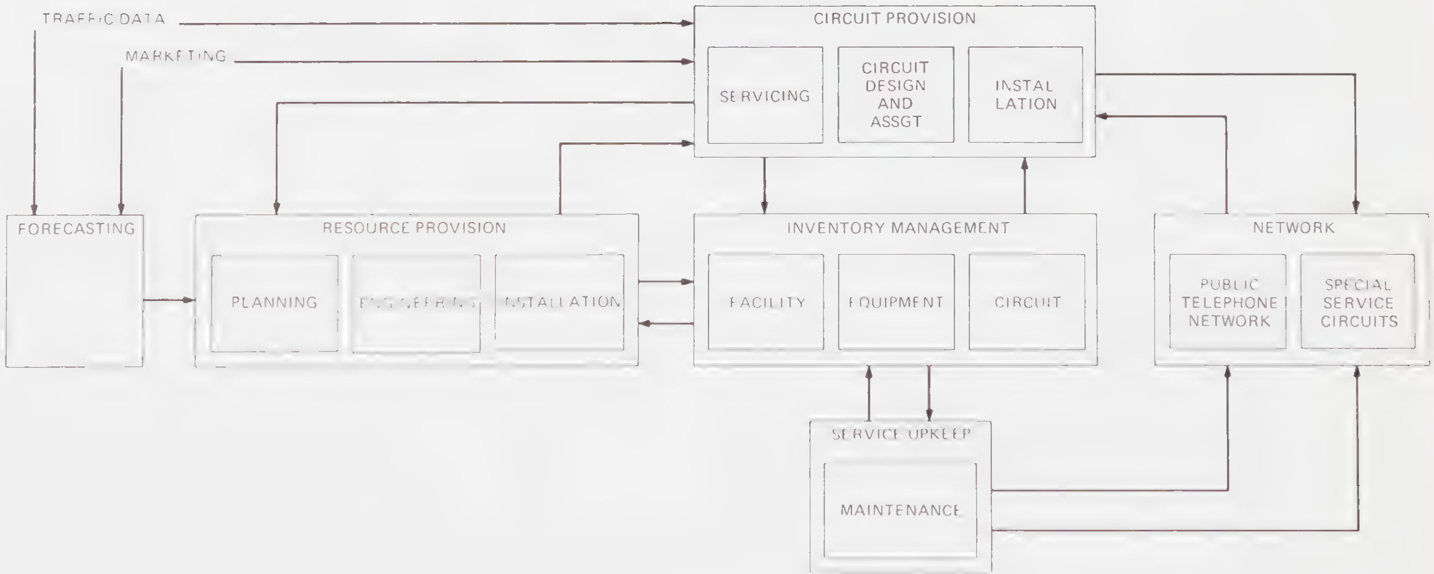


Fig. 15-2. Trunks and Special-Service Circuits Provisioning

process of monitoring trunk service and issuing trunk orders to keep each trunk group in the network at the desired engineered service level. Trunk orders generated by trunk engineers and special-service orders requested by customers are processed in the circuit provision organization of the operating telephone companies as shown in Fig. 15-3. The circuit design of trunks and special-service circuits is carried out, equipment and facilities are selected and assigned to the circuit, and a work order with the detailed circuit record is generated and sent to the installation forces. Using the circuit record, central office personnel connect, disconnect, or rearrange the equipment and facilities making up the circuit. Tests are carried out, and a work completion report is generated by central office plant forces.

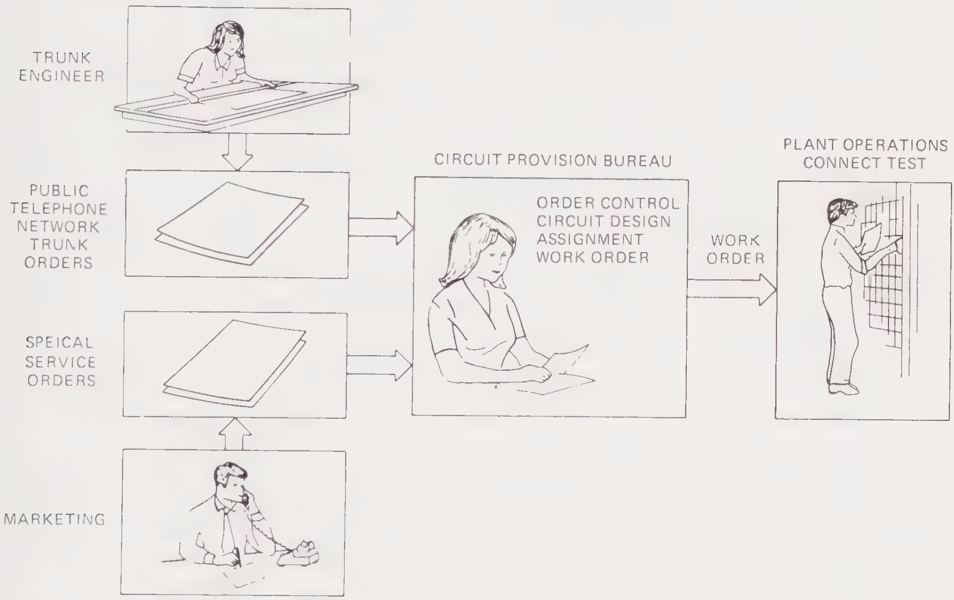


Fig. 15-3. Circuit Provision Operations

Inventory management provides standards, administrative procedures, and controls for managing the facility, equipment, and circuit inventories used in the circuit provision process. Management of field stocks, movable (plug-in) equipment, and hard-wired equipment is directed toward meeting service objectives with minimum capital and expense.

The service upkeep function includes the maintenance of plant to meet service objectives. Corrective maintenance begins with the recording of trouble details as reported by testboards, operators, service bureaus, or repair personnel. Tests are made to isolate the trouble and to find and replace the component(s) causing the problem. Programs of preventive maintenance by routine testing also are carried out. Chapter 16 discusses the testing and maintenance process in greater detail.

15.4 RECORD KEEPING FOR SERVICE PROVISIONING

15.4.1 THE SIZE OF THE PROBLEM

Each year the Bell System operating companies handle over 100 million customer service orders to install, remove, or change equipment. In addition, there are six million trunk orders generated to add, remove, or rearrange trunks and two million orders for special-service circuits. The ratio of service or circuit order activity to net growth may be as high as 10:1; that is, there are 10 orders to connect, disconnect, or rearrange service in order to make one net gain of a customer or a circuit. Millions of equipment and facility items must be updated, added, or deleted from inventory records and circuit records to process these orders. For example, there are 100 million cable pairs in the loop plant, 17 million interoffice circuits,[1] and 38 million units of terminating and signaling equipment. Each of these components and their status, which may be working, spare, or in repair, need to be kept track of in the records. In addition to the existing plant, the inventory of equipment and facilities is constantly growing, and both additions and retirements to existing plant need to be reflected in the records.

Detailed data must be maintained in the operating telephone companies on each service and circuit order from its inception in the business office or in the trunk engineering groups for trunks to its completion by the plant forces. The utilization of existing facilities and equipment is monitored and controlled to determine when additions are required. Division-of-revenue information must be generated based on these records to carry out the settlements for interstate service. Large numbers of management reports for construction program activity, inventory control, and service provision must be generated. Thus, it is clear that there is an enormous job of record keeping to support circuit provision and inventory management processes.

Within the operating companies, forecasts, service demand, and order information must flow from the customer services, sales, and engineering departments to the departments that provide the equipment and facilities. Subsequently, information flows to the accounting and directory departments.

Considering the number of transactions, the size of the Bell System inventory, and the varied nature of its information flow, it is not surprising that the Bell System has turned to computers. In 1963, there were 366 in use; most of these were used in billing and accounting applications. At that time, little attempt had been made to use computer power to resolve service order and inventory record-keeping problems. These computer applications all had been designed in individual companies; many were functionally equivalent, and there was a great redundancy of developmental effort. In 1974, the computers in the Bell System numbered over 2000.

1. Several interoffice circuits may be connected together to form a special-service circuit.

15.4.2 BUSINESS INFORMATION SYSTEM DEVELOPMENT

Transition from manual record keeping to mechanized computer systems in the operating telephone companies is a challenging process. In 1968, an AT&T planning study showed a clear need for a centralized development organization. As a result, a Vice Presidential area of Bell Laboratories was formed, using experienced system development people from the Bell System operating companies and Bell Laboratories as a nucleus. This area was charged with the central development of a series of Business Information Systems (BIS) to support the companies in the service provisioning process.

A contract agreement was reached with the operating telephone companies to fund the centralized development and maintenance of systems for the trunks and special-service provisioning process, customer service, and number services, an area not previously mentioned in this chapter. The next section describes some of these systems that have been developed. It is important to note that these systems have two major subsystems: (1) the computer subsystem, which consists of the application software, system software, and computer hardware and (2) the personnel subsystem, which contains all of the practices, job aids, training material, and operational documentation. Typically, for these large data base systems, careful planning and extensive conversion activity must be carried out to build up to the full capabilities of the system. It is important to note that although these systems are referred to generally as record-keeping systems, they directly support the operational processes for both day-to-day and long-term planning of the service provisioning process.

The systems developed under the BIS contract agreement use computers that can be bought or leased from computer manufacturers. In most cases, the operating companies deal directly with the computer manufacturers; in some cases, Western Electric acts as an agent for an operating company. The development and maintenance of computer programs and personnel subsystems are done by the BIS organization. This organization also assists the operating companies in planning and engineering new installations.

15.5 MAJOR COMPUTER-BASED SYSTEMS

The computer-based systems described in this section are associated primarily with record-keeping aspects of service provisioning. Note that there is a variety of other computer-based systems and computer programs used in various service provisioning functions. A few examples of computer programs used in planning, engineering, and administration of exchange facilities are described in Sections 15.6 and 15.7; others not discussed are used in planning switching system installations, including PBXs, and in planning the long-haul portions of the facilities network. Computer-based systems for maintenance are discussed in Chapter 16.

The systems described in this section include the Business Information Systems Customer Service/Facilities Assignment and Control System (BISCUS/FACS), the Trunks Integrated Records Keeping System (TIRKS), the

Plug-In Inventory Control System/Detailed Continuing Property Records (PICS/DCPR), the Total Network Data System (TNDS), the BIS Communications System (BISCOM), and the White Pages Directory System (DIR/ECT).

TIRKS and PICS/DCPR have an intimate interface since PICS/DCPR carries the inventory and usage of the plug-in equipment that TIRKS specifies in the circuit order process. TNDS generates the forecasts on which fundamental and current planning is based. TIRKS, PICS/DCPR, and TNDS provide a complete trunk and special-services operating system that covers the spectrum from daily operations in the circuit provision bureau to long-term provision of equipment and facilities in the construction program. TIRKS also interfaces with BISCUS/FACS for special-service circuit orders. In addition, TIRKS will be a source data base for some of the Operations Support Systems such as CAROT, CMS-1A, CMS-2A, and others designed to support the maintenance activities of the network operations forces (see Chapter 16). BISCOM provides the message communication capability to support BISCUS/FACS and the other systems. The interrelations of these systems are illustrated in Fig. 15-4.

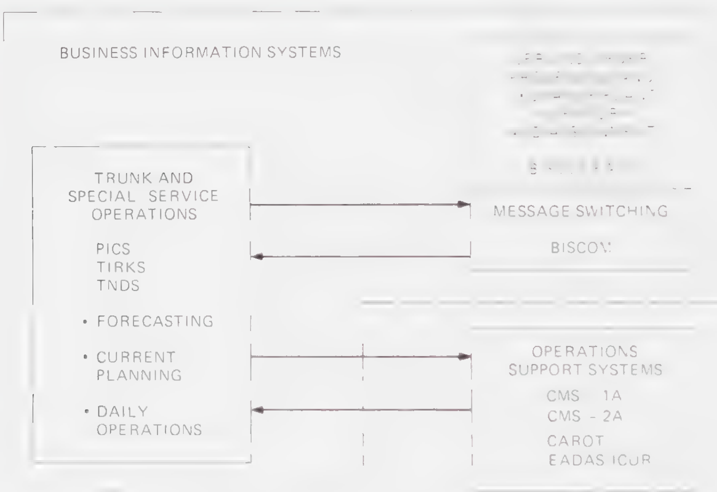


Fig. 15-4. System Interfaces

15.5.1 BISCUS/FACS

BISCUS/FACS maintains an inventory of central office and outside plant facilities and assigns these facilities to service orders. BISCUS/FACS can handle all central office and outside plant assignments that do not require a customized design. The basic input is the service order, which specifies the customer's requirement (top half of service order in Fig. 15-1), and the basic output is the specification of outside plant and installation instructions to provide the service (bottom half of Fig. 15-1). If a custom design is required, the orders are processed manually.

15.5.1.1 An Overview of BISCUS/FACS Functions

A major function of BISCUS/FACS is to maintain the inventory tables required to provide local service. These include:

(1) Cable plant by pairs, complements, and routing.

(2) Terminals by location and, within each terminal, pairs served by binding-post designation.

(3) Central office line and number equipment.

To meet the requirements of the service orders, assignments are made automatically from these inventories as follows:

(1) Cable pair assignment is based on a process that first identifies the serving terminal by its proximity to the customer street address. A spare pair in a complement having access to that terminal is then assigned.

(2) If no spare pairs have access to the serving terminal, alternative assignments based on cable-pair transfer and/or alternate terminal usage are made.

(3) Central office line and number equipment is assigned to each order. Auxiliary equipment, such as message registers or auxiliary line relays, is assigned when required.

In the process of maintaining inventories and making assignments, a number of control checks are made, frequently resulting in report production. These include:

(1) A check for existing assignments at the address shown on the order. If an existing assignment is found and the new order does not specify an additional line, an interfering station notifier is sent.

(2) Disconnected telephone number control. This minimizes reuse of numbers that are still listed in the directory or for which billing accounts still may be open.

(3) Cable and terminal administrative capacity check. Inventory records of cables and terminals are checked regularly, and notifiers are issued when administrative capacity is reached. Cable fill data are available on request.

(4) Load balance administration. Traffic usage data are used to provide up-to-date load balance conditions; assignments are then made to the least-loaded line group.

The inventory, assignment, and control functions described above are carried out under a set of administrative routines. The most important of these are as follows:

(1) Unassignable order process. When an order cannot be fully assigned by the system, notifiers are provided to responsible departments. When additional information is supplied to the system, normal assignment processing continues.

(2) Worksheet output. Worksheets are generated as a result of a "request for worksheets" when physical work is required to complete a transaction; e.g., engineering work orders (EWO) or central office work orders (CWO).

(3) Manual assignment. Assignments may be performed manually during system emergencies. There are also manual assignment procedures for services assigned by BISCUS/FACS that must be changed to satisfy transmission or supervision requirements.

(4) Input message edit. When a transaction is received and before the data base is changed or work order copies are issued, the data contained in the transaction are checked for integrity and completeness. Checks against the existing records in the data base are made for consistency. Early error detection reduces the chance of a more expensive correction later.

(5) Error control. All errors are processed by a single subsystem, which monitors an error file to ensure that each error is corrected. The subsystem also accumulates data for management analysis of error patterns.

(6) Pending-order control. All transactions pending against the system (facility requests, facility work orders, CWOs, and EWOs) are monitored and delivered for action according to the due date. Notices are sent when appropriate to minimize delays. Facility requests held for lack of facilities are monitored and released for assignment when facilities are available. Assignments are changed from "pending" to "in effect" when the telephone installer inputs the completion order to the service order system, and the appropriate information is relayed to BISCUS/FACS.

15.5.1.2 BISCUS/FACS in an Operating Company Environment

Fig. 15-5 illustrates conceptually how BISCUS/FACS fits into an operating company environment that includes mechanized service order preparation.

Service orders are input to BISCUS/FACS through the service order interface subsystem. The input may come from the operating company's mechanized service order processor or from the manual order group. BISCUS/FACS responds with service order assignment data and worksheets which are distributed to the operating departments for implementation.

Work orders for the acquisition or rearrangement of inventory are input by the appropriate operating department through the BISCUS/FACS personnel subsystem. BISCUS/FACS evaluates the changes in terms of customer assign-

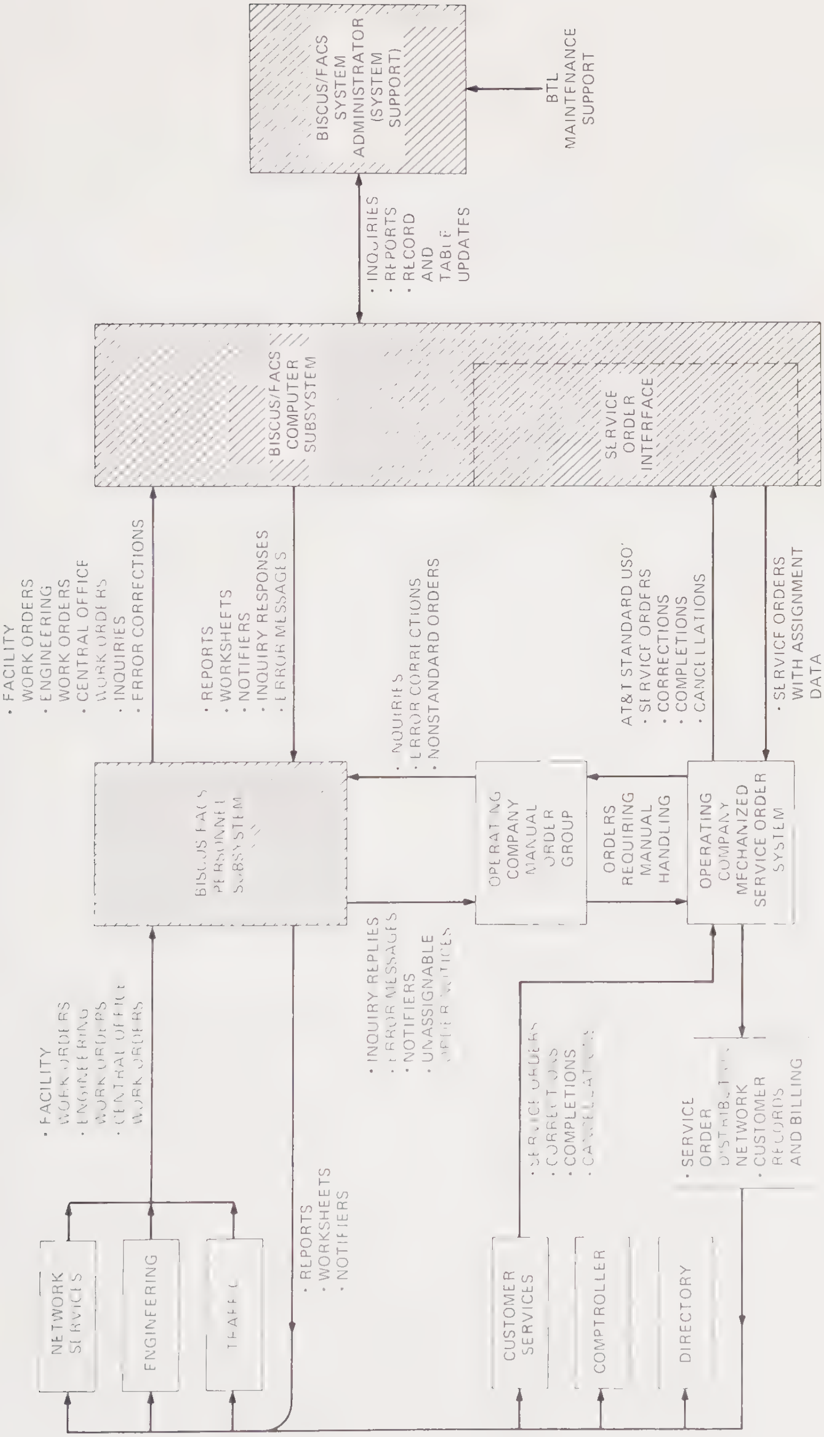


Fig. 15-5. BISCUS/FACS System Operation

ments and issues orders for reassignments if necessary. When construction work is complete, BISCUS/FACS changes the status of the new or changed facilities from "pending" to "in effect."

A manual order group is maintained in the operating company and supports BISCUS/FACS by handling orders requiring manual assignment. Input to this group is a manual service order, an output from the mechanized service order system, or a BISCUS/FACS request for more information to complete an assignment,

In an operating company, the BISCUS/FACS system administrator is the interface point for system support from Bell Laboratories. Such support could take the form of software updates, revisions to system documentation, or assistance with troubleshooting. Nonroutine inputs within the operating company also would be made through the system administrator.

The interface between the service order processor and BISCUS/FACS is the only interface with a mechanized system presently included in BISCUS/FACS. Service orders are treated the same as any other BISCUS/FACS transaction, except that errors are returned to the service order processor for correction. To use this interface, the operating company's service order processor must use standard service order entry codes. Alternatively, the operating company must provide an order entry code translator.

The major benefits to be derived from use of BISCUS/FACS in an operating company are:

(1) Customer service will be improved by faster, more accurate processing of service orders in plant assignment centers.

(2) Computer monitoring of usage levels and more accurate forecasting of facilities will result in more timely relief of congestion and, thus, better use of capital.

(3) Benefits are realized by more efficient use of plant assignment, dial administration, and frame forces.

(4) Management control over new and existing plant will be improved through more timely and accurate fill data, dynamic line equipment assignment, and mechanized load balance administration.

(5) Facility assignment and inventory procedures will be standardized, thus minimizing the necessity for duplicate practices and training materials and providing a standard for interfaces with other computer-based systems.

15.5.1.3 Personnel Subsystem of BISCUS/FACS

The personnel subsystem required for BISCUS/FACS in the operating company is divided into three areas. Two of these, dealing with computer operations and with other operations within the BISCUS/FACS boundary, are developed by the BISCUS/FACS design team. The third deals with related operations beyond the system boundary and must be developed by the operating company. Fig. 15-6 illustrates this division.

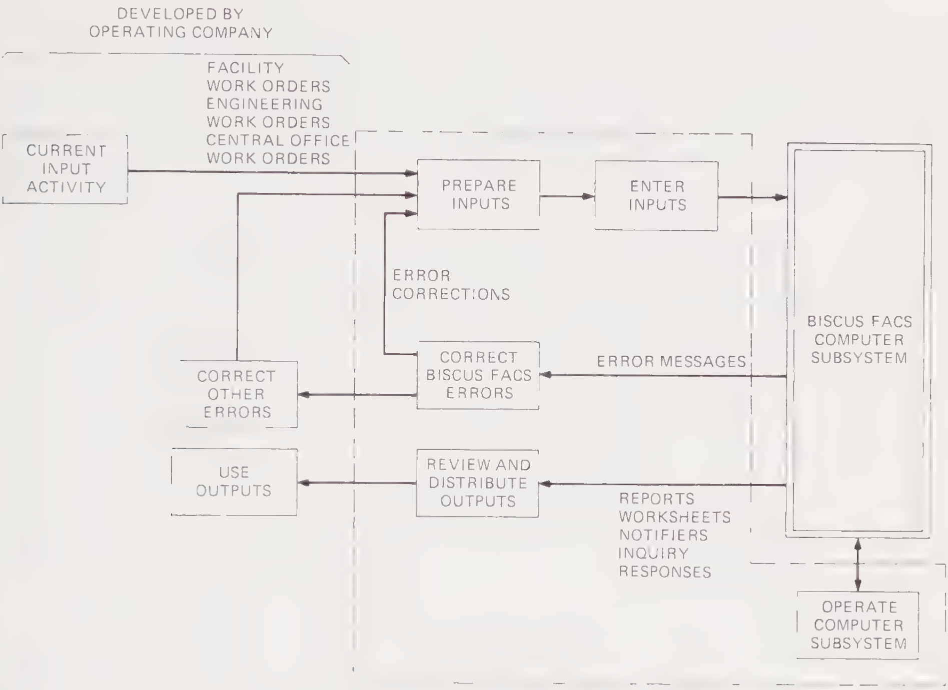


Fig. 15-6. BISCUS/FACS Personnel Subsystem

The operations dealt with by these three areas are:

(1) Computer center operations. BISCUS/FACS provides standard operations documentation for BISCUS/FACS application programs. This documentation is used in conjunction with vendor-supplied manuals and other application-independent documents.

(2) Other operations within the BISCUS/FACS boundaries. The BISCUS/FACS design group provides the complete personnel subsystem for these operations, including administrative guides, position practices, and training packages described in more detail subsequently. A position is a unit of manual work that must be assigned and performed as a whole, not fragmented among several workers. A position practice is a function-oriented document that describes the work to be done.

(3) Operations beyond the system boundaries. The operating company, in conjunction with AT&T, is responsible for design, documentation, and training for these operations. BISCUS/FACS input/output refer-

ence manuals specify the requirements that must be met to interface with BISCUS/FACS.

In general, BISCUS/FACS manual procedures include receipt of a transaction request, analysis of the request, preparation of the necessary computer input, investigation of discrepancies, correction of errors, and review and distribution of printed outputs. In addition, procedures are included to process service orders for which manual intervention is required to complete the assignment process and to provide manual backup in the event the computer is unavailable. Boundaries of these areas are established by analysis of manual functions and tasks.

Several types of documents reflect the BISCUS/FACS personnel subsystem design. They serve as system documentation for maintenance purposes and also ensure adequate performance of the personnel subsystem. These documents include position practices, administrative guides, training materials, and transaction-oriented input/output manuals.

Position practices provide step-by-step instructions that are supported by exhibits, performance aids, guides to error identification, and corrective procedures. A flowchart shows how the work encompassed by each position is related to the other positions and to the computer subsystem.

Administrative guides provide the information and procedures needed to manage the operations within the BISCUS/FACS boundaries. These contain information such as:

(1) Overviews of positions, with emphasis on work flow within each position, between positions, and between the personnel and computer subsystems. These overviews include a detailed flow diagram of system interfaces, identification of input/output requirements, schedule requirements, priority of input from (and output to) other systems, and lists of applicable performance aids.

(2) Qualifications for personnel assigned to the various positions, and estimates of the number of people required to perform a given volume of work. Job performance criteria and assessment procedures also are included.

(3) Control procedures, including those required to monitor personnel subsystems operations and to use reports produced by the computer subsystem to monitor total system performance.

Training material is provided to help ensure that the people who constitute the personnel subsystem will function in accordance with the system design. This material includes:

(1) Instructor guides, which describe course content and material, scheduling sequences, student and instructor prerequisites, and testing and evaluating procedures.

(2) Course material, such as course objectives, student and instructor texts, presentation material, practice exercises, and tests.

(3) Training administration guides, which describe courses briefly and relate them to specific positions or functions.

Transaction-oriented input/output manuals provide information on transactions, e.g., engineering work orders. They help define the interface needed by the operating company to develop the personnel subsystem outside the BISCUS/FACS boundaries. Typically, input/output manuals contain information such as:

(1) A general description of the transaction.

(2) Transaction components, including transaction codes and types, transaction identification, function codes, and action codes.

(3) Data field, code, and code set specifications.

(4) Format rules.

(5) Error output descriptions and correction procedures.

(6) User-initiated change rules and procedures.

(7) Descriptions of other outputs (notifiers and reports).

(8) Descriptions of the effect on system processing of parametric data (tables) provided by the operating company.

15.5.1.4 Computer Subsystem of BISCUS/FACS

The BISCUS/FACS computer subsystem uses a UNIVAC 1100 computer and is designed to provide an orderly hardware growth from the initial installation through all conversions to the final configuration. The final arrangement is dependent upon a number of factors, the principal ones being transaction volumes, ratio of business to residence lines, and number of main stations. This latter number can vary from 500,000 to 1,500,000, depending mainly upon the first two factors mentioned and the size of the area served. This interdependence makes hardware planning rather complex, and an operating company must deliberate carefully to determine the final configuration required. Typically, a complete BISCUS/FACS entity includes the following major components:

(1) A UNIVAC 1100 Series multiprocessing computer system utilizing a common operating system and sharing common memory.

(2) 98K 36-bit words of high-speed main memory, and 262K words of extended memory.

(3) A mixture of high- and medium-speed magnetic drums for high-usage program modules (executive routines, frequently referenced tables, application programs, etc.).

(4) Magnetic disc storage for the bulk of the BISCUS FACS data base.

(5) Magnetic tape facilities for system auditing, recovery provisions, and operating system generation.

(6) Hard-copy input/output equipment, including line-printing and card-reading devices, used primarily to support installation activity and system report generation.

15.5.2 TRUNKS INTEGRATED RECORDS KEEPING SYSTEM (TIRKS)

In recent years, there has been a dramatic increase in the size and complexity of the Bell System in its daily operations. While the number of trunks for telephone service has increased tremendously, a substantial portion of the increase in the Bell System plant has been in special-service circuits. As indicated in Section 15.3, the circuit provision operation is a complicated process; it has outgrown manual methods and requires mechanization for efficient use of inventory and personnel. As the volume of records increases, the inadequacies of the manual record-keeping systems cause a number of adverse effects, among which are:

(1) Increasing errors in assignment and inventory records reduces the utilization of the inventory and causes inefficiencies in central office work operations.

(2) Slow manual processing causes delays in meeting customer service dates.

TIRKS has been developed to mechanize circuit provision functions including circuit order control, circuit design, selection and assignment of equipment and facilities, and work order generation and distribution. In addition, TIRKS is an inventory control system that keeps track of equipment changes in central offices and changes in interoffice trunking. The objective of TIRKS is to mechanize the circuit provision, inventory management, and resource provision functions as depicted in Fig. 15-2. The inventory controlled in TIRKS consists of hard-wired terminating and signaling equipment, trunk relays, traffic usage registers, cable pairs, cable carrier systems, etc. Basically, TIRKS has inventory data on all assignable components for trunks and special-service circuits. The Plug-in Inventory Control System/Detailed Continuing Property Records (PICS/DCPR) maintains records of plug-in equipment and interfaces with TIRKS in the circuit provision process. Fig. 15-7 shows the major subsystems within TIRKS.

TIRKS consists of seven conversion and four ongoing TIRKS modules. The conversion packages provide programs and procedures for physical inventory

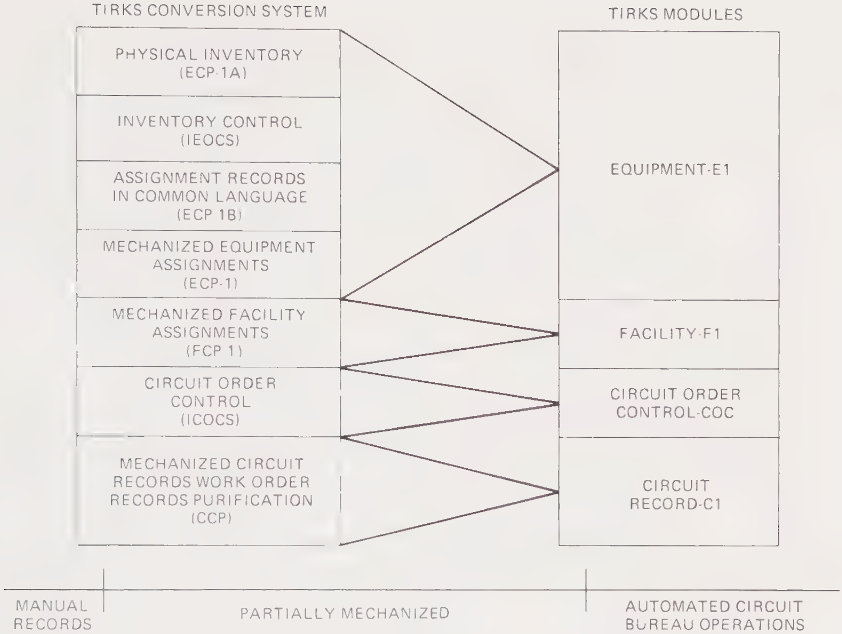


Fig. 15-7. Trunks Integrated Records Keeping System

of the terminating and signaling equipment in each office. The inventory control packages keep a record of equipment orders and retirements. Assignment records are supported in two subsystems, one of which is directed toward creating assignment records, and the other, a minicomputer subsystem, provides on-line access to the equipment inventory in each office and facilitates the selection and assignment of spare equipment. Another minicomputer subsystem provides on-line CRT access to records of the cable pair and carrier facilities between offices. A circuit order control system tracks the circuit order and requires positive completion reporting from plant. Another module, the circuit conversion package, mechanizes the circuit records and provides programs and procedures for record purification. The seven conversion systems support all the elements of the full TIRKS operational system and enable an operating company to phase into mechanized operations from paper records and manual procedures.

The four TIRKS modules related to equipment, facility, circuit orders, and circuit records replace the TIRKS conversion packages. The TIRKS modules provide additional capabilities in inventory control, mechanized circuit design, circuit order tracking and design, long-term equipment and facility provision, and work order generation and distribution. The system is supported by an IBM 370/158 computer for an average-size company. TIRKS is an on-line system accessed by CRTs for transaction processing. The average number of transactions handled daily will be between 50,000 and 150,000, depending on the size of the company, and the data base will range between 3 billion and 7 billion characters.

Benefits to operating telephone companies using TIRKS are improved utilization of equipment and facilities and more efficient use of personnel. The TIRKS data base is a very large and rich data base in terms of its use. Not only does it support the operational processes related to circuit provision operations, but also it generates hundreds of reports that enable management to control inventory, assess effectiveness of service provisioning, provide division-of-revenue information, and provide the information used for plant extension and construction program forecasts.

15.5.3 PLUG-IN INVENTORY CONTROL SYSTEM/DETAILED CONTINUING PROPERTY RECORDS (PICS/DCPR)

The Bell System has more than 40 million units of plug-in transmission equipment worth 3 billion dollars in thousands of different locations. Use of this easily movable, modularized equipment has grown rapidly and is expected to result in an 8-billion-dollar investment by 1980. PICS/DCPR was developed to assist the Bell System operating companies in maintaining accurate and timely inventory and investment records for this quickly changing environment.

Until recently, plug-in equipment was administered on a local basis using manual records. Each local manager was responsible for determining requirements for both growth and maintenance spare units. The introduction of PICS/DCPR, with centralized control and computerized processing and record keeping, is expected to result in improved utilization of the growing plug-in inventory. PICS/DCPR is designed to increase plug-in availability and to reduce spare levels while maintaining quality of communications service.

PICS/DCPR has been designed as a total system with equal attention to both the computer subsystem and the personnel subsystem consisting of the design of human interfaces, documentation, and training materials. The design incorporates an efficient, 2-stage transition from a manual to a computerized environment.

The first stage, PICS/1, establishes a plug-in equipment administrator (PIA) with a small staff to provide centralized control of all plug-in movement, and one or more central stock facilities for collecting and storing spare plug-in equipment to make it available to all users within the company. These central stocks are populated with equipment by a recall of spare equipment from the field locations. Manual procedures and forms are then introduced for controlling the flow of new, repaired, and to-be-repaired equipment between the suppliers, the central stocks, and the field locations.

When this manual system is operating smoothly, usually within two years, a transition to a computerized system takes place (see Fig. 15-8). This ongoing computerized system, PICS/DCPR, is a large data base, on-line, interactive, inventory control system whose principal elements are the administrator and

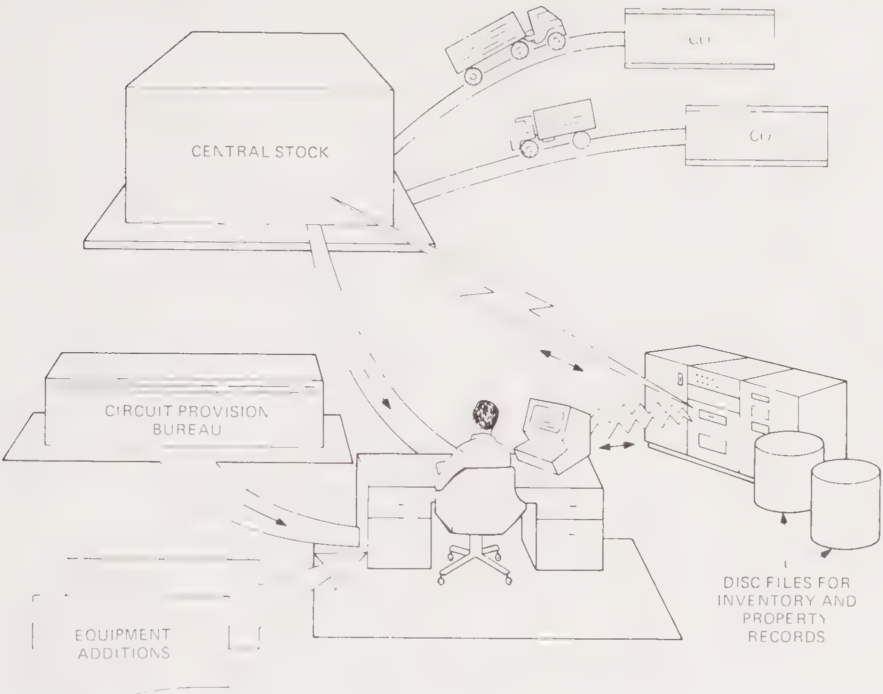


Fig. 15-8. Plug-In Inventory Control System/Detailed Continuing Property Records (PICS/DCPR)

staff, the computer and its files, and the central stock. Major inputs to the system are orders from the circuit provision bureau to connect or disconnect circuits and equipment addition records from the engineering department. Plug-ins flow from suppliers into the central stock and then are shipped to and from field locations (central offices). The system includes the following functional features:

(1) Procedures, forms, and instructions for a physical inventory of all plug-ins in each central stock and field location are provided together with conversion and load programs for initial loading of the computer inventory and investment files.

(2) Detailed inventory records of the quantity of each type of plug-in, for each central stock and for each field location, together with the status of each item (working, growth spare, or maintenance spare) and a detailed property or investment record of equipment cost are maintained on direct-access, secondary-storage devices.

(3) Procedures to monitor and control the acquisition, utilization, movement, repair, and retirement of plug-in equipment are initiated by

on-line transactions with the computer. A key procedure is a hierarchical search of the inventory files for satisfying plug-in requirements at any field location.

(4) Inventory algorithms are introduced to identify overstock and understock conditions together with recall or reorder recommendations.

(5) Numerous reports, with varying degrees of detail, can be obtained periodically to show the current status of plug-in equipment for selected administrative areas within a company.

PICS/DCPR is designed to run on IBM computer equipment. Software consists of approximately 200 on-line, interactive programs and over 300 batch COBOL programs. These programs generate over 8 million bytes of object code. A typical operating telephone company will have 20 to 30 on-line CRT terminals to process an average daily load of 5000 to 6000 transactions involving plug-in equipment. These transactions will result in the generation of about 350 notices to ship or to use existing plug-ins.

Over 400 personnel subsystem user documents were developed to support PICS/DCPR installation. These documents fall into four major categories: planning and installation, training, user operations, and computer operations.

15.5.4 TOTAL NETWORK DATA SYSTEM (TNDS)

The purpose of TNDS is to provide the operating company personnel responsible for traffic engineering, network administration, network management, and force administration with network data that will permit efficient, accurate planning and management of the telephone network (see Chapter 14). TNDS is a coordinated set of subsystems that mechanizes the process of gathering, sorting, and processing network data. The subsystems are listed in Table 15-1.

15.5.4.1 TNDS Data Gathering Subsystems

The TNDS subsystems that gather data from the switching and operator systems and sort it for subsequent use are: the Engineering and Administration Data Acquisition System (EADAS), the major collection vehicle for central offices; EADAS/Network Management (EADAS/NM), the primary network management subsystem; the Traffic Data Administration System (TDAS), which receives, sorts, stores, and routes traffic data to other downstream systems; CDO/PBX data processing; point-to-point data collection options; and the Automated Force Administration Data System (AFADS), the operator data subsystem.

Engineering and Administration Data Acquisition System

Under control of a central processor, EADAS (see Section 14.8.1) collects traffic data automatically from electromechanical and electronic switching systems and from some operator systems over a combination of dedicated and

TABLE 15-1
SUBSYSTEMS OF TOTAL NETWORK DATA SYSTEM (TNDS)

DATA GATHERING SUBSYSTEMS

EADAS — Engineering and Administration Data Acquisition System

EADAS/NM — EADAS/Network Management

TDAS — Traffic Data Administration System

AFADS — Automated Force Administration Data System

CMDS — Centralized Message Data System

CDO/PBX Data — (Under study)

Local Point-to-Point Data — (Under study)

NETWORK ENGINEERING AND ADMINISTRATIVE REPORTING SUBSYSTEMS

COER — Central Office Equipment Reports

COEES — Central Office Equipment Engineering System

LBS — Load Balance System

TSS — Trunk Servicing System

TFS/TRS — Trunk Forecasting System and Traffic Routing System

SSFS — Special-Service Forecasting System

ICAN — Individual Circuit Analysis

IFAMS — Integrated Force Administration Mechanization System

CU — Common Update (updates record files for many of the TNDS subsystems)

dial-up voice-grade data links. For downstream use, EADAS sums the data and, at regular intervals, outputs the data on a magnetic tape for subsequent input to TDAS. For network management purposes, EADAS provides 5-minute sums of selected data to EADAS/NM and also passes alarm and control information between EADAS/NM and switching systems. EADAS processes the data for network administration to provide reports on selected parameters as well as routine and demand reports on the condition of the switching offices and data flow.

EADAS can be arranged for individual circuit usage recording (ICUR). The acronym ICUR relates to an EADAS option by which usage measurements of individual circuits are acquired using existing 4A traffic usage recorders. Usage data, detected on an individual circuit basis, have heretofore been grouped into circuit-group usage data by using a hardware cross-connection field at the TUR output. With the ICUR option, this circuit-grouping cross-connection field is removed and replaced with a software grouping map at the EADAS processor.

EADAS/Network Management

The EADAS/NM subsystem provides a means to establish network management control centers having surveillance over both local and toll networks. Using EADAS traffic data and other network status information, EADAS/NM continually scans the network for congestion problems which it reports to the network manager on an exception basis by operating wall displays organized for the portion of the network under surveillance. EADAS/NM can be arranged to exchange selected data with other EADAS/NM centers by way of the network operation center (NOC). This data will increase the network surveillance capability of each individual EADAS/NM system and will provide source data for the new NOC that will maintain overall surveillance of the national network.

Traffic Data Administration System (TDAS)

TDAS is a batch-process subsystem whose function is to administer the traffic data flow primarily on behalf of the downstream user subsystems. From data requests and schedules supplied by each user, TDAS generates data collection schedules for EADAS and for other data collection subsystems, so as to coordinate and minimize the data to be collected for all users. TDAS accepts data that arrive by magnetic tape, paper tape, or punched card and, in accord with user requests, sorts, labels in common language, stores, and finally outputs the data in the proper format expected by each downstream user subsystem. Thus, TDAS acts primarily as a warehouse for data and performs no operations on the data other than to ensure elementary validity and proper labeling.

To avoid a troublesome source of error, TDAS must agree with EADAS (or with any other data collection subsystem) on the assignment of each traffic register, i.e., upon the meaning of the number recorded by each register. Thus, TDAS must have access to translation tables enabling it to label each piece of data it receives. TDAS relies on the Common Update (CU) subsystem for input of translation information of this type which must be kept current with the physical assignment of measurement leads in the switching offices.

CDO/PBX Data

Traffic data are needed from community dial offices (CDOs) and the larger PBXs for administration and engineering purposes. Historically, mechanized data acquisition costs have been too high for these smaller switching systems. Bell Laboratories is beginning to plan data collection for this large source of traffic data.

Automated Force Administration Data System (AFADS)

AFADS (see Section 14.9) serves as a data acquisition system, a data processor, and a data distribution system for operator services systems. AFADS collects usage and peg count data via switched or dedicated connections from READ (remotely accessible data) terminals or their equivalents, which electronically store counts from electromechanical systems, or directly from electronic systems.

Periodically, the AFADS processor begins a polling cycle through the operator services complexes served. Once a channel is established to a given complex, data are transmitted from the complex to the processor. The processor computes the FADS load/service and force results and a forecast of operators required for the next period. These results are returned to the complex's force center, and the channel is dropped.

Point-to-Point Data

Point-to-point data are used to postulate new trunking configurations. For the toll trunking portion of this task, data from the Centralized Message Data System (CMDS) are used.

CMDS accumulates a 5-percent sample of all toll telephone messages from the automatic message accounting (AMA) tapes that are transmitted daily from each regional accounting office to a Long Lines central processing facility. The sampled message records are converted to toll point-to-point conversational loads and output on tapes. These tapes, corrected for nonconversational usage, provide the basic information required to determine new trunking candidates.

For local point-to-point traffic data, the sources are not as well defined and are still under study.

15.5.4.2 TNDS Network Engineering and Administrative Reporting Subsystems

The TNDS subsystems that process network data to produce the necessary engineering and administrative reports are the central office equipment reporting systems; the Central Office Equipment Engineering System (COEES); the Load Balance System (LBS); the Trunk Servicing System (TSS); the Trunk Forecasting System and Traffic Routing System (TFS/TRS); the Special-Service Forecasting System (SSFS); the Individual Circuit Analysis (ICAN) program, which performs administrative and usage analysis of individual circuit traffic data; the Common Update (CU) program, which maintains the data base for most of the TNDS downstream processes; and the Integrated Force Administration Mechanization System (IFAMS), which produces operator forecasts, schedules, and force planning information.

Central Office Equipment Reporting Systems

Central office equipment reports (COER) is a generic term that is applied to the reports used by both the traffic engineer and the network administrator. For each report, extensive validation checks are made and doubtful results are marked. Simple calculations also are made. These consist of conversion from peg count and overflow count into percent overflow. In addition, more complex computations, such as theoretical estimates of peak-day traffic to compare with measured peak day, are performed. Certain of these reports enable the network administrator to assess the overall service of an office as well as trend information to predict future service criteria. Other reports provide component busy-hour, busy-day, and busy-season measurement to permit the traffic engineer to assess office capacity and to forecast future needs.

At present, it is planned that both the No. 4 ESS and the No. 4A ETS COER reports will be produced on-site, since these large toll machines have internal or associated processing capacity. For other electromechanical switching systems, TDAS accumulates traffic data, and reports are produced at a centralized batch processing location.

The No. 1 and No. 2 ESS reports are produced by the Program for the Administration of Traffic Reports On-Line (PATROL), which is a system combining batch and time-shared processing. PATROL's input data are obtained from EADAS/TDAS. PATROL's data base can be accessed directly over a dial-up link. Since PATROL is an experimental system, it may be superseded by a system referred to as No. 1 and No. 2 ESS COER. The COER function for CDOs and PBXs is presently being studied.

Central Office Equipment Engineering System (COEES)

COEES programs support equipment engineering for No. 1 and No. 2 ESS and No. 5 Crossbar Systems and are divided into several categories according to their functions: sizing, pricing, and economic evaluation. Equivalent programs are available for No. 4 ESS and No. 4 Crossbar switching systems. The sizing programs first calculate the equipment quantities required to serve expected customer demand at management objective service levels.

The pricing programs apply broad gauge cost factors to required items of equipment, providing estimates of Western Electric billing charges for engineering, furnishing, and installing equipment. Results include capital costs for engineering, furnishing, and installing equipment and operating costs for engineering and rearrangements of lines and trunks.

The economic evaluation program applies established engineering economics principles to produce present-worth analyses of the possible alternative jobs for four busy seasons considering calculated exhaust dates and equipment quantities and associated costs.

COEES outputs are used to decide which jobs should be included in the construction budget. The traffic engineer and the equipment engineer then generate the traffic order (internal operating company document) and the telephone equipment order (equipment production authorization). The mechanization of these latter two tasks is a major enhancement for COEES.

Load Balance System (LBS)

LBS computes the load balance index on a central office basis and on a company-wide basis. In addition, LBS provides corrective reports that indicate the location and magnitude of the existing imbalance. Also, the LBS can provide corrective reports on nonindexed equipment, e.g., trunk link frames.

Trunk Servicing System (TSS)

TSS processes peg count, overflow, and usage measurements on trunk groups in the public telephone network to provide a data base for trunk engineering and to compute service levels and trunking requirements to assist in trunk administration. TSS is a batch process designed to run on a weekly basis using hourly data supplied by TDAS. Common language circuit identification, network characteristics, and servicing parameters are supplied by the Common Update program. Common Update also maintains the trunk-group base loads developed by TSS that are required as input to TFS/TRS. TSS provides the over- and under-loaded trunk-group reports and the trunk identification records. In the future, TSS will perform a busy-season trunk-group base load selection and will provide the AT&T Monthly Trunk Service Report and the AT&T Annual Busy-Season Report.

Trunk Forecasting System and Traffic Routing System (TFS/TRS)

TFS is a batch process that produces forecasts of trunk requirements, both local and toll, for five years to assist in the determination of future trunking requirements. TFS uses trunk-group base loads as determined by TSS, office growth factors, and trunk-group projection ratios to produce its forecasts. The Common Update program supplies the data base for circuit identification, network configuration, trunk-group base loads, and forecasting parameters.

TRS is presently being developed as an enhancement to TFS. TRS will assist in the identification of new trunk groups and will estimate the traffic that would be diverted to these groups. As a result, it will indicate the new traffic routes for TFS. Using local and toll point-to-point information, combined with measured base load and network busy-hour data from TSS, TFS/TRS will project this information and develop route candidates.

Special-Service Forecasting System (SSFS)

SSFS is a batch process that produces 5-year forecasts of interoffice special-services point-to-point requirements. The forecasts are for use in future facility provisioning. SSFS uses a history of the demand for special services. It is an interactive system requiring manual modification of forecasts whenever historical trends do not adequately forecast the future because of changes in the economic climate, company tariffs, service offerings, etc.

The history data for SSFS can come from a record of circuits in service such as is available in TIRKS.

Individual Circuit Analysis (ICAN) Program

The ICAN program is a batch process that reads and processes the data on the ICAN tape produced by EADAS/ICUR. The two major functions performed by ICAN are administration analysis and usage analysis. Administration analysis helps to ensure the integrity of the EADAS/ICUR circuit-grouping map. Usage analysis is used primarily to detect equipment faults. It identifies abnormal load patterns observed on individual inputs to the traffic usage recorder.

Common Update (CU)

CU is the centralized record-keeping process for many of the TNDS downstream processes. This process uses basic input documents to establish and maintain data base files in common language format on data collection equipment, trunk groups, and other data pertinent to those programs that utilize CU.

A mechanized interface between CU and TIRKS is being developed to reduce the duplication of manual transactions in the updating process when both systems are employed by the same operating company.

Integrated Force Administration Mechanization System (IFAMS)

IFAMS is a set of time-share programs that provides force managers with operator forecasts, schedules, tour allocations, operator assignments, and long- and short-range force planning information.

15.5.4.3 The Future of TNDS

TNDS is composed of many subsystems that have been developed, are now being developed, are planned for development, or are under study. The goal of TNDS is to provide all users with timely, economical, and reliable information required to manage, administer, and engineer the network. It is expected that TNDS will continue to develop as field needs are clarified and technological opportunities arise.

15.5.5 BIS COMMUNICATIONS SYSTEM (BISCOM)

Most of the systems described in this section require many different types of input/output terminals at a wide range of locations. Interconnection of these terminals with each other and with the associated computers is a major challenge. A message-switching system, BISCOM, has been developed to resolve this matter. BISCOM operates on a store-and-forward basis; that is, a message is input to a computer which examines the message header to determine the characteristics of the message and its addressee(s). Having had the network and its characteristics predefined, the computer now is able to translate the message into the appropriate code and queue the message for delivery to the proper terminal at the proper speed whenever the terminal is available.

BISCOM can be configured to provide a wide range of message capacities up to 240,000 600-character messages per day. This capacity range allows consideration of BISCOM for many purposes including service order preparation and distribution, as well as corporate administration. In addition to resolving the problems of interconnection, BISCOM provides the following benefits:

(1) Message control, through message numbering and time and date stamping.

(2) A resend file from which previously delivered messages may still be retrieved.

(3) A file in which messages may be stored, replaced, and retrieved by predesignated stations.

(4) Dynamic changes to the network such as polling list changes, alternate delivery, etc.

(5) Broadcast capability.

15.5.6 WHITE PAGES DIRECTORY SYSTEM (DIR/ECT)

The preparation of directory information is one of the main peripheral functions associated with service order post-completion processing. This includes both listings in the next directory to be issued and update listings for use by directory assistance operators.

One of the main problems in directory preparation is the magnitude of the task. The total directory volume in the Bell System is 80,000,000 listings in 2250 directories, of which 170,000,000 copies are printed each year. An average telephone operating company could have 3,000,000 listings, subject to 10,000 changes per day. Errors and delay in manually processing this quantity of changes are significant. The manual preparation of lists from which hard type can be set results in a slow preparation process. As a result, the listings must be "frozen" for an excessively long time prior to printing.

Today, an increasing number of operating companies are using a computer-based system, DIR/ECT, to resolve these problems. Fed by post-completion service order data, DIR/ECT uses certain customer information to build and maintain a telephone master file. Directory assistance updates are produced daily. At appropriate intervals, the information from the telephone master file is reformatted to produce magnetic tapes which, in turn, drive a photocomposer. This produces master pages for White Page customer directories and revisions of directory assistance sheets. Directory delivery lists, address labels, and address telephone directories also are produced by DIR/ECT.

DIR/ECT resolves most of the problems associated with the manual preparation of directory information. In particular, it:

(1) Allows greater flexibility in rearranging directories.

(2) Provides a much shorter "freeze" interval, resulting in more accurate directories.

(3) Reduces clerical and printing costs.

(4) Keeps directory assistance information current.

(5) Produces more readable directories.

15.6 COMPUTER TECHNIQUES FOR PLANNING AND ENGINEERING

The intent of this section is to broaden the understanding of provisioning by describing some additional applications of computer techniques used in the planning and engineering of facilities. The basic aim of planning and engineering is to provide transmission and switching facilities to meet the growing demand for communication services at the lowest possible long-term cost. Computer techniques used in planning and engineering exchange facilities are significant because of their importance in telephone company operations and because they represent an area in which computers were used quite early. Computer techniques exist for planning and engineering other parts of the facilities network, but for brevity, they will not be discussed here.

From the discussion in Section 5.3 of the structure of local and exchange facilities, recall that facilities in an exchange area generally consist of a number of wire centers, each connecting with customers via 2-wire loops in cables and with neighboring wire centers via trunks in cables. Fig. 15-9 illustrates an exchange area. The loop network is made up of feeder, lateral, and distribution cables. Feeder cables fan out from the wire center in tree-like networks known as feeder cable networks or feeder routes. Distribution cables terminate at individual residence and business locations and are brought together into lateral cables that connect into the feeder cable network. Fig. 15-10 is a simplified illustration of a loop cable network indicating the feeder, lateral, and distribution components.

Wire-centering studies are a good example of planning. New wire centers must be planned well in advance to meet the growing demand for service. Two computer programs have been developed as tools for use in wire-centering studies. The Mechanized Wire-Centering Cross-Section (MWC/CS) program determines the optimum location for a given number of proposed wire centers and serving area boundaries at a particular time in the future; that is, a cross section in time. The Mechanized Wire-Centering/Present Worth of Annual Charges (MWC/PWAC) program uses the results of MWC/CS to determine the year-by-year plan for establishing new wire centers and their serving areas.

The strategy developed in wire-center planning is implemented by a series of construction programs, which are preceded by more detailed engineering studies. A number of computer programs have been developed to enable operating company engineers to carry out these studies thoroughly and efficiently. Three of these engineering programs will be described: Exchange Feeder Route Analysis Program (EFRAP), Central Office Equipment Engineering System (COEES), and Time Share Outside Plant PWAC Studies (TOPPS). Each of these programs is designed to make economic comparisons among alternate plans for providing exchange plant facilities. Each alternative plan is

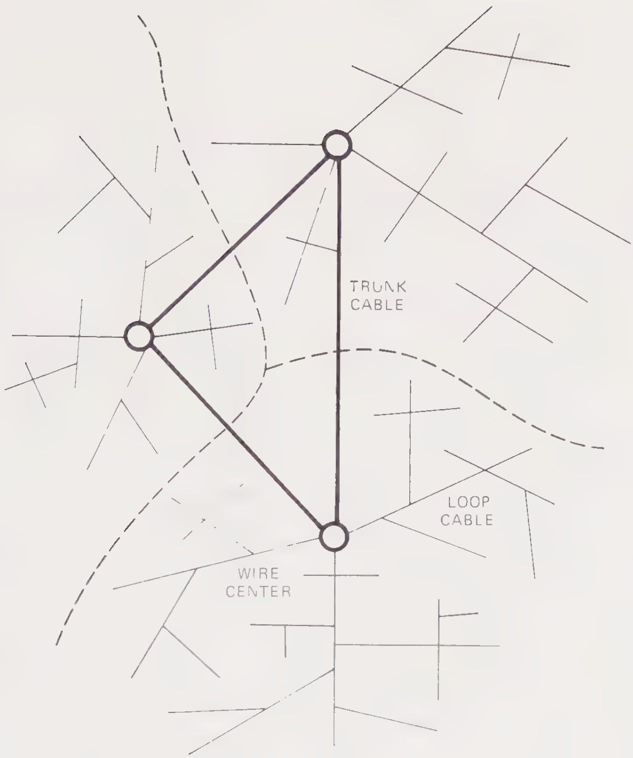


Fig. 15-9. An Exchange Area

actually a sequence of placements, removals, and rearrangements of facilities. Each component of such a sequence involves construction activity and capital expenditure. Economic comparisons are made on the basis of the present worth of annual charges (PWAC) criterion, which includes the effects of initial investment, cost of maintenance, rate of depreciation, tax rate, and cost of money. PWAC is computed as the weighted sum of annual expenditures over the study period. The weighting factors decrease exponentially with time, so that future expenditures have less effect upon the choice of alternative than earlier expenditures.

A necessary input for planning exchange facilities is an accurate knowledge of the fill status of cables. The Loop Cable Record Inventory System (LCRIS) provides this data for loop cables.

Metropolitan area transmission facilities to be used for trunks and special-service circuits are planned with the aid of the Metropolitan Area Transmission Facility Analysis Program (MATFAP).

Fig. 15-10. Loop Cable Network

15.6.1 MECHANIZED WIRE-CENTERING/CROSS-SECTION (MWC/CS) PROGRAM

The object of a wire-centering study is to choose the most economic number of, and locations for, wire centers and serving areas at a given point in time. The planner must select the most economical among the many alternatives that satisfy the projected demand. The cost of a given alternative includes the costs of loops, trunks, and switching equipment, as well as the cost of land and buildings.

Before using the MWC/CS program for the exchange network problem, the planner defines a study area, as in Fig. 15-11, and determines the years to be studied. On an arbitrary coordinate system, points are located at which forecasted numbers of customers could be concentrated, producing a discrete customer distribution. The points are usually the centers of small forecast areas studied by the operating company. Existing offices and routing points also are located. These routing points are used primarily to funnel either trunk or feeder cables through existing routes (for example, where conduit is available) or to assign specific customers to particular offices. They also can be used to indicate obstacles that must be considered in determining the cable layout. The planner also develops loop and trunk cost curves, which reflect installed cable costs in different parts of the study area.

Having defined a study area and having assembled growth forecast and cost data, the planner is ready to run the MWC/CS program. The planner must partially specify the solution by indicating which, if any, of the existing wire centers are to be discontinued, the number of new wire centers, and a set of candidate locations for new wire centers. Optionally, MWC/CS may be run in an automatic search mode, which does not require specification of candidate wire-center locations. In either case, the planner must use good judgment in defining the range of alternatives to be examined by the program.

This is true of all present engineering and planning programs. Of course, the planner may run the program several times, varying the number and candidate locations of wire centers as well as the growth and cost data each time.

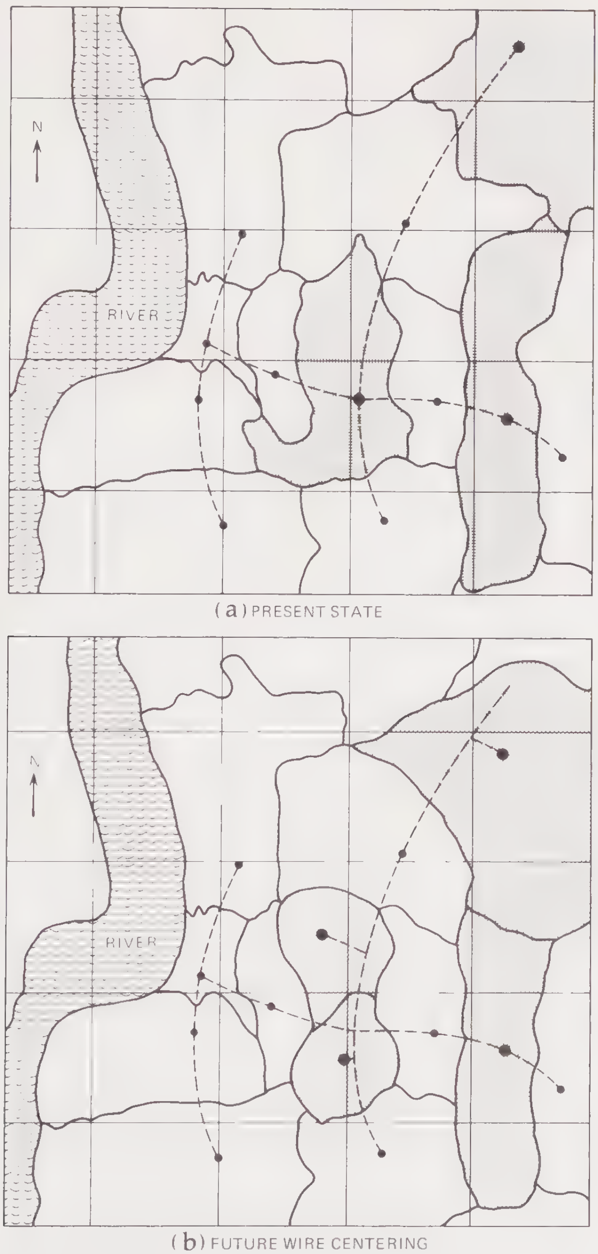


Fig. 15-11. Wire-Centering Study Area

The output of each MWC/CS run lists the cost of offices in the current arrangement and a detailed report of the most economical wire-centering plan, including customer assignments, loop costs, and trunk costs. In addition, unless the automatic search mode is used, the output includes an ordered list of the ten most economical plans, with their costs and possible savings over the present network arrangement. The choice among these plans may be based on factors not explicitly considered in the program, such as the availability of land or the amount of available floor space in existing buildings.

In the automatic search mode, MWC/CS uses an iterative optimization algorithm to converge on locally optimum wire-center locations. This technique is useful for non-metropolitan areas, where most locations in the study area may be treated as candidates. In metropolitan areas, where potential locations are scarce, the automatic search mode may be used to evaluate the penalty caused by this limitation. Moreover, the automatic search may uncover a feasible location that the planner had not considered.

The planner's decision generally is based on several MWC/CS runs. The growth forecast and cost information may be varied and the sensitivity of various solutions to these factors studied. The solution chosen will reflect the experience and judgment of the planner.

Fig. 15-11 illustrates the present state and a potential future wire-center arrangement of a study area. The central area is split and served by two new wire centers. One wire center is relocated in the eastern region, and several boundaries are realigned. Those customers who are transferred to a new wire center must have their telephone numbers changed. The interoffice trunk layout shown in the figure is considered in determining the solution.

Having completed an MWC/CS study, the planner knows the current and anticipated arrangements; but how should the latter be achieved? The Mechanized Wire-Centering/PWAC program considers this question.

15.6.2 MECHANIZED WIRE-CENTERING PRESENT WORTH OF ANNUAL CHARGES (MWC/PWAC) PROGRAM

The MWC/PWAC program determines the best time to establish a new wire center. Input data for this program include the new location and eventual serving boundaries supplied by the MWC/CS program, together with the following information supplied by the planner: a description of the installed feeder cable plant (pairs and gauges in each section of cable), a yearly growth forecast for each cable section, and the switching equipment available at each central office. The most important control parameter is the cutover year of the new wire center, because once the planner sets this time, a whole sequence of schedules for customer transfers to the new office, for cable relief jobs, and for additions of central office equipment is determined.

Assume, for example, that the planner selected 1975 as the cutover year for the new office (see Fig. 15-12). Starting with the 1970 situation, the computer program determined the yearly line requirements in each gauge for each cable

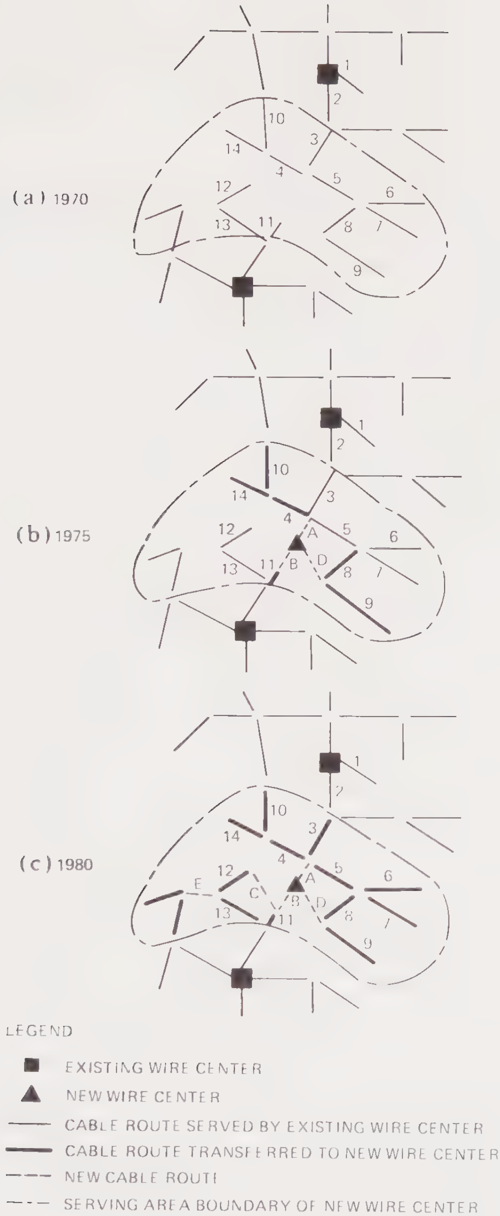


Fig. 15-12. Evolution of a Wire Center

route and compared these requirements with available facilities. If a shortage occurred before 1975, for example, in cable route 2 in 1974, relief cable would have to be provided. The program sizes this relief cable on an economic basis, consistent with gauge requirements and the fact that the demands on it will be reduced in a year, when customers currently served through this cable are transferred to the new office. [This cable-sizing procedure is similar to one employed by the Exchange Feeder Route Analysis Program (EFRAP), discussed in Section 15.6.3.]

In 1975, the new office was installed and the feeder routes indicated in Fig. 15-12(b) were transferred to it, along with new routes A, B, and D. Thus, the number of assigned feeder cable pairs in cable route 2 dropped in 1975. For each subsequent year, the program examines each cable route for shortages and, whenever possible, defers the installation of relief cable, either temporarily or permanently, by transferring customers to the new office. For example, if in 1979 route 2 is again fully assigned, route 7 will be transferred to the new office; if this does not relieve the congestion in route 2, route 6 also will be transferred, and so on, either until relief is obtained or it is obvious that the growth cannot be met by transfers. In the latter case, economic engineering of relief cable is begun.

The program also takes structural problems into account. For example, local engineering rules usually limit the maximum number of cables or pairs that may be put on pole lines. When these limits are reached, an underground conduit system is added and the program decides how many ducts are needed, another question of economic sizing. Finally, when all ducts in a conduit system are filled, the program chooses between adding another conduit or deferring conduit relief by substituting a larger cable for a small cable already in place.

Economic sizing to meet growth requirements also is necessary for central office equipment. The program determines the number of customer lines needed in each office for each year, with transfers between offices taken into account. For common-control offices, there is the added complication that at various times major units of equipment must be added to accommodate growth. By observing limits in lines, traffic loads, and attempt rates, the program suggests schedules for these additions.

The trunk network is sized for each year in the study period, considering the interoffice traffic at the beginning of the study and adjusting this traffic to reflect growth and customer transfers as the study progresses.

The planner using the MWC/PWAC program will vary the cutover year and possibly the office location from run to run, each time receiving a detailed plan for facilities required during the study period and the cost. (In our example, the planner would have investigated a cutover earlier than 1975 possibly eliminating the 1974 cable installation.) With this information and the results of the MWC/CS program, the planner will choose the appropriate site and schedule for the new office and will make plans for its integration into the local network.

Programs like MWC/CS and MWC/PWAC produce a clearer and considerably more thorough plan of how the exchange plant should grow than can be generated by manual calculations. Planning schedules can be shortened and situations restudied rapidly to keep pace with changing forecasts of customer demand. Freed from detailed calculations, the planner is better able to estimate future requirements for manpower, material, and funds. A comprehensive plan for the efficient and economical coordinated growth of cable and switching equipment in the exchange area is produced.

15.6.3 EXCHANGE FEEDER ROUTE ANALYSIS PROGRAM (EFRAP)

The feeder route is the backbone of the loop cable network. Basically, it is made up of cable, supporting structure (poles and conduit), and access points (manholes and splices). A feeder route serves part or all of the area served by the wire center from which it feeds. As demand for service grows, additional cable and supporting structure are placed in the feeder route. The operating company engineer's job is to size and time these facility additions to meet the demand at the lowest possible cost. EFRAP addresses this problem.

Prior to making an EFRAP run, the engineer makes a thorough study of the present state of the feeder route and of the forecasted growth in demand during the study period. The route is broken down into interconnected sections that are uniform throughout their length with respect to existing and future facilities. Each feeder section is associated with a segment of the serving area, because all customers in that segment connect into the feeder network at that section. The growth forecast is specified on a segment-by-segment or, equivalently, a section-by-section basis. For each section, the engineer must provide the following information:

(1) The existing facilities (the number of cable pairs, conduit ducts, etc.).

(2) The type of structure (aerial, underground, or buried).

(3) The forecasted growth.

(4) Routing information (i.e., through which sections the customers are routed to the wire center).

The engineer also must provide economic data, specifying the costs of cable, conduit, and trenching, and local engineering data, specifying various constraints on the solution (e.g., aerial pair limits).

EFRAP computation proceeds in two phases. In the initial assembly phase, EFRAP computes the yearly cable requirements by gauge for each section. These requirements are a function of the growth data and the routing scheme input by the engineer. In the study program phase, each section is analyzed separately. EFRAP computes, for each section, a sequence of placements of cable and supporting structure that satisfies the section requirements. The solution sequence is the one, among all sequences that satisfy the requirements, that has the lowest PWAC. The number of candidate sequences is huge, and therefore an efficient optimization technique, known as branch and bound, is employed to find the optimal solution without exhaustive searching.

Table 15-2 shows a cable/structure placement sequence output by EFRAP for one section. Note that the first three placements are accompanied by removals. The engineer may indicate removal candidates among the existing facilities in order to defer conduit placement. In September 1985, conduit is required, and the conduit-sizing algorithm of EFRAP chooses nine ducts as being most economical. Three additional cable placements are required to satisfy the demand during the remainder of the study period.

TABLE 15-2
EFRAP SECTION SOLUTION SEQUENCE

DATE	CABLE SIZE (NO. OF PAIRS) AND GAUGE		CONDUIT DUCTS	ANNUAL CHARGE
	REMOVED	PLACED		
1/74	100-24	1200-26		$1900
2/77	100-26	900-22		$2600
8/80	200-19	1800-26		$2500
9/85		200-19	9	$5100
1/87		900-24		$2000
12/89		600-22		$1900
6/92		200-26		$ 700
	20-Year PWAC			$64,200

As with the wire-centering programs, the engineer may make multiple runs to evaluate sensitivity to growth and facility cost changes. The engineer also may evaluate and compare different routing schemes.

The EFRAP solution serves as a starting point in determining the actual construction program. The engineer generally varies the cable size and timing in order to synchronize relief in adjacent sections and to otherwise smooth the solution. Smoothing is done to reduce complex interconnections at section boundaries and to develop a more orderly construction program. These departures from the EFRAP solution require judgment, since EFRAP does not consider all aspects of the construction process.

15.6.4 CENTRAL OFFICE EQUIPMENT ENGINEERING SYSTEM (COEES)

Central office equipment is another basic facility that must grow in discrete increments to meet continuously increasing demand. COEES is a time-sharing program that has been developed to enable the engineer to plan facility additions for central offices. It is a part of the Total Network Data System, described in Section 15.5.4, and is mentioned again here because of its role in planning and engineering exchange facilities.

The objectives of COEES are:

(1) To evaluate all possible relief plans or alternatives for a central office in a 4-year period of growth.

(2) To estimate the required equipment for each busy season when calling rates are highest.

(3) To permit engineers to determine the capability of existing equipment (or of any alternative) to handle calling traffic during a busy season.

(4) To estimate the cost of any plan and units of equipment required.

(5) To estimate the cost of selecting less economical plans.

Simply speaking, COEES may be used for plan evaluation and plan selection. The number of alternative plans is quite small in comparison with the EFRAP problem. Thus, COEES determines the optimum plan by exhaustive search without using extensive computer time. As with EFRAP, the final plan selection is made by the engineer.

The interactive nature of COEES provides the engineer with added flexibility. For example, the sensitivity of the cost of a plan to changes in the growth rate or equipment costs can be examined. This analysis can be carried out in a real-time environment. COEES is an example of a general trend toward interactive, time-shared computer programs for planning and engineering.

15.6.5 TIME-SHARED OUTSIDE PLANT PWAC STUDIES (TOPPS) PROGRAM

There is a host of engineering problems in the Bell System that are characterized by PWAC comparisons. TOPPS is a time-share program designed for use in PWAC studies of outside plant.

Unlike EFRAP and COEES, TOPPS does not perform PWAC comparisons among alternatives. The engineer makes comparisons by using TOPPS to analyze predetermined alternatives one by one.

In general, an alternative plan is a sequence of placements, removals, and rearrangements of plant items. In addition to basic economic data such as the rate of return and the length of the study period, the engineer specifies the particular plan to be analyzed. TOPPS computes annual charges for each item of plant, based on first cost, cost of money, depreciation rate, maintenance, and taxes. The total PWAC of the plan is then computed and output to the engineer. The engineer is spared from many tedious calculations involving compound interest and depreciation formulas. This frees the engineer to devote more attention to basic decision-making tasks.

15.6.6 LOOP CABLE RECORD INVENTORY SYSTEM (LCRIS)

LCRIS provides accurate and comprehensive mechanized reports monitoring cumulative cable fills. This permits operating companies to achieve improved utilization of existing cable facilities and to intelligently plan and schedule additions to the plant. LCRIS provides the capability of obtaining, on a batch basis, cable fill and other related information from a separately maintained loop plant data base. This eliminates the need for manual counts of records and translation into usable summaries for planning. Some of the types of reports available are:

(1) Main frame fill summary by wire center.

(2) Cable fill summary by central office cable.

(3) Route layout summary by sheath and EFRAP section for every central office cable.

(4) Listing of defective pairs by central office cable.

(5) EFRAP cross-section fill summary for all sheaths in a section.

15.6.7 METROPOLITAN AREA TRANSMISSION FACILITY ANALYSIS PROGRAM (MATFAP)

MATFAP is an example of computer programs that aid in facility planning. It analyzes, in terms of present worth of annual charges and other measures, the alternatives available to an operating company for its future transmission facilities. By combining trunk and special-service circuit forecasts with switching plans, network geometry, facility unit costs, and engineering rules, MATFAP identifies what, where, and when transmission plant is needed. It also determines the economic consequences of particular facility selection and routing choices. The least cost assignment of trunks to each facility is provided as a guide to the circuit provision bureau. As the name implies, MATFAP is basically oriented to transmission facilities commonly found in metropolitan areas such as voice-frequency cable, T1, T4M, and DR18. Other programs directed toward nonmetropolitan area problems are being developed.

15.6.8 FUTURE COMPUTER AIDS FOR PLANNING AND ENGINEERING

This section has surveyed a sample of planning and engineering problems and the computer programs that have appeared in response to these problems. Computer programs are accepted tools in each of these areas, and it is clear that the list of programs will grow. Programs applicable to the exchange area have been emphasized because of their importance to operating companies.

Planning and engineering programs are tending more and more toward the time-shared environment. In the time-sharing mode, the engineer may interact with the program in solving a problem. This environment leads to a more effective blending of engineering judgment and computational power. The relatively slow turnaround of batch programming breaks the continuity of the problem-solving process, although some planning problems are so complex that the batch mode is essential.

Many planning and engineering programs are available to the operating companies through Engineering Planning and Analysis Systems (EPLANS), a service offered by Western Electric. Processing is done in central computing facilities in either a time-sharing mode with remote input-output terminals at operating company locations or in a batch mode as appropriate. An operating company is billed for its use of a program to solve a particular problem. Some programs, referred to as deployed programs, are made available to operating companies for use on their own computing facilities; these programs are not made available on the central computing facilities. Western Electric funds the development of EPLANS programs and is responsible for maintenance of the programs and operation of the central computing facilities.

Another trend in planning and engineering programs is the packaging of programs into problem-solving systems. For example, a long-range exchange planning system may consist of MWC/CS, MWC/PWAC, COEES, and EFRAP, along with written guidelines and planning methodology. This integrated system of programs and practices unifies and facilitates the total planning process. There is less chance of redundancy and ambiguity in data gathering, and interactions among network elements (e.g., switching/transmission trade-offs) are more completely taken into account. Exchange planning is truly a large-scale problem, and the program package approach addresses itself to this fact.

Several existing programs have evolved with the development of new hardware systems. A greater variety of communication facilities complicates the planning process and creates the need for more computer aids. There is, therefore, a good deal of dependence between hardware and planning programs. When a new hardware system is developed to provide better service, the planning program helps to determine where, when, and how to use the system in order to realize its full benefit. An ongoing challenge is to integrate these individual programs into an overall planning system.

15.7 COMPUTER TECHNIQUES FOR ADMINISTRATION

Another aspect of provisioning is the administration of existing facilities to achieve maximum utilization, thus deferring the need for new construction as long as possible, with minimum size force. Main distributing frame (MDF) operations is a pertinent example; two computer systems that aid in assigning terminals for jumper wires will be described. The Computer System for Main Frame Operations (COSMOS) is designed for large main frame applications, and the Simplified Modular Frame Assignment System (SMFAS) is designed for smaller applications.

15.7.1 COMPUTER SYSTEM FOR MAIN FRAME OPERATIONS (COSMOS)

COSMOS is a minicomputer based system that aids in assigning terminals for jumper wires and in maintaining records of existing jumpers on MDFs. It keeps records of feeder cable pairs, line equipments, telephone numbers, and existing jumpers. Basic objectives of COSMOS are to select the shortest jumpers consistent with service requests and traffic and to reuse in-place jumpers when possible, thus minimizing main frame congestion. The major economic benefits accrue through reductions of personnel involved in work on MDFs and their administration and through extension of the service life of MDFs.

COSMOS is implemented on a PDP 11/70 minicomputer and associated peripheral equipment. The computer is accessed from remote computer terminals. The system is economically viable for wire centers of 30,000 or more lines as part of a multiwire center configuration or for wire centers of 50,000 or more lines when the system serves only that wire center. The upper limit of capacity is approximately 150,000 lines. The system can be used with any combination of the following switching and frame systems:

(1) No. 1 Crossbar, No. 5 Crossbar, No. 1 ESS, Step-by-Step, and Panel switching systems.

(2) Conventional, ESS modular, and COSMIC frame systems.

The plant assigner is aided in choosing a cable pair to fill a service order by stored information on existing jumpers, both working and nonworking. After selection of the cable pair, COSMOS automates the assignment of MDF cross-connections taking into account load balancing—the distribution of traffic over switching system components. In addition, the system automates the administration of the work of running and disconnecting jumper wires on the frame. It produces a printout identifying the terminals for a connection or disconnection for the frameman. It also can give instructions to leave certain jumpers in place when they are disconnected, in anticipation of future use. Easy access to stored data avoids interdepartmental telephone calls and time-consuming manual record searching. COSMOS also enhances the operations of the MDF forces through work scheduling assistance and real-time access to the COSMOS data base.

The COSMOS system is used in converting an existing wire center to COSMOS control. The existing plant and traffic records are read into the computer and compared. Operating company personnel resolve the record discrepancies which are noted by COSMOS. Although data conversion is a time-consuming and expensive process, the conversion results in a highly accurate data base and usually turns up more than enough unused line equipment and cable pairs to pay for the conversion.

COSMOS provides a central data base that is accessible and useful to many functions in an operating company, including the business office and the repair service bureau.

15.7.2 SIMPLIFIED MODULAR FRAME ASSIGNMENT SYSTEM (SMFAS)

SMFAS is a time-share computer system developed to meet the requirements for a less extensive mechanized approach than provided by COSMOS. It keeps minimal records and performs only a subset of COSMOS functions. SMFAS does not keep an inventory of working circuits. However, it does maintain location information on all cable pairs, line equipments, and left-in jumpers. SMFAS assigns line equipment to cable pairs when both the desired cable pair and a list of available line equipment have been specified. The line equipment resulting in the shortest jumper is selected. It is designed to administer the following MDF/switching system combinations:

(1) An ESS MDF accommodating 15,000 to 50,000 No. 1 ESS working lines and experiencing growth congestion and management problems.

(2) A new COSMIC MDF accommodating 15,000 to 50,000 No. 1 ESS or No. 5 Crossbar working lines.

16 Testing and Maintenance

This chapter is concerned primarily with evolving maintenance concepts and with new maintenance and administration systems employing minicomputers. To provide appropriate background, basic maintenance functions will be defined, a number of environmental factors that have a bearing on maintenance will be considered, and the motivations for centralization of maintenance activities will be discussed. Then, the repair service bureau operation, the usual customer interface with Bell System maintenance, is described. The remaining sections deal with maintenance of the loop plant, station equipment, switching systems, trunks, carrier systems, and special-service circuits. The facility-oriented organization of the chapter is simply for ease in understanding the material; in practice, there is often considerable overlap in maintenance activities.

16.1 BACKGROUND

Testing and maintenance are undergoing revolutionary change brought about by new concepts in operation and administration that affect the operating organizations, by the advent of remote surveillance and testing techniques, and by the use of minicomputers in maintenance systems. These techniques and the new maintenance systems evolving from them pervade nearly every area of maintenance activity. To give an idea of the magnitude of the effort in this area, Fig. 16-1 illustrates a number of the new systems for maintenance of loops, switching systems, trunks, carrier systems, and special-service circuits.[1] Many of these systems are still under development or in the process of field trials. Consequently, Fig. 16-1 is not comprehensive nor can it reflect the rapid rate of change.

Another area of major improvement in the new maintenance systems is that of record administration for the equipment, facilities, and circuits being monitored (see Section 15.4). This is an extremely important area. For example, in the loop plant, the accuracy and availability of cable pair and terminal information are essential for any corrective work following a customer trouble

1. Extensive use of acronyms is made in this chapter. Each is defined where first used, and Table 16-1 (at the end of this chapter) lists acronyms introduced in this chapter and their meanings.

report. Computer technology makes possible improvements not only in record storage techniques, but also in the way data are displayed to craft personnel and in the interactive capabilities available to them. These aspects are discussed in more detail later in the chapter.

16.1.1 SYSTEM MAINTENANCE

System maintenance is divided into two broad categories: preventive maintenance and corrective maintenance. Preventive maintenance includes routine procedures such as lubrication, cleaning, and adjusting. It also may include detection of potential trouble conditions before they affect service; this may be accomplished by marginal testing procedures.

Corrective maintenance involves a number of separate functions:

Trouble Detection—Recognizing that a trouble condition exists. Troubles in station equipment and some troubles in loops usually are detected by customers. Troubles in switching systems and carrier transmission systems usually are detected automatically.

Trouble Notification—Alerting craft personnel to the existence and severity of a trouble condition. Once a trouble condition has been detected and the associated information is available, craft personnel are notified so that they may begin corrective actions. The trouble notification may have an audible alarm associated with it to draw attention.

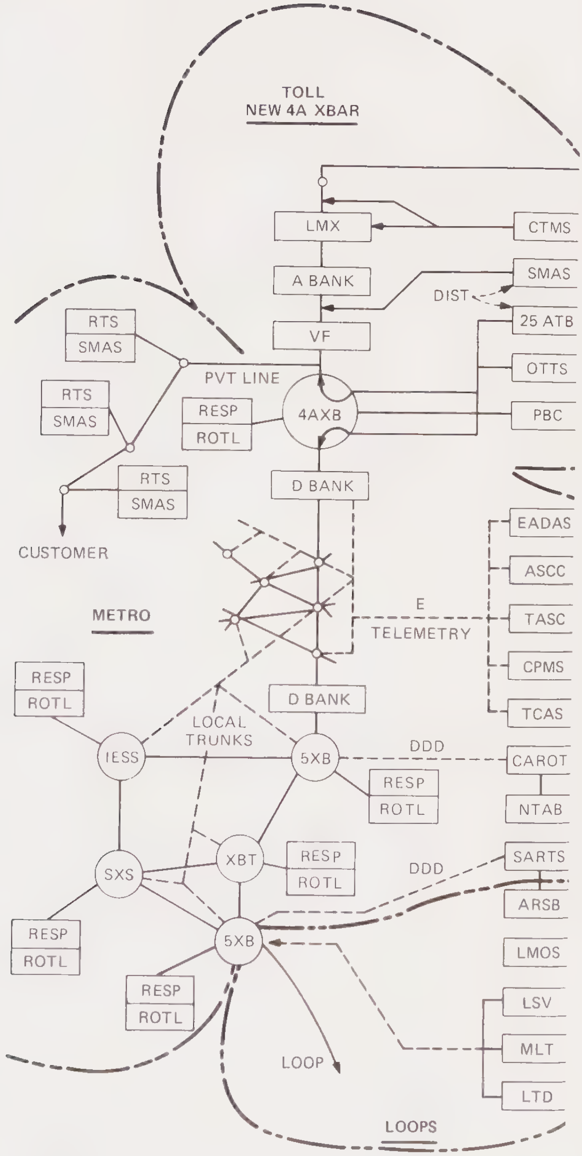
Trouble Verification—Determining if a reported trouble condition still exists. A considerable time interval may occur between trouble notification and the start of trouble location. Experience has shown that many trouble indications are transient and may or may not recur. First priority is given to correcting verified troubles.

Trouble Location—Sectionalizing a trouble to an area of maintenance responsibility so that the appropriate craft force can take action to locate and repair or replace the defective unit. This is frequently the most difficult and time-consuming step in the maintenance process.

Trouble Repair—On-site repair is required in some instances. In other cases, the defective unit can be removed and replaced with a spare.

Service Verification—After the repair is completed, the craftperson should verify that the trouble condition has been cleared.

Every system is planned and designed for a near-optimum combination of system reliability, preventive maintenance, and corrective maintenance. It is intuitively obvious that a system can be designed to have very high reliability and thus require very little maintenance. However, a more economical arrangement might be a less reliable, and hence less expensive, system that requires a greater amount of maintenance support. It is important to achieve an economic balance.



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LMX
CTMS
A BANK
SMAS
DIST
25 ATB
VF
OTTS
PVT LINE
4AXB
PBC
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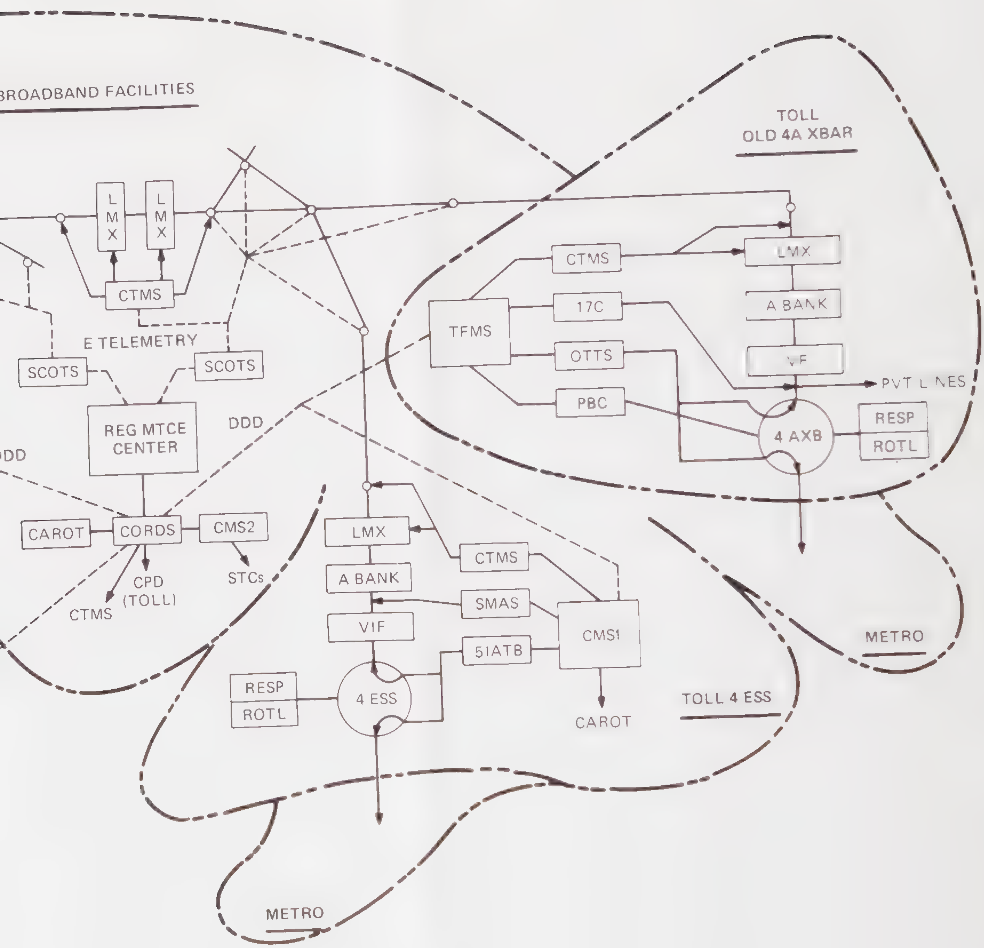

Fig. 16-1. Centralized Maintenance Systems

16.1.2 ENVIRONMENTAL FACTORS

There is a variety of factors that have a bearing on maintenance operations and maintenance systems. Some of them will be discussed here.

16.1.2.1 Location of Equipment

Equipment items in telephone company buildings, such as switching systems and carrier system terminals, are readily accessible for maintenance. Other items, such as station equipment and PBXs, are located on customers' premises and are widely dispersed. Repeaters for transmission facilities are placed at numerous unattended locations along facility routes. It will be seen that locations influence the appropriate maintenance arrangements.

16.1.2.2 Equipment Design Features

Modern solid-state circuit designs are becoming more sophisticated. In order for craft personnel to maintain this equipment with minimum training, functional design concepts are followed, with individually identifiable functions, usually on separate printed circuit packs. Each circuit pack contains an adequate number of easily accessible test points. Troubleshooting can be accomplished on the basis of functional diagnostics coupled with test point measurements and eventually circuit pack substitution until the trouble is corrected. The faulty circuit pack may then be repaired later, either locally or at a Western Electric service center.[2]

For very complex equipment such as an Electronic Switching System (ESS), the provision of adequate maintenance procedures requires that the system itself have certain built-in self-diagnostic capabilities to provide an actual analysis, and in some cases, a printout of the nature of the problem.

Specially trained maintenance personnel sometimes can be justified for highly centralized systems such as large switching systems; however, most systems usually are maintained by craft personnel who must be familar with maintenance procedures for a variety of equipment. Thus, maintenance procedures for any individual piece of equipment must not be too complex.

16.1.2.3 Test Equipment

The selection of available test equipment to support the maintenance of a specific system or the specifications for the design of new test equipment are usually the responsibility of the designers of specific systems. The actual design of the test equipment may be done by another group within Bell Laboratories, by Western Electric, or by another vendor. An important objective is to minimize the number of different types of test equipment required.

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2. The use of printed circuit packs is so extensive today that keeping track of those circuit packs that are actually available as spares and those that are being repaired is a monumental job. A Plug-In Inventory Control System (PICS) has been developed that will save the Bell System millions of dollars annually in circuit pack inventory control and utilization (see Section 15.5.3).

Many kinds of test equipment are available; some for testing specific types of equipment (such as the 914B test set for testing data sets) and some for the measurement of specific characteristics (such as the 3C noise set for measuring voice-frequency circuit noise). Quite often, more than one test set is required to maintain a particular system.

Most of the test sets presently used in the Bell System are manufactured by Western Electric or by other companies under contract to Western Electric. They are described in a catalog of standard test equipment. There is a trend today, however, to have a larger portion of this equipment supplied directly by other vendors. In conjunction with this trend, Bell Laboratories has compiled a book of test set specifications that serve as Bell System standards to which vendors may design. Specific equipment designs are evaluated, and a document identifying which test sets meet the prescribed specifications is issued to the operating companies by AT&T.

16.1.2.4 Maintenance Documentation

The need for proper documentation of maintenance procedures is recognized. Each type of equipment normally is supported by three Bell System Practice (BSP) sections dealing with the areas of description, operation, and maintenance. Timely preparation of a pertinent maintenance section is essential to the orderly introduction of new equipment and is a challenge to Bell Laboratories and Western Electric.

In addition to the provision of maintenance BSPs, there is a trend under way known as the Task Oriented Plant Practice (TOPP) concept in which step-by-step procedures necessary to perform a complete task, such as maintenance procedures for a large system, are compiled in a single document. It has been estimated that job efficiency increases from 10 to 25 percent with the use of TOPPs.

Bell System Repair Specifications (BSRSs), another maintenance document classification, are used primarily by Western Electric service centers for detailed repair of apparatus and printed circuit packs.

16.1.2.5 Capabilities of Craft Personnel

A high school education is usually the only preemployment formal training required of craft personnel. Some formal company training generally is provided prior to assignment to equipment maintenance, but in the past has been predominantly theoretical in nature. Now, however, new training courses are placing greater emphasis on practical experience.

Knowledge of frequently performed normal tasks usually is committed to memory. However, craft personnel are expected to use BSPs and other descriptive material including Circuit Descriptions (CDs) and Schematic Drawings (SDs) when performing infrequently applied maintenance routines or trouble location and repair tasks.

Because of personnel turnover, promotions, and transfers, craft personnel usually average three to four years in a particular assignment. The majority of craft personnel are dedicated employees who are thoroughly familiar with Bell System service objectives. However, they are prone to errors in those cases in which human engineering concepts have not been applied to facilitate correct job execution. Motivation to do a thorough, correct job is a continuing objective of management.

16.1.3 CENTRALIZATION OF MAINTENANCE ACTIVITIES

A concept coming into extensive use is centralization of maintenance activities. One area in which this centralization is apparent is a central office building where all customer loops in the serving area are brought for connection to switching systems. Testing can therefore be done on all of these loops from a central location.

A motivation for centralization is more effective use of personnel. This is evident in the arrangements for switching system maintenance discussed in Section 16.5. Centralization permits a small number of highly trained people to deal with the difficult trouble conditions that occur within a large area. It also permits people to be dedicated to routine preventive maintenance rather than having the same people do both corrective and preventive maintenance as was done in the past. Furthermore, maintenance centralization makes it possible to provide more clerical support for administration of activities.

Further evolution of centralization is due to minicomputer control of maintenance systems. Some of the newer systems have remotely controlled access to circuits and test equipment, facilitating test control from one central point for an entire operating company territory. Examples are the Centralized Automatic Reporting On Trunks (CAROT) system and the Automatic Data Test System (ADTS) described in Sections 16.6 and 16.9, respectively. In systems of this type, routine tests are controlled automatically by computer programs, and the results are recorded for subsequent analysis. The need for dispatching personnel for field tests is minimized.

Computer use will increase in centralized maintenance. In addition to controlling routine testing and analyzing results, they will be used for such things as keeping records of equipment and facilities, displaying selected records to craft personnel as needed, and scheduling preventive maintenance. The application of computer technology does not eliminate the crucial role of the Bell System craft forces; they will still decide the manner of response to maintenance situations. However, computer technology does change the type of work they do. Nonetheless, every equipment fault will be repaired by a human being in the foreseeable future.

16.2 REPAIR SERVICE BUREAU

There is a significant difference between the way troubles are detected in station equipment and the loop plant and the way they are found in switching and toll transmission systems. In the latter, many troubles normally are reported by alarms or are discovered as a result of scheduled periodic tests, whereas at the present time the vast majority of loop and station troubles are first discovered and reported by customers.

The customer interface with the telephone company in this instance is the repair service bureau (RSB) to which a customer reports trouble by dialing 611. On the average, a trouble report is generated per residence station once every two years; business stations average one per year. Many reported troubles do not result in confirmed troubles. About 55 percent of the reports require dispatch of a repairman; the remainder are handled in the office.

The Bell System has approximately 1800 repair service bureaus. Some are responsible for only a few thousand lines, but others, in metropolitan areas, are responsible for 100,000 lines or more. Operations of the RSB start when the RSB attendant, sometimes called the 611 clerk, receives a trouble report from a customer. In large RSBs, the attendant passes the report to a file clerk, who maintains and updates the records during and upon completion of the repair process. Next, a foreman or screener reviews the trouble reports and decides their disposition. A tester, operating from a local test desk (LTD), then detects, verifies, and classifies the trouble as accurately as possible. If the trouble is in a cable pair, the tester will attempt to sectionalize it further to aid in dispatching the repair crew to the right location.

A number of recent developments will have considerable impact on the RSB operation. Significant among these developments are the Line Status Verifier (LSV) and the Loop Maintenance Operations System (LMOS), described in the following section.

16.3 LOOP MAINTENANCE

As previously mentioned, the major source of trouble reports in the loop plant is the customer, rather than alarm and surveillance systems as in the switching and toll plant. There is a difference, too, in the seriousness of these two trouble categories to the customer. In the toll and switching plant, there is considerable redundancy and automatic rerouting, so that an individual customer is seldom aware of any problems. However, because a customer is permanently associated with a particular loop, the customer will always be affected by a loop trouble and is aware of it until it has been corrected.

The emphasis in loop maintenance development has been toward improving the efficiency of inside and outside craft forces through mechanized aids and improved testing facilities. Surveillance systems have been developed for automatic line insulation testing and for cable pressure monitoring. These systems will be described in Sections 16.3.4 and 16.3.5.

16.3.1 LINE STATUS VERIFIER (LSV)

The LSV allows the RSB clerk to perform a basic line status verification, usually with the customer still on the telephone at the time of the trouble report. The LSV identifies major loop problems, such as foreign battery potentials, low leakage resistance, open circuits in the central office, and open circuits outside the central office. The customer often can be told the nature of the problem immediately and how long it will take for repairs. Many problems can be referred immediately for repair and need no further sectionalization action by the local test desk. In a significant number of cases, the expense of calling the customer back can be saved when the LSV results indicate (and the customer can be convinced) that no real trouble presently exists.

16.3.2 LOOP MAINTENANCE OPERATIONS SYSTEM (LMOS)

When a clerk takes a report in a repair service bureau that uses only manual methods, a trouble ticket is filled out. This ticket includes the customer's name, address, telephone number, and any pertinent information that may help to identify the trouble. All of this information is entered on the ticket manually, with the ticket eventually passing through many hands. In addition to this source of information, cable pair assignment, cable makeup information, and trouble history for each customer are kept on file in large bins, or file tubs. This information is used by the tester to help isolate the problem. Through the use of LMOS, all of this information can be stored in a computer and displayed on CRTs at the 611 position and other locations. In addition to simplifying information retrieval, the accuracy and readability of the information will be greatly improved. The CRT display will allow the RSB to advise the customer immediately of the status of the trouble, should the customer happen to make a followup inquiry. It also produces administrative reports including jeopardy reports, facility status reports, cable fill reports, and reports with respect to closed out troubles. LMOS includes documentation such as training materials and position practices.

LMOS can be installed separately or with the LSV or mechanized loop testing (MLT) modules, which mechanize important testing functions. The system is economically viable for typical groupings of repair service bureaus that serve one-half million to five million lines.

Labor savings benefits result from:

(1) Mechanization of the line record.

(2) A mechanized service order interface for automatic line record updating.

(3) The ability to centralize the repair service attendants for many repair service bureaus.

(4) A flexible report generator that produces standard statistics or processed trouble reports and special reports on demand.

(5) A repair force administration algorithm that optimizes the travel time of the repair personnel.

16.3.2.1 System Configuration

LMOS is a 3-level network interconnected by data links as shown in Fig. 16-2. The hub of the network is an IBM 370 computer and associated peripherals. The master line record data base is maintained in the hub, which can support up to five million working lines.

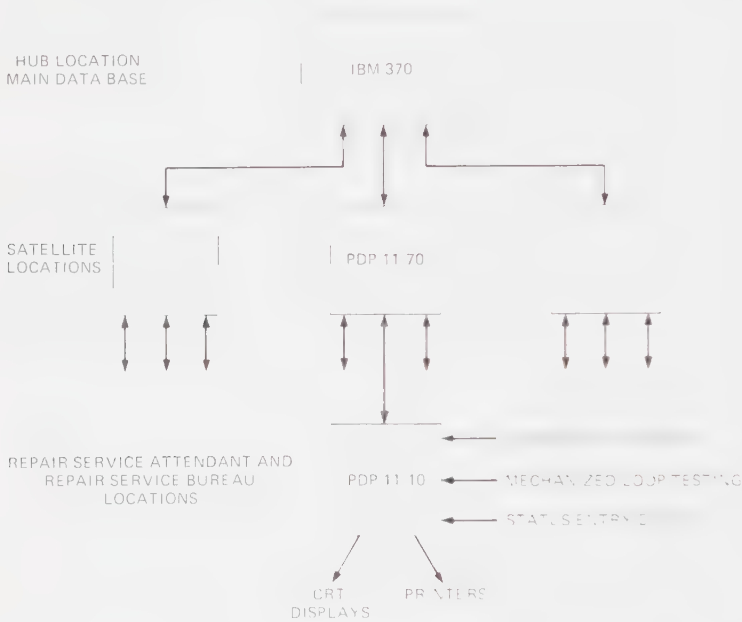


Fig. 16-2. Loop Maintenance Operations System

The second level of the system consists of a number of satellite locations which are linked with the central data base. A satellite consists of a PDP 11/70 minicomputer and associated peripheral equipment. Each satellite has an estimated capacity of one million lines. The satellites support almost all of the real-time transactions and provide response times on the order of 5 seconds or less for most transactions. Because these satellites have such a large capacity and since the cost of the minicomputer equipment is a minor portion of the overall system cost, a duplexed configuration is recommended for reliability.

The third level of the system is at repair service bureaus and centralized repair service attendant locations. Each location has a PDP 11/10 minicomputer which is linked with one of the satellite minicomputers. The repair service attendants and other personnel interact with the system through CRT terminals, printers, and status entry devices which are special purpose data entry terminals that enter data with a TOUCH-TONE pad and display data on a light-emitting diode readout strip.

The lower limit on the capacity of a LMOS installation is based on economic constraints imposed by fixed cost items such as software support personnel, training center costs, and IBM 370 costs. This limit is estimated to be 500,000 lines.

16.3.2.2 Operations

The following descriptions of ways that LMOS can be used in an operating company will further explain the organization and functions of the system.

The Repair Service Attendant Position

Each repair service attendant position is equipped with a CRT terminal through which LMOS accepts trouble reports. Following keyboard entry of a customer telephone number or special-service circuit number, LMOS responds within 5 seconds with a CRT display that includes:

(1) Customer name, address, and service data such as disconnected, non-working, affiliated with a telephone answering service, or date of last trouble.

(2) An appointment time that can be offered to the customer if a repair visit appears to be necessary.

(3) LSV or mechanized line testing system responses (if installed at the serving RSB) to LMOS initiations.

(4) Information on cable and other equipment failures that are known to be affecting the particular customer's circuit.

(5) Information on the initial report (if the current report is identified as a subsequent report) concerning repair status, promised appointment time, and number of previous subsequent reports.

The appointment time mentioned above takes into account both the backlog of trouble reports awaiting dispatch and the size of the craft force responsible for the corresponding repair coverage.

The LSV or mechanized line testing system response usually is not available at the time of initial trouble report transmission, but is written into a reserved space on the display as the repair service attendant is talking to the customer. Response time of these systems is on the order of 10 seconds and can be longer if delays are encountered because of test equipment usage.

As in the case of the appointment time offering, the LSV or mechanized line testing system response is made from the RSB covering the service in question and need not be the same RSB that contains the originating repair service attendant position. It is this independence of the repair service attendant position from the responsible RSB that permits one of the more significant operational capabilities: centralization of the repair service attendant task. Such centralization is possible because all of the repair service attendant transactions are designed to operate with access to all of the line records contained within the serving satellite minicomputer (this also implies access to all LSV and mechanized line testing systems covering these lines). Thus, 24-hour coverage and other desirable features possible with a centralized repair service attendant location are provided within the LMOS design.

16.3.2.3 RSB Handling of the Trouble Report

Once a trouble report has been entered in LMOS, the line record data base is accessed and a basic output report is transmitted within seconds to a printer at the appropriate RSB. In addition to the trouble report and line record data, this paper document contains:

(1) Assignment information.

(2) Service and equipment information.

(3) Trouble history for the past 40 days.

(4) Warning of potential trouble causes such as cable failures.

As repair action takes place following a trouble report, status updates, such as test results and trouble report closeouts, are entered into LMOS in the RSB, using status entry devices described previously.

LMOS will aid in the dispatching of the repair force through the use of a repair force administration module that will provide a CRT-equipped dispatcher with a short list of recommended dispatches each time a member of the repair force calls in for a new dispatch. Repair force administration will take into account the repair work backlog, available repair force, promised appointment times, and travel times.

Note that since each line record is keyed to a serving RSB, LMOS permits functional repair operations such as coin telephone repair centers and PBX repair centers; the basic output report always arrives at the correct serving RSB or repair center.

16.3.2.4 Control of Testing

Not only can the repair service attendant position trigger LSV action against a particular telephone number, but also RSB personnel can use LMOS to drive a LSV in an automatic verification mode. This is done by using a RSB CRT terminal to enter a list of telephone numbers, a particular cable complement, a range of central office equipments, or a specific class and period of closed-out trouble reports such as all-test-OKs for the last two days. LMOS then accesses its data base for cross-reference lists that provide the appropriate telephone numbers and initiates automatic sequential line status verification against the telephone number list. Results are printed out at the requesting RSB within seconds of completion. The testing capabilities of the mechanized line testing system can be used by LMOS in the same manner.

16.3.2.5 Operational Reports

Over and above individual trouble report tracking, LMOS provides three basic classes of operational reports: one covering open troubles, one covering closed-out reports, and one covering the line record and equipment file.

Open trouble reports are used to aid in the hour-to-hour administration of the RSB. An example of this kind of report is the jeopardy report, which flags trouble reports in jeopardy of missing their appointment times.

Closed-out trouble reports relate to troubles that have been closed out within the last 40 days.

Line record and equipment reports fall into three categories:

(1) Batch reports that use the line record file as input, for example: all circuits on temporary suspension can be listed by telephone number.

(2) Batch reports that list unallowed multiple assignments of cable and pair or central office equipment.

(3) Equipment reports that are fixed in format but that are available in real time in response to CRT-entered transactions, for example: cable pair versus telephone number by complement.

Since many of these reports can be retrieved from a centralized location, the potential for a formal program of centralized analysis exists under LMOS. Note that some reports will be useful in connection with operating company activities other than maintenance such as business office and network administration activities.

16.3.3 AUTOMATED REPAIR SERVICE BUREAU (ARSB)

Both LSV and LMOS initially were designed as stand-alone systems, LSV as a manually operated line verification system and LMOS as a mechanized line record and trouble administration system. Recently, an interface was provided for LSV so that it can be directed from a LMOS operator's position to run its sequence of measurements on a particular line. This is a first step toward a total RSB system concept.

Development is under way for a mechanized line testing (MLT) system, which is an improved version of the LSV. In addition to improved testing capabilities, it will have the ability to test in the presence of known terminations. In the new arrangement, the MLT system, working in conjunction with LMOS, will have a priori knowledge of expected values and allowable deviations for a particular line being tested. For example, when testing a ground-start PBX line, it would know that -48 volts is the normal on-hook condition, whereas this would indicate a fault for a station line. The new system also will make routine rapid scan measurements automatically during the early morning hours when lines are normally idle. All of these developments are part of what will be known as the automated repair service bureau (ARSB).

16.3.4 AUTOMATIC LINE INSULATION TEST (ALIT)

An ALIT system is already in use in about 40 percent of Bell System central offices. It is designed to detect incipient deterioration in the line insulation of cable pairs before it affects service. The test is performed routinely, usually in the early hours of the morning. In its present form, ALIT has two problems: its printout is quite voluminous, and its list of suspect lines includes those that have a bona-fide resistive connection between tip and ring, namely PBX trunks and lines with cable pressure transducers.

The printout also includes lines whose insulation resistance has only fleetingly dropped below the threshold. Thus, without substantial clerical screening, subsequent repair service bureau tests of the majority of lines listed on the ALIT printout do not confirm that a real trouble condition exists. To alleviate this problem, a support program has been developed called Analysis of Automatic Line Insulation Tests (ANALIT). ANALIT performs the necessary screening function, and lines listed after this critical examination are much more likely to have a real fault.

16.3.5 CABLE PRESSURE MONITORING SYSTEM (CPMS)

Of the various loop maintenance tools so far described, only ALIT anticipates customer reports. The others are used in reacting to such reports. Another procedure that anticipates customer trouble reports is cable pressure monitoring. The Cable Pressure Monitoring System (CPMS) is used to monitor interoffice exchange cable and certain station cable (primarily feeder cable) that has been pressurized. Frequently, cables containing pulp-insulated pairs are filled with air maintained at pressure above atmospheric to keep out water. There are many devices for monitoring the cable pressure at a succession of points along a route, ranging from a simple hand gauge used by craft personnel, to transducers that convert cable pressure to resistance values measurable from the local test desk.

The CPMS utilizes a data acquisition terminal in each central office building that has a great deal of pressurization equipment or in other locations where measurement capability exists for monitoring transducers on cable routes. The CPMS central, operating from a central point, will then scan each remote transducer in turn, gathering cable pressure information over a large geographical area. The scanning will be done over the public telephone network using E telemetry modules (described in Section 16.7.2) that are part of each CPMS remote terminal. It is expected that one CPMS central will be able to handle an entire state with 100 or more remote terminals, by providing dial-up access to each remote location during the early morning hours. The information reported to the CPMS central will then be analyzed by a minicomputer, with pressure leaks and problem areas sectionalized and printed out. Copies of reports showing suspected troubles will be sent to teletypewriters at cable maintenance locations. Comprehensive monthly reports are prepared to help management allocate manpower so as to minimize the number of service-affecting troubles.

16.3.6 PORTABLE TEST EQUIPMENT

Once a customer loop problem has been identified and sectionalized by the various systems in use by the RSB, it is still necessary in many cases for someone to go to the main distributing frame (MDF) or to go out on a cable route to pinpoint the specific trouble location. In this effort, framemen, cablemen, and station installer-repairmen are aided by a number of portable test sets. Three newer examples of such test sets are described briefly below.

A go/no-go test set has been developed to allow the frameman to make a rapid check of all MDF pairs for dc voltage, length of the pair (compared with a standard expected length), and the presence of resistive and capacitive leakage faults. Previous testing methods required the frameman to disconnect the circuit and connect it to a test trunk back to the local test desk for testing, a 2-man operation requiring 10 minutes per pair. With the go/no-go test set, a craftsperson can test approximately 500 pairs in an hour.

A probe has been developed to help telephone installers identify specific customer pairs, which are often difficult to locate because of the large number of pairs contained in a cable terminal and because of badly worn color coding. The new probe allows detection of a test tone (applied from the local test desk) by simple proximity to the pair without metallic contact or damage to the wire insulation.

The third item is a new and safer breakdown test set for pinpointing insulation defects in aerial and underground cable with pulp insulation. The set assists in detecting the location of breaks in the cable sheath, which if neglected, would lead to further deterioration in the cable pairs.

16.3.7 CABLE UPKEEP REPORT

In addition to test equipment and adequate troubleshooting procedures, one of the major problems in the exchange cable plant area (customer loops and interexchange cable pairs) is keeping track of cable problems and manpower hours spent in cable upkeep. A computer system has been developed that takes as input the cable upkeep report ticket filled out by a cableman and an installer-repairman and automatically generates summary reports to advise management of costs and manpower allocations.

16.4 STATION EQUIPMENT MAINTENANCE

The importance of station equipment maintenance can best be illustrated by describing the size of the station equipment operation. Of the almost one million Bell System employees, approximately 100,000 are classified as installer-repairmen of station equipment. Station equipment in this context refers to residential, coin, and business telephone service, the latter including regular telephone sets, key telephone systems, data sets, and PBX equipment.

In 1974, these installer-repairmen saw a net gain of 4 million telephones in the Bell System. However, in order to achieve that gain, they handled 46 million telephones (25 million connections and 21 million disconnects), or 11 handlings for every one unit gained. The cost for these 46 million installation-disconnects, at about $25 each, is $1.2 billion, or an expense equivalent to about 5 percent of all Bell System revenue.

The reason for including installation statistics in a section on maintenance is to illustrate that whatever problems exist with station equipment are multiplied many-fold when seen by the installer-repairmen. It is essential that the equipment they install works, that it withstands the environment, and that it accommodates to the real world, both for installation and maintenance. Good BSPs are essential and should follow the Task Oriented Plant Practice concept mentioned in Section 16.1.2. The resulting efficiencies are extremely significant when one considers the numbers involved.

Some companies have had considerable problems with the availability and turnover of qualified installer-repairmen. In many cases, they do not attempt to repair a defective telephone set on the customer's premises, but rather return it to the Western Electric service center for repairs. The size of the Western Electric repair operation is enormous. It is well known that Western Electric manufactures a large number of telephone sets; in fact, about 8 million per year. However, over 25 million telephone sets per year flow through the service centers for repair.

The recent cost for an average telephone set repair by Western Electric was about $5, whereas the cost of a new 500-type telephone set is about $17. It is important to note that in recent years, labor costs for maintenance have been steadily rising faster than material costs. Therefore, it is important not to initiate minor cost-saving items in the design and manufacturing processes that do not have proven integrity and that may end up requiring a repair visit to the customer's premises and costing expensive maintenance dollars.

There are several tests that an installer-repairman can make at a customer's premises by dialing appropriate numbers. These tests are useful in verifying that an installation is satisfactory and also to aid in identifying troubles. The tests include verification of ability to dial, verification that the telephone set will ring when the signal is applied at the central office, measurement of a 1000-Hz tone sent from the central office at a standard amplitude, and measurement of noise at the telephone set when the loop is terminated in a resistance at the central office.

A test circuit has been developed to enable an installer-repairman to test a coin telephone without assistance from centrally located personnel. The test circuit consists of electromechanical and solid-state apparatus located in a central office. When the repairman at a coin telephone dials the assigned test number, the central office automatically sets up a 2-way connection between the coin station and the test circuit. Once this connection is established, the repairman can use the test circuit to conduct up to six different tests: ground resistance, loop resistance, leakage resistance, coin-collect operation, coin-return operation, and coin relay timing. Each test is assigned a single-digit access code, and the entire operational status of the coin station can be tested in less than 2 minutes. The test circuit saves time since it gives the repairman direct access to the testing facilities, whereas previously the operator and/or a test deskman was needed to apply coin-collect, coin-return, and coin-sensing signals. In addition, the test circuit allows detection of marginal performance under controlled testing conditions.

16.5 SWITCHING SYSTEM MAINTENANCE

A large central office switching system is a substantial piece of capital investment located in a single building. Some buildings have a number of switching systems, handling up to 100,000 customers. In these cases, dedicated craft personnel usually are justified for maintenance purposes. These same people have other maintenance responsibilities for transmission and signaling equipment located in the building. In contrast to these large installations, there are small switching offices that are unmanned one or more shifts per day. In these cases, system alarms are transmitted to a manned office to initiate maintenance action.

The maintenance procedures associated with electromechanical and Electronic Switching Systems are substantially different. The electromechanical systems have more frequent minor trouble conditions and require more extensive periodic maintenance. The electronic systems are relatively trouble-free, but when they do fail, the trouble symptoms usually are more difficult to diagnose and some failures can affect a large number of customers.

16.5.1 MAINTENANCE OF ELECTRONIC SWITCHING SYSTEMS

A feature of an ESS is a common-control diagnostic program that usually can pinpoint a fault to a few circuit packs. The diagnosis is printed out on a teletypewriter and can then be looked up in a trouble locating manual. The faulty circuit pack then can be located by a reasonably simple substitution method. There is also a master control center (MCC) for each ESS which displays the system configuration and selected status information to assist in rapid diagnosis of trouble. The MCC has controls for manually reconfiguring the system and initiating other remedial actions.

The basic reliability and automated maintenance characteristics of ESSs do not afford the craft force much practice on difficult trouble analysis and location tasks. However, in the infrequent case that the ESS is not able to restore call processing automatically because of serious trouble, a highly skilled craftsperson is required to intervene. The craftsperson must accurately determine and execute necessary recovery action in a short time to minimize customer service reaction. To maintain such high quality craft coverage on an individual office basis is typically not possible because of the limited opportunities for gaining on-site experience. The relatively small force in each office generally would not allow effective use of manpower through specialization or the efficiency associated with larger forces.

These conditions led to a centralized maintenance concept in which the operation, administration, and maintenance of a number of electronic switching offices are supervised and the majority of the maintenance functions performed on a remote basis from a suitably equipped switching control center (SCC). Regularly scheduled individual central office on-site maintenance often can be reduced and necessary on-site work performed on a dispatch basis from a central pool, possibly collocated with the SCC. SCC locations are expected to be manned continually by well-trained, skilled craft personnel.

The objectives of centralized switching system maintenance are:

(1) To gain manpower efficiency by pooling expertise and allowing the pooled force to work on the problems of many offices.

(2) To improve proficiency and training by exposing the SCC forces to more switching systems and their problems, thereby facilitating skill development and retention.

(3) To provide an economical means of continuous service protection by around-the-clock surveillance and control from the SCC.

A Switching Control Center System No. 1 (SCCS No. 1) has been developed to implement the centralized maintenance concept. The SCCS No. 1 consists of (1) a critical indicator panel, (2) work stations consisting of a control and display panel, teletypewriter, and telephone, and (3) receive-only teletypewriters.

The critical indicator panel consists of a subset of alarms and or lamps associated with every ESS connected to the SCC. This subset of alarms is provided to alert the SCC force if a particular ESS requires attention. The critical indicator lamps are updated by a central telemetry unit which is connected to all the ESSs on a party-line basis. Each remote telemetry unit is polled periodically for the subset of alarms that represents the critical indicators.

The work stations may be associated with any ESS connected to the SCC. There are generally fewer work stations than ESSs connected to the SCC. However, there must be at least one work station for each type of ESS connected to the SCC, since the control and display panels are unique for each type of ESS. When a work station must be associated with a particular ESS to respond to a critical indicator or for routine reasons, the control and display panel, teletypewriter, and telephone are switched to the designated ESS. When this occurs, the remote telemetry unit is under control of a central telemetry unit associated with the particular control and display panel. In this mode, the status of all the lamps and/or alarms of the particular ESS is displayed at the console. In addition, the craftsperson has the ability to remotely operate the keys of the ESS maintenance center. The teletypewriter at the work station performs all of the functions of the maintenance teletypewriter at the ESS such as requesting tests to be performed, configuring the system hardware, requesting status reports, and receiving detailed reports on system operation. The telephone provides communications with any craft personnel at the ESS site.

The receive-only teletypewriters are dedicated on a one-for-one basis for each office controlled by the SCC. These teletypewriters provide a permanent record of all messages received or typed at the local teletypewriter at each ESS.

A Switching Control Center System No. 2 (SCCS No. 2) also has been developed; its capabilities are similar to those of the SCCS No. 1 with the addition of computer storage, processing, and display of teletypewriter messages. The teletypewriter messages received from the ESSs are entered in the bulk storage memory of a computer. Hard copy can be provided by a printer if needed. However, the principal use will be display of selected messages or processed information on CRT displays at work stations.

16.5.2 MAINTENANCE OF ELECTROMECHANICAL SWITCHING SYSTEMS

The maintenance of electromechanical systems differs from electronic systems in a number of ways. More periodic maintenance is required, and more frequent minor trouble conditions occur, resulting in more frequent craft activity. The reasons for centralization of maintenance, although basically similar, have not been as compelling as for Electronic Switching Systems. The need for a few highly skilled craftspersons who can analyze difficult troubles that occur infrequently in any of a large number of systems is not as pressing as it is for electronic systems. Furthermore, maintenance organizations and procedures for electromechanical systems have long been established. However, it has become clear that there are a number of operational advantages to increased centralization of the administration of maintenance for electromechanical switching systems, including the following:

(1) Increased clerical support can be provided to handle paper work such as logging work orders, scheduling preventive maintenance, and recording time.

(2) Once clerical work is centralized, it becomes possible to use computers to improve efficiency of the clerical operations and to provide additional reports and analyses not possible in a manual operation.

(3) Preventive maintenance can be assigned to a group that will do only preventive maintenance and will cover a number of central offices. This avoids interruption of scheduled maintenance by trouble conditions that must be corrected.

Centralized administration can form the basis of an organizational structure called the electromechanical switching control center (EM-SCC). Several computer programs and systems that have been developed have applications within the EM-SCC framework.

A Central Office Maintenance Management System for Scheduling Preventive Maintenance (COMMS-PM) is available. The input to the system is a description of the equipment in a central office. The computer accesses a data base to assign tests that should be performed for each item of equipment. The foreman then can specify the force level to be assigned to preventive maintenance work. The computer will then provide forms to be used to administer the execution of the tests. After the tests are performed, results are put into the computer, and summaries are provided for management purposes.

No. 5 Crossbar Switching Systems have been equipped with a trouble recorder that makes a punched card record of information in the common-control circuits at the time some calls encounter trouble. These trouble records have been very useful in diagnosing trouble conditions by noting patterns in trouble records. An automatic trouble analysis (ATA) arrangement has been developed to replace the manual analysis. An on-site unit in a central office, the maintenance data transmitter, accesses and encodes the trouble card data in a No. 5 Crossbar office or trouble indicator display data in a No. 1 Crossbar office. The data are sent via data link to a central computer to be stored and processed. The computer programs sort and process the card data in much the same way that craft personnel have processed cards in the past except with greater speed and uniformity. If a pattern is found, a report is sent to any designated site such as an EM-SCC.

The Telecommunications Alarm Surveillance and Control (TASC) system provides the capability to monitor alarms and status of electromechanical switching systems. The TASC system uses a minicomputer and E telemetry (see Section 16.7.2) on one or more multipoint data networks. It is capable of monitoring 100 to 200 offices or locations; however, not all of the capacity may be available for monitoring electromechanical switching systems because TASC is designed also to monitor transmission systems and building and power equipment. The central minicomputer will poll the remote stations in turn for alarm and status information, activate the central audible alarm, and print out teletypewriter messages when conditions warrant. In addition, commands can be sent from the EM-SCC to central offices to remove faulty common equipment from service. An optional wall-mounted critical indicator panel will be available at the EM-SCC to display the overall real-time status of the connected central offices.

Other systems that have been developed and are being studied within the context of an EM-SCC include the Computerized Maintenance and Administration System (COMAS) for Crossbar Tandem offices, the Peripheral Bus Computer (PBC) for No. 4 Crossbar, and the Step-by-Step Monitor and Selector Hold (SMASH) for Step-by-Step offices.

16.5.3 MAINTENANCE OF PBX SYSTEMS

In most cases, PBX systems are located on customers' premises. There may be one or more craftspersons on the premises during normal business hours at large PBX installations; however, there usually will not be any maintenance personnel on the premises at most of the PBX sites. The telephone companies have relied primarily on customer complaints for trouble detection. The handling of customer complaints and the dispatching of maintenance personnel to widely scattered locations for preventive and corrective maintenance force a degree of centralization in the administration of PBX maintenance.

New electronic PBXs will have advanced features to aid the craftsperson in detecting and locating a fault. The CSS 201 (DIMENSION) PBX has an alarm panel that indicates the general area of a fault and a maintenance and administration panel that assists the craftsperson in diagnosing a fault and locating a circuit board to be replaced. The CSS 201 program includes off-line diagnostic routines which can be brought into use through the maintenance panel. Planning is under way on methods to provide remote maintenance capability for CSS 201 systems using a data link to a maintenance center.

16.6 TRUNK MAINTENANCE

In the days before direct distance dialing, a customer making a long distance call first had to speak to an operator, who would set up the connection and speak to operators at the other end. If a particular trunk was not operating properly, the operator could identify and report it. Today, a customer can establish a connection without the aid of an operator. The particular circuits assigned to a customer are not identifiable, even if the customer calls the operator to report a trouble. Consequently, an important source of trouble reports on trunks has been lost. Several new systems have therefore been developed for routine testing of trunks between central offices.

To ensure high quality transmission, each trunk should be tested at intervals ranging from daily to monthly, depending on its makeup. At least four transmission measurements are necessary to determine if a trunk is within its design limits. Transmission loss, usually a 1000-Hz measurement, and noise must be measured in both directions, even for 2-wire trunks. With almost seven million trunks in the Bell System, it is obvious that this procedure must be automated. Systems designed for this purpose are ATMS, ROTL, and CAROT. There are, in addition, systems unique to No. 4 Crossbar offices, such as ADOIT, AOTT, OTTS, and TFMS. All of these systems will be described in this section.

16.6.1 AUTOMATIC TRANSMISSION MEASUREMENT SYSTEM (ATMS)

ATMS is illustrated in Fig. 16-3. It consists primarily of a director at the near end office and a responder at the far end office. Although this equipment makes the measurements automatically and assembles all information at the near end for a printout, neither the director nor the responder can set up connections and hold lines for test. An automatic test frame and a far end test line perform these functions by (1) connecting the director and the responder to the trunk to be tested, (2) performing the necessary functions to connect and hold the trunk, and (3) passing starting information to the director and the responder.

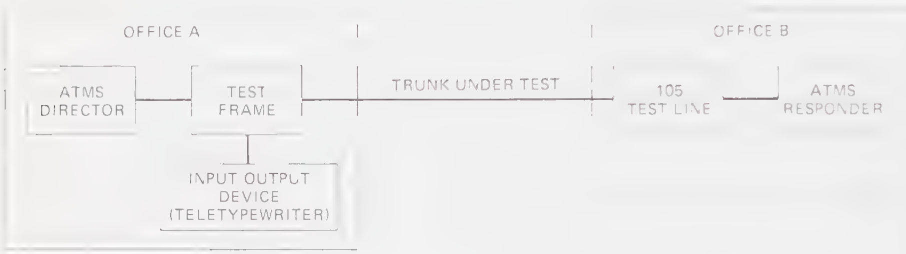


Fig. 16-3. Automatic Transmission Measuring System (ATMS)

The ATMS director can work in conjunction with one of several types of automatic test frames, which provide an appropriate interface with the electromechanical switching system. The trunks to be tested are punched on paper tape and read in by the teletypewriter. The output to the teletypewriter can be a complete listing of all trunk measurements or only those that exceed some predetermined limit.

16.6.2 REMOTE OFFICE TEST LINE (ROTL)

The ATMS automatic test frame is too expensive to install in small local offices. A ROTL has therefore been developed that allows up to 1000 outgoing trunks connecting to other far end offices to be selectively seized, connected to test lines, and tested. Results are passed back to the control location.

Fig. 16-4 illustrates how measurements are made between remote office B, equipped with a ROTL and responder, and far end office C, equipped with a 105 test line and a responder. The ROTL is directed to seize a particular trunk, and the ROTL responder conducts the transmission tests. The setup is under control of the test frame at office A, and the test results are transmitted back to office A over the public telephone network connection. This connection has no effect on the measurement.

Different types of ROTLs originally were developed for different types of switching offices, such as Step-by-Step, No. 5 Crossbar, etc. A new series of ROTLs with expanded capabilities has been developed for use with all switching systems except Panel. These, as well as the original small ROTLs for Step-by-Step and No. 5 Crossbar, can be controlled by the CAROT system described in the following section.

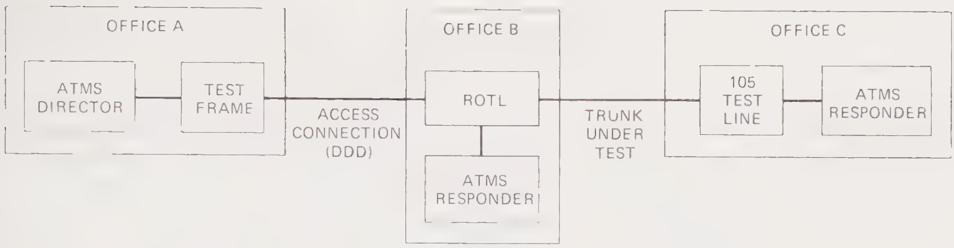


Fig. 16-4. Remote ATMS Testing Via Remote Office Test Line

16.6.3 CENTRALIZED AUTOMATIC REPORTING ON TRUNKS (CAROT)

Fig. 16-5 illustrates the CAROT concept with a system that provides ROTLs for all types of offices. The remaining functions of the automatic test frames and directors can be gathered at a central location, with the CAROT controller replacing the test frames and director, at substantial economic and administrative savings.

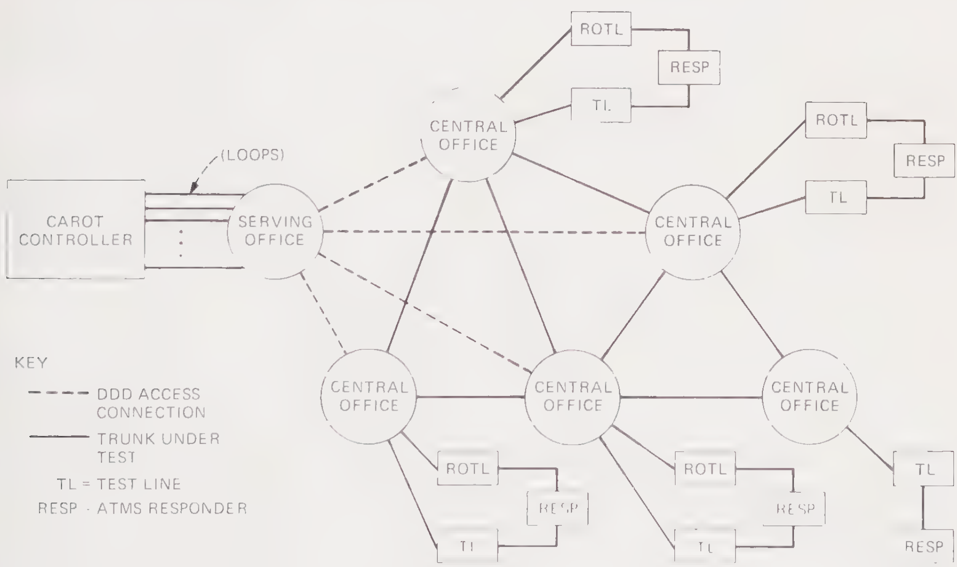


Fig. 16-5. Centralized Automatic Reporting on Trunks (CAROT)

The CAROT controller contains a minicomputer system and data base configured so that, from a central location (not necessarily a central office), it can direct ROTLs, responders, and test lines to perform both transmission and operational tests on trunks between various central offices. The use of a minicomputer system also allows efficient analysis of the measurement results and generation of management reports. The controller is connected by several loops to a nearby central office labeled "Serving Office" in Fig. 16-5. Connections to a number of other central offices can be dialed over the public telephone network as needed.

The CAROT system provides control for the remote testing of as many as 100,000 trunks in a geographic area. The geographic extent is determined by the density of trunks within the area. For example, one CAROT system will be necessary for a large metropolitan area, but one CAROT system might also cover several of the less populated states.

The present version of the CAROT controller contains up to 14 independent ports which can be involved simultaneously in test setups. Trunk maintenance files (TMFs), containing lists of trunks to be tested and expected measurement parameters, are kept on discs.

One interesting new concept to evolve from the data base problems is the concept of positive completion reporting associated with the circuit order completion process. The trunk data base used by CAROT has a high turnover rate with new and rearranged circuits. When a circuit order has been completed by craft personnel, a call can be made to the CAROT controller via DATAPHONE and a circuit test requested. If the tests made by CAROT are satisfactory, a positive completion report is given to the craft personnel and to the circuit provision bureau. Depending on operating company practice, the CAROT controller may use this completion to update its own routine trunk testing data base.

Due to the increased efficiency of trunk testing by the CAROT method, more sophisticated measurements are now also being made. A new responder is available which not only measures 1000-Hz loss and C-message-weighted noise but also measures loss slope, by making measurements at 400 and 2800 Hz as well as at 1000 Hz, and noise in the presence of a 1000-Hz tone. The 105 test line also has been modified to work with the new responder.

16.6.4 OUTGOING TRUNK TESTING SYSTEM (OTTS)

At the present time, large toll and tandem offices, such as No. 4 Crossbar, have self-contained automatic trunk testing capabilities. Two systems are presently in use for intertoll and toll-connecting trunks leaving a No. 4 Crossbar office. These are known as the Automatically Directed Outgoing Intertoll Trunk (ADOIT) test circuit and the Automatic Outgoing Trunk Test (AOTT) circuit. Both make use of a test frame and ATMS director, such as described in Section 16.6.1, at the No. 4 Crossbar office.

To gain access to the office at the far end of the trunk, a signal is transmitted, and the distant office responds by setting up a connection to a test termination circuit for transmission or operational (ringing, supervision, and address signaling) testing.

The two systems have testing consoles that may be located remotely from the associated switching system, typically in the same building or another telephone company building in the same city. The input to ADOIT is a deck of punched cards and to AOTT, a punched paper tape, which selects and tests trunks in a controlled sequence. The output can be either a printed page or a card deck (for ADOIT) which subsequently can be used for statistical analysis. The capacity of these systems is quite large, with AOTT recently increased from 10 to 20 thousand trunks. An AOTT of a different design also is used in class 4 and 5 Step-by-Step offices to test toll-completing trunks.

OTTS is a computer-controlled test frame for tests on No. 4 Crossbar intertoll and toll-completing trunks. OTTS contains a programmable set of equipments to provide seizure of any specific trunk leaving the No. 4 Crossbar office and signaling over the trunk to obtain a test line connection at the far end. It also contains logic circuits to recognize a variety of operational features during call setup, ATMS responder equipment for transmission measurements, and sequencing and control equipment to administer the process of automatic measurements.

OTTS itself does not contain a computer, but is designed to operate under the direction of other program-controlled systems. The control can be from the Trunk and Facilities Maintenance System (TFMS) (described in Section 16.6.6) located in the same office, or, alternatively, OTTS can be configured as a ROTL for a No. 4 Crossbar office, under the control of CAROT. The primary purpose of the new OTTS test frame is to provide for computer-controlled trunk testing to be used in automation of several phases of maintenance. These include preservice testing, routine testing, service protection, and trouble sectionalization in No. 4 Crossbar offices.

16.6.5 SWITCHED MAINTENANCE ACCESS SYSTEM NO. 3 (SMAS NO. 3)

SMAS No. 3 is a fast and efficient arrangement for gaining access to toll trunks for testing and for finding the section of a trunk where trouble is located. SMAS No. 3 itself does not test or measure; rather, it is a switching system that provides the access capability to make measurements. Measurements are performed from a testboard which, in conjunction with SMAS No. 3, provides all controls and displays necessary to gain access to any of the thousands of trunks emanating from a toll office.

Fig. 16-6 illustrates the SMAS concept. Without SMAS, sectionalizing test signals must be applied and measured by a craftsperson at the near end voice-frequency patch point, the point at which the trunk enters the intertoll network. If the section of the trunk within the toll office is to be tested, another craftsperson must select the trunk at a testboard several hundred feet away, near the point the trunk enters the switching system. The same process may apply to the other end, necessitating four craftspersons, a difficult and time-consuming procedure. SMAS will allow this to be done by one person.

SMAS No. 3 is designed to grow in steps of 12,000 circuits to a capacity of 120,000 circuits. The SMAS concept has been incorporated in the new voice-frequency facility terminals described in Section 11.3.3. Other SMAS systems

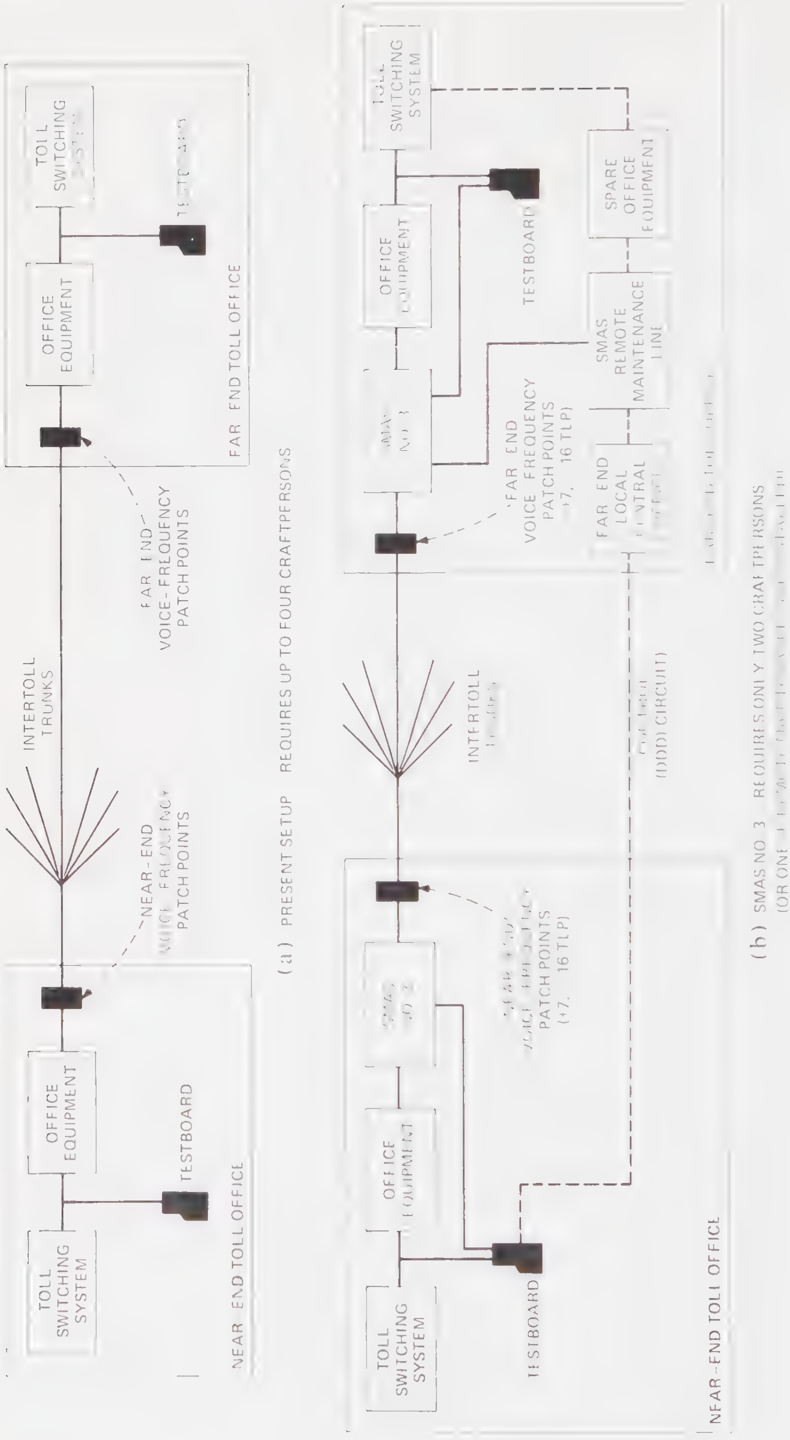


Fig. 16-6. SMAS No. 3

also are utilized in the maintenance of special services, which are described in Section 16.9.7.

16.6.6 TRUNK AND FACILITIES MAINTENANCE SYSTEM (TFMS)

Recent developments in trunk maintenance and facility maintenance, such as the OTTS, the Carrier Transmission Maintenance System (CTMS) (described in Section 16.7.1), and SMAS, have provided the impetus for an overall coordinating transmission maintenance system for No. 4 Crossbar offices. Although some of these tools are automated to some degree, there is little interaction among them. Moreover, the increase in automation has brought a proliferation of problems in the areas of circuit designations, access codes, and other translation data necessary to operate and administer these automated maintenance tools.

A development for No. 4 Crossbar offices, TFMS, provides a centralized working data file for the office and improves the effectiveness of the existing tools by automating the interactions among them. An objective of TFMS is to automate or simplify several phases of the maintenance process such as trouble detection, service protection, routine testing, trouble sectionalization, and preservice testing. This development combines the TFMS function and the CTMS function in a single minicomputer system wherever TFMS is implemented in a No. 4 Crossbar office.

16.6.7 CIRCUIT MAINTENANCE SYSTEM NO. 1A (CMS NO. 1A)

The No. 4 ESS toll switching system will be associated with an office environment handling hundreds of thousands of trunks. CMS No. 1A has been developed to provide the necessary tools for the coordination and administration needed in a large modern office. CMS No. 1A is not a measurement system; rather, it is a maintenance administration system which provides a highly interactive CRT interface with craft personnel for trunk and special-service circuit maintenance.

The craftsperson will have access to complete circuit layout information, work orders, SMAS access codes, and information for interacting with CAROT for trunk testing and with CTMS and TCAS for carrier system testing (CTMS and TCAS are described in Section 16.7). From this position, the craftsperson can direct other systems to make measurements and can see the results displayed on the CRT.

It is expected that CMS No. 1A, in conjunction with the 1A Processor in a No. 4 ESS, will provide a highly automated environment for interaction with circuit provision (see Section 15.3) and network administration (see Section 14.7) operations. CMS No. 1A is scheduled for the first six No. 4 ESS installations. CMS No. 1B, which has greater capacity, is planned for subsequent installations.

16.7 CARRIER SYSTEM MAINTENANCE

The maintenance of carrier systems is handled quite differently from that of trunks. The combining of many voice-frequency circuits on a single carrier facility (close to 100,000 on some of the larger systems) necessitates the use of sophisticated alarm and surveillance techniques. In addition, periodic testing and maintenance usually are performed to ensure that the systems are properly aligned, although the trend with newer solid-state systems is toward reducing the amount and frequency of periodic maintenance.

Analog carrier systems use pilot tones applied at various frequencies throughout the band. These tones fall between standard channel frequency allocations and operate an alarm if they fall below a predetermined amplitude, thus indicating a system trouble condition. In addition, certain analog systems are monitored at intermediate repeater points. An example of this is the use of the C1 alarm system for long-haul microwave radio. In the event of a failure in a repeater station, a station-identifying alarm is transmitted back to the C1 alarm central. The central operator then can request a telemetry scan of the station for a limited amount of information regarding the detailed nature of the failure.

In the past several years, there has been considerable modernization in both system performance monitoring and alarm surveillance techniques. CTMS is an example of the former, and SCOTS, utilizing E telemetry, is an example of alarm surveillance. These are described in the sections immediately following. Section 16.7 concludes with a description of the T Carrier Administration System (TCAS), which provides alarm and performance monitoring of digital transmission systems.

16.7.1 CARRIER TRANSMISSION MAINTENANCE SYSTEM (CTMS)

CTMS is designed for use in major toll transmission offices in which the larger L carrier and broadband radio systems have appearances. CTMS provides a centralized and automated means for routine maintenance and trouble isolation in long-haul analog carrier systems and associated multiplex terminal equipment.

At the heart of CTMS are a minicomputer and a program-controlled selective detector tunable over a range of up to 60 MHz. This detector allows precise measurement of all incoming facility line pilot tones and scanning of the various multiplex equipments to determine whether they are aligned properly. In addition to measuring the actual frequency response of the system by monitoring pilot tones, the detector can pick up any spurious tones that will affect system performance. Also, slot noise measurements are made between supergroups throughout the system.

All of these measurements are done on an in-service basis, with a complete cycle performed almost daily. The minicomputer also allows the data to be analyzed to determine a transmission performance index and to display data in a format most useful for office personnel. In No. 4 Crossbar offices, CTMS and OTTS will be under the control of TFMS to provide rapid sectionalization of trunk and carrier system problems. CTMS also can be used on a stand-alone basis or can work in conjunction with systems such as CAROT and CMS No. 1A to provide sectionalization.

16.7.2 E TELEMETRY

The nature of facility alarm surveillance changed considerably with the advent of the family of E telemetry systems and components. In contrast to its B, C, and D alarm system predecessors, E telemetry is a true data acquisition and transmission system. Depending on the system configuration, it can monitor up to 4096 2-state status indications and can issue up to 4096 remote switch commands to each of a large number of E telemetry remote stations from a single central point.

Depending on the configuration, an E telemetry system can operate in an inquiry-response mode. A word is transmitted from the central location, containing a particular remote station's address and asking the remote station if it has anything to report. This procedure is repeated in rapid succession for each remote station. The remote reports can be of two basic types: alarm reporting or status reporting. With status reporting, all or a portion of the status information (usually in groups of 16, 64, 256, or 512 bits) is reported; status items are reported whether or not there is any new information. With alarm reporting, only the fact that a basic change-of-state alarm condition has occurred is reported, with a subsequent status report request required to find the specific cause of the alarm. Which type of reporting is used depends on the system being monitored and the activity factor of status changes. The data transmission speed is either 600 or 1200 bits per second, depending on the system being monitored, and requires a full voiceband data-grade network. The basic 16-bit word format used with E telemetry data transmission makes it particularly useful for applications utilizing minicomputers.

The versatility of E telemetry is such that it has become a general-purpose telemetry system for surveillance and control and is used as the backbone of many centralized maintenance systems. Included in this category are CPMS for cable maintenance, SCCS for centralized switching system maintenance (described in Section 16.5), and SCOTS and TCAS for analog and digital facility monitoring (described in the following sections).

16.7.3 SURVEILLANCE AND CONTROL OF TRANSMISSION SYSTEMS (SCOTS)

SCOTS is used for surveillance and control of broadband analog transmission systems for the purposes of facility maintenance and, eventually, facility management. SCOTS utilizes E telemetry to monitor approximately 100 radio and L coaxial carrier stations throughout a particular geographic area. The system is used primarily by AT&T Long Lines, and it is expected that there will be 25 to 30 SCOTS centrals located throughout the country to monitor the nearly 2500 long-haul radio and L carrier stations.

The SCOTS central contains a minicomputer and data base system that aids in trouble diagnosis and sectionalization to allow rapid manual restoration and maintenance of the troubled section.

The major benefits of SCOTS are that it consolidates the administration of routine facility maintenance activities and provides electronic data processing and record keeping for both routine maintenance and trouble isolation. In addition, the complete implementation of SCOTS will provide remote monitoring and control access to all the major nodes in the long-haul transmission facility network. It is anticipated that this real-time access to the status and control of working and spare (protection) facility channels will provide much of the data needed to allow more efficient utilization of long-haul facilities.

16.7.4 T CARRIER ADMINISTRATION SYSTEM (TCAS)

A typical T1 Carrier System, when viewed from end to end, is composed of channel banks at each end and a number of span lines (four or five on the average), where a span line is defined as a repeatered line section between two central offices. A faulty T1 system is restored on the basis of sectionalizing the trouble to the defective span line section and then patching a maintenance line (a spare span line) into the system while the faulty span line is being repaired. The coordination required for manual span line sectionalization and the efficient utilization of maintenance lines have been most difficult.

TCAS allows in-service monitoring of all T1 Carrier Systems in a metropolitan area and provides for efficient system administration and service restoration after a failure. The initial version of TCAS utilizes E telemetry to monitor all terminal carrier group alarms and the status of all maintenance lines that terminate in major hub offices. This capability will allow broad-scale patterning to rapidly determine when a major span cross section has failed and will improve the use of maintenance lines. In addition to actual failures, all alarm hits in excess of 300 milliseconds will be reported, so that systems with bad hit statistics can be identified. TCAS will be expanded to make actual line performance measurements at office repeater bays in terminal and intermediate offices by using E telemetry and directed line monitors. This added capability will allow automatic trouble sectionalization to faulty spans, efficient maintenance line utilization, and in-service system performance monitoring.

One of the major differences between the monitoring of digital systems and analog systems is that a direct measurement of system performance is readily available in the digital system from the error-rate performance. This performance can be monitored on an in-service basis by TCAS, and a report can be made when the quality becomes degraded. With analog systems, one has to determine the degree of quality from many indirect measurements such as white noise, impulse noise, envelope delay distortion, etc.

16.8 NETWORK TROUBLE ANALYSIS BUREAUS

Each of the systems discussed in Sections 16.5, 16.6, and 16.7 for switching system maintenance, trunk maintenance, and carrier system maintenance is designed to aid one portion of the telephone network. To ensure that the overall network provides good telephone service, network trouble analysis bureaus have been established. Their major inputs are reports of troubles encountered by operators and other Bell System employees. Their function is to analyze these trouble reports for patterns pointing to specific problems in the telephone network, which then can be referred to the local repair forces. To aid in the analysis of trouble reports, AT&T Long Lines has developed a central computer program, called NOTIS, which is run on a large computer in Cleveland every night. It processes trouble reports from the whole country and returns suspected trouble patterns to network trouble analysis bureaus in each operating company.

16.9 SPECIAL-SERVICE CIRCUIT MAINTENANCE

Special-service circuits include special-access switched circuits such as foreign exchange lines and trunks, off-premises extensions and stations, WATS and INWATS access circuits, CCSA access lines, CCSA trunks, PBX-CO trunks, and PBX tie trunks. They also include private lines such as point-to-point or multipoint voice and data circuits. Space limitations preclude covering specific maintenance on all of these different types of special-service circuits; however, major testing concepts and a number of new maintenance systems will be described.

To understand maintenance of special services, one must first understand that special services contain circuit layout, transmission, or signaling features that are not found in the public telephone network. Examples of special layouts include trunking between two PBX customers (PBX tie trunks) and multipoint data networks in which a particular station may communicate with many geographically dispersed stations. An example of a special transmission feature is channel conditioning for 9600-bit-per-second data transmission. An example of a special signaling feature is selective signaling, whereby a given station on a multipoint private-line voice circuit can ring any other station.

16.9.1 CONSOLIDATED EQUIPMENT CONCEPTS

One major improvement in special-service circuit maintenance is the use of new consolidated equipment arrangements. The voice-frequency facility terminal concept, described in Section 11.3.3, consolidates transmission, signaling, and circuit maintenance access functions in one equipment assembly, eliminating the need for intermediate distributing frames and complex office wiring. The use of functional plug-in units makes the initial engineering and subsequent maintenance of the circuits much simpler.

In a similar manner, special new bridging arrangements have been developed for multipoint private-line circuits. The transmission equipment for bridging and for level and equalization control has been combined in one unit, which also includes maintenance access jack panels.

16.9.2 SPECIAL-SERVICES HANDBOOK

One of the major problems in maintaining special services is that the printed material available for this purpose is spread over many sources: BSPs, Plant and Engineering Letters, Schematic Drawings (SDs), and Circuit Descriptions (CDs). An effort to remedy this is a newly compiled special-services handbook, known as the "Transmission and Signaling Test Plan and Analysis Concept (TSTPAC) Consulting Guide" or "Special-Services Consulting Guide." This document, published as BSP Section 660-215-500, provides a comprehensive reference for special-service circuits.

The material in the guide is divided into two major sections: (1) information applying directly to the process of testing and (2) background or reference information. Category (1) contains sections about symptom analysis and classification, trouble sectionalization procedures, installation testing procedures, and circuit element testing information. Category (2) contains descriptions of transmission and signaling performance requirements and test setups, descriptions of test sets and testboards, and a glossary of test-related items. It is expected that the guide will be a major step toward providing craft personnel with the information needed to perform their job more efficiently.

16.9.3 PRIVATE-LINE CIRCUITS

One major class of special-service circuits consists of private-line circuits reserved for the exclusive use of individual customers, but, of course, sharing the facilities network with the public telephone network and other traffic networks. Private lines vary enormously in length and complexity. Some are just 2-wire connections between 2 telephones, some are multipoint circuits connecting together 20 or more stations, and others are parts of large private-line networks. When one considers the special transmission and signaling implementations (see Section 11.3) required, there are over 2000 different arrangements of private lines.

One of the basic concepts in maintenance of multipoint private-line circuits has been to arrange the circuits so that many legs or branches terminate in a common office for test access. This is generally referred to as a hubbing layout, and the hub or test access office is known as a serving test center (STC). For large dispersed networks, one hub is often not practical, in which case a few STCs are used, with one being designated the network control office (NCO). Located at STCs are private-line testboards, or the equivalent, which have the testing responsibility for all private-line legs that emanate from the hub and terminate at the customers' premises. An STC may be responsible for testing circuits to which it does not have direct access; therefore, all the circuits for which an STC has testing responsibility do not necessarily have to be in a hubbing configuration.

16.9.4 TELEGRAPH NETWORKS

As mentioned in Section 3.3.4, certain teletypewriter and low-speed data services are provided by telegraph networks. Maintenance of telegraph networks is largely separate from maintenance of other telephone facilities and is, to some degree, unique. For example, telegraph testboards serve to maintain customer-premises' data communication terminals (teletypewriters) as well as the channels. Telegraph networks may have a very large number of stations and branch lines, and trouble on any one could disrupt a whole network. Thus, techniques for rapid localization of trouble have long been essential.

Telegraph networks have made extensive use of hubbing, STCs, and special-purpose testboards and have pioneered many of the maintenance concepts presently used for higher-speed data networks and other multipoint private-line services.

Telegraph networks use a special form of hub for connecting branch lines and for maintenance access; the signal at the hub point is direct current. This approach entails substantial expense in converting carrier signals to direct current, but it does permit a very high level of maintenance. For example, the signal at the hub can be monitored for what is called telegraph distortion, and, if a circuit is degrading, there will be an alarm at the testboard before an error has been made.

16.9.5 PRIVATE-LINE DATA NETWORKS

A major class of private-line networks consists of those handling data transmission. These networks are engineered and equalized (if necessary) to specified requirements,[3] so the network nominally will provide a particular bit error-rate performance between data sets at various locations. When performance is degraded, the source of the problem must be isolated to the data set equipment or the network.

Some data sets have local self-testing features, and others can be tested to some degree by the business machine at the terminal. Most sets, however, are optionally tested from a private-line data test center (DTC) which gains access to the data sets through appropriate STCs. With the data set put in a loop-back condition, data performance tests can be run between data transmission equipment at the DTC and the remote data set. The tests are basically of two types: static and dynamic. Static tests measure parameters such as facility gain margins in each direction and the data set slicer threshold frequency (in

3. These include the basic type 3002 data channel or C-1, C-2, and C-4 conditioning for progressively flatter amplitude and delay response. The tendency in recent data set designs is to require only the basic 3002-type channel.

the case of frequency-shift keyed sets). Dynamic tests include an actual bit error-rate measurement.

When these tests are performed in conjunction with certain line-side loop-back tests from the DTC or STC, the problem usually can be sectionalized to a particular network leg or terminal data set. If the data set is the source of the problem, a station repairman trained in data set repair is dispatched.

A new portable 914B test set is available. With this set, system tests, somewhat analogous to those made from a DTC, may be made from an STC. The 914B also may be used by the station repairman to test any of the Bell System voiceband data sets while on the customer's premises. The 914B replaces a whole series of earlier test sets and can be put in a number of different modes by proper setup of a front panel programmable matrix. A set with still further improvements, the 914C, is under development.

Data test centers also are used to test data sets and lines used in conjunction with DATAPHONE service. The access in this arrangement is via the public telephone network. There is usually a distinction between DATAPHONE DTCs and private-line DTCs, although they can be collocated.

16.9.6 AUTOMATIC DATA TEST SYSTEM (ADTS)

An ADTS has been developed. This system utilizes a minicomputer and disc file and is capable of performing tests on a number of remote data sets on a time-shared basis. A fully equipped ADTS can support the maintenance of about 20,000 data sets and will be deployed initially on the basis of about one per operating company. Access between the ADTS and the equipment to be tested will be via the public telephone network for DATAPHONE applications and via the public telephone network and SMAS (see Section 16.9.7) and or PL testboards for private-line systems.

To facilitate data set testing, ADTS stores those portions of the circuit layout record card information that relate to the station. The stored information includes the data set code and options, send level, receiver sensitivity, and SMAS access codes. In addition, the ADTS will retain the results of the five most recent measurements on each circuit so that it can detect trends and repetitive poor performers.

ADTS is compatible with and will work in conjunction with SARTS and CMS No. 3A, described subsequently.

16.9.7 SWITCHED MAINTENANCE ACCESS SYSTEMS FOR SPECIAL-SERVICE CIRCUITS

The growth in switched and nonswitched special-service circuits has been such that testboards with manual jack access to each circuit cannot possibly cope with the growing maintenance problems. To assist in this area, the Switched Maintenance Access System No. 1A (SMAS No. 1A) was developed. SMAS No. 1A includes a Crossbar switching arrangement that connects a few jacks at a 22A testboard to any of up to 2000 special-service circuits. All of the standard tests, such as transmission loss, noise, and delay distortion, that special-service circuits require can be made at the testboard. Connections are selected by dialing 4-digit numbers from a test console.

The SMAS No. 3 described previously in Section 16.6.5 was developed primarily for switched access to trunks as part of the unitized terminal equipment (see Section 11.3.3). Since the unitized terminals are utilized for the buildup of many special-service circuits in addition to public telephone network trunks, the SMAS No. 3 equipment in this arrangement also is used for special-service circuit access for local testing and will be compatible with remote testing via SARTS as subsequently discussed.

SMAS No. 4A was developed as a primary building block for the Switched Access Remote Test System described in Section 16.9.8. It includes a Crossbar switching arrangement that can make connections to a maximum of 40,000, 20,000, or 18,000 access points depending on whether the access points are 2-wire, 4-wire, or 6-wire, respectively. When there are mixes of access point types, the maximum capability depends on the mix.

16.9.8 SWITCHED ACCESS REMOTE TEST SYSTEM (SARTS)

SARTS will use SMAS access and remote-controlled test equipment to give one person, located at a central test position, the capability to access and test the various segments of special-service circuits.

SARTS No. 1A will be implemented in three phases, with phase 1 calling for the installation of SMAS No. 4A at various remote central office buildings (that is, remote from the SARTS central position) and for manual testing to be performed from those offices. In phase 2, a Remote Test System No. 1A (RTS No. 1A) will be added at the central offices, providing one-man testing from the SARTS central test position No. 52A (TP No. 52A). Records, procedures, and administration will be handled manually. Phase 3 will provide for integration with the Circuit Maintenance System No. 3A (CMS No. 3A) to further automate the testing, administration, and record-keeping procedures as described in Section 16.9.9.

SARTS No. 1A, shown in Fig. 16-7, will consist of four elements: at the far end remote offices, a SMAS No. 4A and the RTS No. 1A; at the central location, the TP No. 52A and a process controller (PC No. 1A). The TP No. 52A will include a DATASPEED 40 terminal for interactive control and display of test information.

The RTS No. 1A will include the capability to test transmission characteristics (noise, level, frequency), ac/dc quantities (current, voltage, resistance, capacitance), and operational and signaling functions (talking, ringing, dialing, supervision). More sophisticated tests (such as signaling and envelope delay distortion tests) will be added in the future.

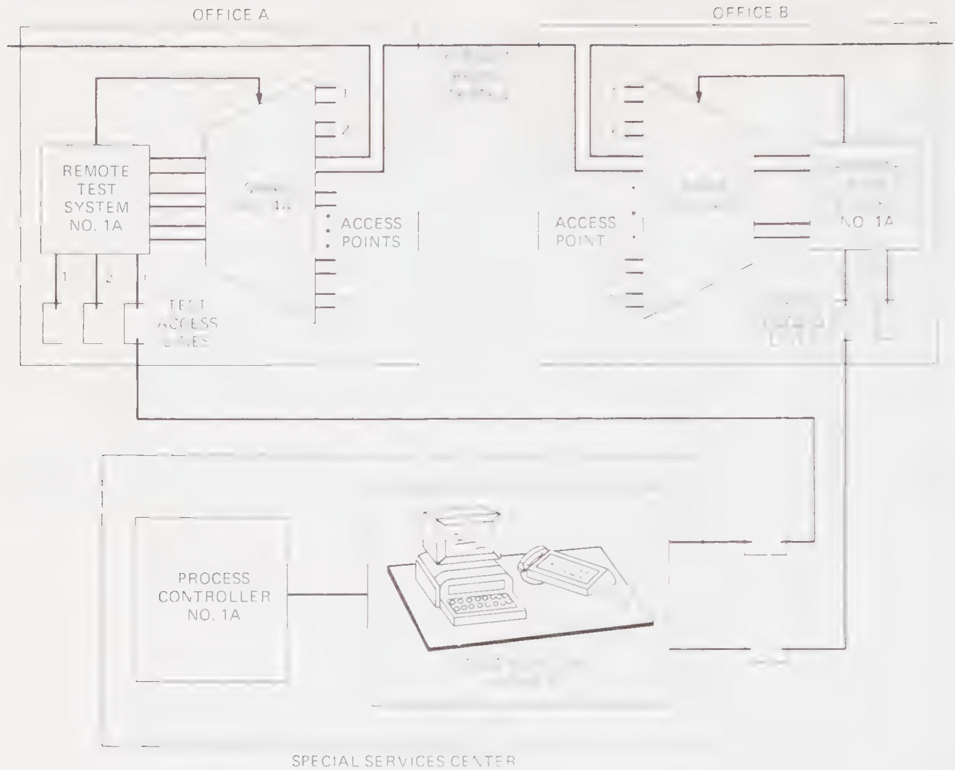


Fig. 16-7. Switched Access Remote Test System No. 1A

16.9.9 CIRCUIT MAINTENANCE SYSTEM NO. 3A (CMS NO. 3A)

CMS No. 1A was described in Section 16.6.7 in conjunction with trunk testing in a No. 4 ESS office. CMS No. 3A is a regional system initially aimed at special services.[4]

CMS No. 3A will initially mechanize the administrative and record-keeping functions associated with special-service maintenance. Later, CMS No. 3A will be integrated with SARTS to automate the testing, record-keeping, and administrative procedures fully. The system also will interface with record-source systems such as TIRKS to obtain its circuit-related data base. In addition, operational interfaces will be provided with other test and maintenance systems (e.g., CTMS, TCAS, LMOS, and ADTS) in order to perform the total special-services maintenance function in a coordinated manner. CMS No. 3A will mechanize the entire maintenance function and will display circuit layout cards automatically on an operator's CRT. CMS No. 3A will be a

4. CMS No. 3A is designed for operating company applications. CMS No. 2A, not described here, is designed for Long Lines applications.

regional system providing for all maintenance operations within a geographic area and will have interfaces with other CMS No. 3A systems to coordinate operations for circuits traversing multiple areas.

16.10 SUMMARY AND TRENDS

As this chapter has emphasized, the trends in maintenance today are obviously toward further centralization, the extensive use of monitoring with telemetry systems, and the development of sophisticated maintenance centrals utilizing minicomputers. The main advantages of this approach include effective use of craft personnel, more frequent monitoring, specific sectionalization of trouble conditions, automatic data analysis, and issuance of management reports.

Fortunately, technology is available today to make the centralized automated approach to maintenance economically feasible. Minicomputer main frames have been reduced dramatically in cost, to the point where some of the smaller maintenance applications can be developed with the hardware portions of automated centrals costing only about $15,000. The larger disc-supported systems may cost as much as $600,000 for central hardware, but each of these applications also has been economically justified.

Some of the automated surveillance and testing systems that have been described are ALIT and CPMS for loops; SCCS for switching; CAROT and OTTS for trunks; CTMS, SCOTS, and TCAS for transmission facilities and terminals; and SARTS and ADTS for special-service circuits. All of these systems have unique capabilities and requirements; however, they have in common their provision of either surveillance and control or making measurements associated with their particular application.

To support these systems and to make the operations more meaningful to craft personnel in terms of their working environment, a number of maintenance administrative systems exist. These either deal with the equipment and circuit records needed by craft personnel when a trouble condition occurs or actually provide an interactive environment from which one or more of the maintenance systems can be exercised to localize the problem. Typical of these administrative systems are LMOS for station loops, TFMS for No. 4 Crossbar trunks, and CMS for No. 4 ESS trunks and special-service circuits.

Most of the systems described in this chapter, known as Operations Support Systems, are or will be available to operating companies through direct purchase from Western Electric. Development of the systems, including software and special purpose hardware as required, is funded by Western Electric. In most cases, computers are purchased from computer manufacturers by Western Electric for the operating companies. Western Electric services available to the operating companies in connection with these systems include assistance in planning, engineering, and installing systems and in establishing large data bases.

One of the major problems that will develop as these systems are implemented is that of providing an optimum environment for interactions between the various maintenance systems. Each system has been justified on its own merits; however, there are obvious cases in which a certain amount of synergism could be generated by combining system concepts. This is not just a Bell Laboratories problem in providing technical interfaces and computer-to-computer interactions. The problem extends to the ways in which the operating companies are organized to do business today. Some of the present boundaries that have been established for administrative purposes are obviously not as meaningful with these new system capabilities. The organizational interactions within a particular area also are affected. Studies are under way to determine how operating companies can make most effective use of the systems that have been described.

It may be well to look again at Fig. 16-1, which was introduced at the beginning of this chapter. At present, the primary problem in maintenance for the Bell System is the successful field implementation and utilization of these many sophisticated maintenance systems. Following that, the principal problem clearly will be the synergistic interaction of these various systems from both the technical and administrative viewpoints.

TABLE 16-1
ACRONYMS

ADOIT	Automatically Directed Outgoing Intertoll Trunk
ADTS	Automated Data Test System
ALIT	Automatic Line Insulation Test
ANALIT	Analysis of Automatic Line Insulation Tests
AOTT	Automatic Outgoing Trunk Test
ARSB	Automated Repair Service Bureau
ATA	Automatic Trouble Analysis
ATMS	Automatic Transmission Measurement System
BSP	Bell System Practice
BSRS	Bell System Repair Specification
CAROT	Centralized Automatic Reporting On Trunks
CD	Circuit Description
CMS	Circuit Maintenance System
COMAS	Computerized Maintenance and Administration System
COMMS	Central Office Maintenance Management System
CORDS	Coordination of Record and Data Base System
CPMS	Cable Pressure Monitoring System
CTMS	Carrier Transmission Maintenance System
DTC	Data Test Center
EM-SCC	Electromechanical Switching Control Center
LMOS	Loop Maintenance Operations System
LSV	Line Status Verifier
LTD	Local Test Desk
MCC	Master Control Center
MLT	Mechanized Line Testing
NCO	Network Control Office
NOTIS	Network Operations Trouble Information System
OTTS	Outgoing Trunk Testing System
PBC	Peripheral Bus Computer
PC	Process Controller
PICS	Plug-In Inventory Control System

ROTL	Remote Office Test Line
RSB	Repair Service Bureau
RTS	Remote Test System
SARTS	Switched Access Remote Test System
SCC	Switching Control Center
SCCS	Switching Control Center System
SCOTS	Surveillance and Control of Transmission Systems
SD	Schematic Drawing
SMAS	Switched Maintenance Access System
SMASH	Step-by-Step Monitor and Selector Hold
STC	Serving Test Center
TASC	Telecommunications Alarm Surveillance and Control
TCAS	T-Carrier Administration System
TFMS	Trunk and Facilities Maintenance System
TMF	Trunk Maintenance Files
TOPP	Task Oriented Plant Practice
TP	Test Position
TSTPAC	Transmission and Signaling Test Plan and Analysis Concept

17 Evaluation of Services and Operations

Previous chapters have presented aspects of engineering and operations having the objective of providing communications services. This final chapter addresses the subject of evaluating the quality of services and the effectiveness of operations. It indicates that the loop is closed as the evaluations react back on engineering objectives and on management of operations.

17.1 INTRODUCTION

It is the aim of the Bell System to provide service that is satisfactory to the customer and to do so economically. Pursuit of this goal raises a number of difficult questions:

(1) What service levels will satisfy the customer, and at what point is the added cost of improving service no longer commensurate with the accompanying increase in customer satisfaction?

(2) How can technical objectives be set for network elements so that final end-to-end connections meet desired levels for customer satisfaction?

(3) How can system performance be monitored to ensure that the objectives are being met?

This chapter will attempt to provide some insight into the approaches and methods employed to address these questions.

Section 17.2 focuses on setting objectives. It is appropriate to discuss objectives first because they have an important bearing on the level of service provided to the customer and on the service evaluation process itself. Furthermore, service evaluation results can in turn be used to study the adequacy of specified objectives.[1]

Sections 17.3 and 17.4 are concerned with two means of monitoring system performance: index results and characterization surveys. Index results are

1. Some aspects of performance objectives were previously discussed in Section 6.3, "Transmission Plans," and Section 14.2, "Traffic—Setting Objectives."

generated within the operating companies and are summarized by AT&T to determine if satisfactory network performance is being maintained in the various subdivisions of the Bell System. Network performance characterization surveys are conducted periodically by Bell Laboratories, in cooperation with AT&T and the operating companies, to provide data needed (1) to refine network parameters[2] and performance models, (2) to analyze trends that may be developing for specific network parameters, and (3) to characterize parameters that may not have been surveyed previously. Such parameter characterization is needed to set realistic objectives and to determine if performance is adequate for anticipated voice and data uses.

Section 17.5 describes customer attitude measurements and customer trouble report analysis. Customer opinion, as reflected by these measures, is contrasted with human factors experiments as a tool for service evaluation.

Finally, Section 17.6 emphasizes the interactive and continuing nature of the work described in Sections 17.2 through 17.5.

17.2 SETTING PERFORMANCE OBJECTIVES

17.2.1 DIMINISHING RETURNS EXEMPLIFIED

An important element in setting objectives is striking a balance between striving for the best possible service and striving for the minimum possible cost. To strike this balance, it is helpful to identify performance regions in which the return in customer satisfaction is not commensurate with the increase in dollar investment needed to further improve performance or, conversely, in which savings can be realized without significant reduction in customer satisfaction.

A few specific examples will illustrate this point. First, consider a trunk group that does not overflow to an alternate route and is experiencing customer bids for service, where the service demand can be characterized mathematically as 720 CCS (20 Erlangs) of traffic per hour. The probability that a customer's call will encounter all trunks busy in the group can be determined for various trunk group sizes through the use of Poisson trunk capacity tables. Some illustrative probabilities are given in the following table:

NUMBER OF TRUNKS	PROBABILITY OF BLOCKING
28	0.07
32	0.01
36	0.001

It can be seen that the same number of trunks (four) must be added to the group to realize the 0.009 improvement in blocking between 0.01 and 0.001 as must be added to the group to realize the 0.06 improvement in blocking between 0.07 and 0.01. It seems reasonable to expect that customers will ac-

2. Such network parameters as, for example, noise and phase jitter.

cept some small probability of encountering all trunks busy (on the order of 0.01, for example) in preference to having their bills reflect the significant sums of money required to drive blocking closer and closer to zero.

As a second example of a diminishing-returns situation, consider the case of customer reaction to varying amounts of noise at the line terminals of a 500-type telephone set. Subjective tests have been conducted wherein received volume was held constant, noise was varied, and test participants were asked to rate circuit quality as excellent, good, fair, poor, or unsatisfactory. It was found[3] that a satisfactory model of opinion, showing the proportion of respondents rating the circuit quality as good or better, could be obtained by fitting a normal distribution function to the data. This is represented in the following table:

NOISE LEVEL AT STATION SET IN dBrnC	PERCENT OF PARTICIPANTS RATING CIRCUIT QUALITY GOOD OR BETTER
39	50.00
33	84.13
27	97.73
21	99.87
15	99.99

If the assumptions are made that each 6-dB improvement in noise is about equal in cost and that customers will react to noise in the same way as the test subjects, it then costs the same to satisfy an additional 47-3/4 percent of the customers in reducing the noise level from 39 to 27 dB as it costs to satisfy an additional 2-1/4 percent of the customers in reducing the noise level from 27 to 15 dB. Obviously, some judgment must be exercised regarding where to draw the line on the stringency of objectives (and hence the magnitude of costs) for noise mitigation programs and new transmission system designs.

The preceding two examples show some of the tradeoffs and judgments that are inevitable in setting objectives. Section 17.2.2 will give a more elaborate example.

17.2.2 TRANSMISSION OBJECTIVES

A concept known as grade of service is commonly used to determine acceptable telephone transmission objectives.[4] It combines the distribution of customer opinion with the distribution of plant performance to obtain the expected percentage of customer opinion in a given category (circuit quality good or better, for example).

3. See References 1 and 2.

4. Chapter 3 of Reference 1 contains an informative discourse on message channel transmission objectives. Much of the material presented here is taken from that discourse.

Grade of service is defined by the integral

$$\int P(R\,|\,X)f(X)dx$$

where $P(R\,|\,X)$ is the conditional probability that a customer will rate a call in category R, given a value X of the stimulus, and $f(X)$ is the probability density function of obtaining that stimulus. The distribution function, $P(R\,|\,X)$, is obtained through subjective tests that measure reactions of groups of subjects to various controlled levels of the given stimulus (which may be noise, volume, bandwidth, etc.). The density function, $f(X)$, characterizes overall system performance for the given stimulus.

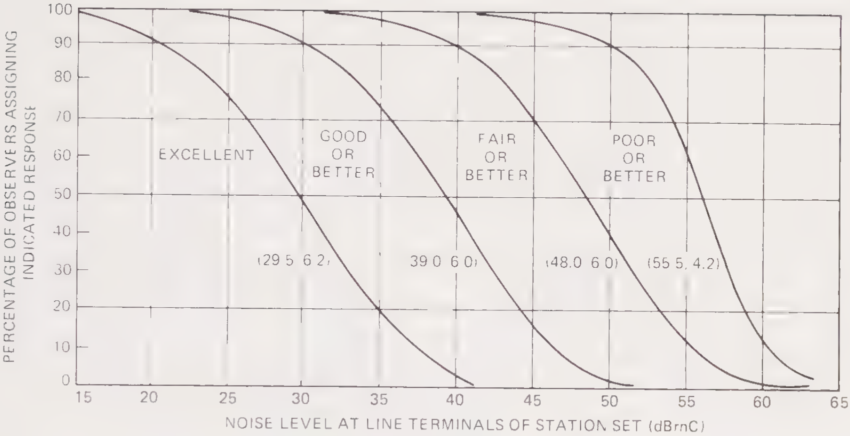
The process used to determine grade of service is illustrated in Fig. 17-1. Controlled subjective tests provide the needed opinion curves, and surveys of connections provide the required performance distributions.

Fig. 17-1. Approach Used in Deriving Grade of Service

One problem faced in conducting subjective tests is that the effects of various stimuli are interdependent. In testing the effects of noise and loss, for example, both the noise and loss stimuli must be varied so that different combinations of noise and loss can be observed. Parameters whose variation would have only second-order effects on subjective reaction to the stimuli under investigation can be held at typical or nominal values while the stimuli of interest are varied.

The grade-of-service determination process was used to set carrier system objectives for telephone circuit noise as follows. Subjective tests were conducted using 500-type telephone sets as discussed in connection with the diminishing returns example. The results of these tests, plotted in cumulated categories, are shown in Fig. 17-2. Presented in this way, the curves show the proportion of excellent, good or better, fair or better, and poor or better judgments at particular noise levels. A simplified model that adequately represents the results is obtained by fitting normal distribution functions to the data.

Several surveys of noise performance of toll connections have been taken (see Section 17.4.1). Results of the 1962 connection survey are shown in Fig. 17-3. These results, combined with the subjective test results, gave the noise grades of service shown in the box in Fig. 17-3.



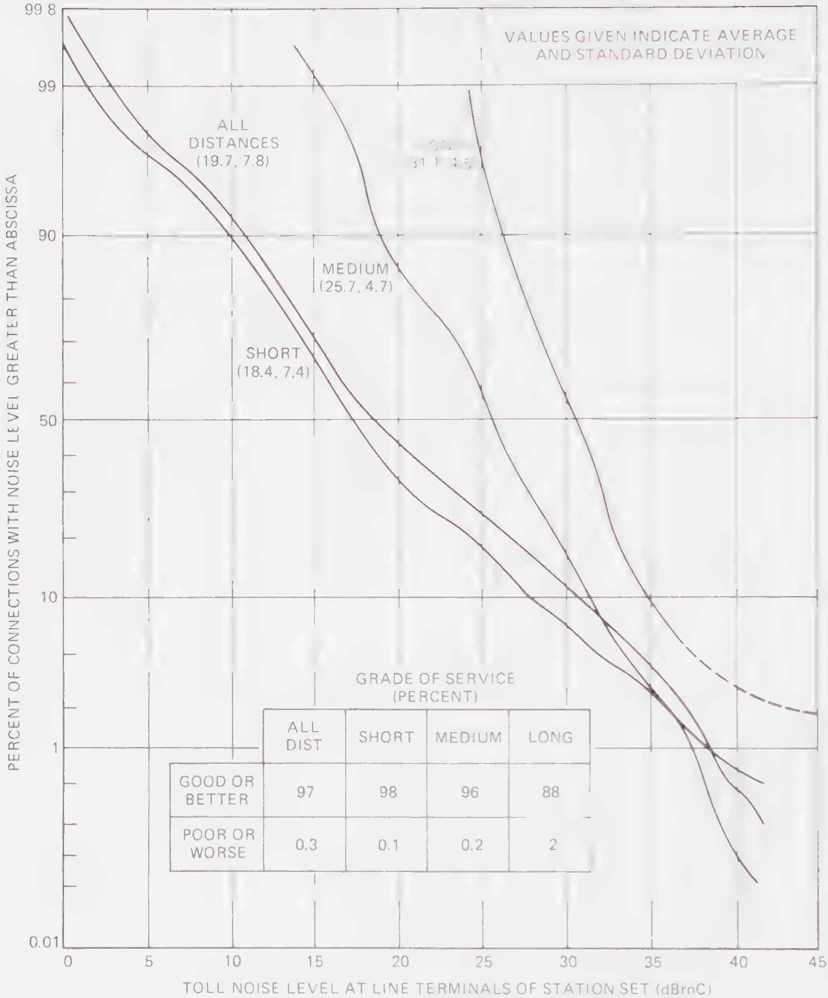
NOTES
1. VALUES IN PARENTHESES INDICATE AVERAGE AND STANDARD DEVIATION
2. RECEIVED VOLUME CONSTANT, − 28 VU.

Fig. 17-2. Noise Judgment Curves

These noise grades of service are a measure of customer satisfaction for the performance distribution reflected in the curves of Fig. 17-3. The overall noise grade of service was 97 percent good or better. Note, however, that it was 88 percent good or better for the long (721- to 2900-mile airline distance) calls. The reason for the poorer performance on the long calls is that mean noise doubles with a doubling of distance. Since the number of calls made decreases rapidly with distance, these long calls, although individually important, have a small effect on the total grade-of-service calculation.

It was decided, after analysis of the 1962 data, that the mean noise on long distance calls could be and should be economically reduced about 3 dB by future carrier system designs, so that the noise grade of service would be 95 percent good or better for long calls.

Since system noise is in part controlled by the design objectives for carrier systems that make up toll connections, it will be instructive to turn now to the carrier system design objectives that were set for telephone circuit noise. Long-haul (for distances greater than 250 miles) and short-haul (for distances less than 250 miles) carrier noise objectives were derived to satisfy customer-to-customer requirements when these systems are switched together to form connections of 1000 to 4000 circuit-miles. Satisfaction of requirements for shorter distances is thereby accomplished as well. These objectives specify not only the noise attributable to the transmission portion of a trunk, but also that attributable to a representative set of multiplex terminals.



	ALL DIST	SHORT	MEDIUM	LONG
GOOD OR BETTER	97	98	96	88
POOR OR WORSE	0.3	0.1	0.2	2

Fig. 17-3. Estimated Toll Noise Distribution (From 1962 Connection Survey Data)

The optimum allocation of total noise between short-haul and long-haul facilities is not directly proportional to length. Economic considerations make it desirable to allow more noise per mile on short-haul facilities.

Noise on long-haul and short-haul carrier facilities is assumed to be normally distributed at any given route mileage. The mean values of the distributions are assumed to vary as a function of distance as shown in Fig. 17-4; the standard deviations are assumed to be a constant 4 dB at all distances.

For the noise objective, mean values of 28 dBrnC0 at 60 route-miles and 34 dBrnC0 at 1000 route-miles have been selected for short-haul and long-haul

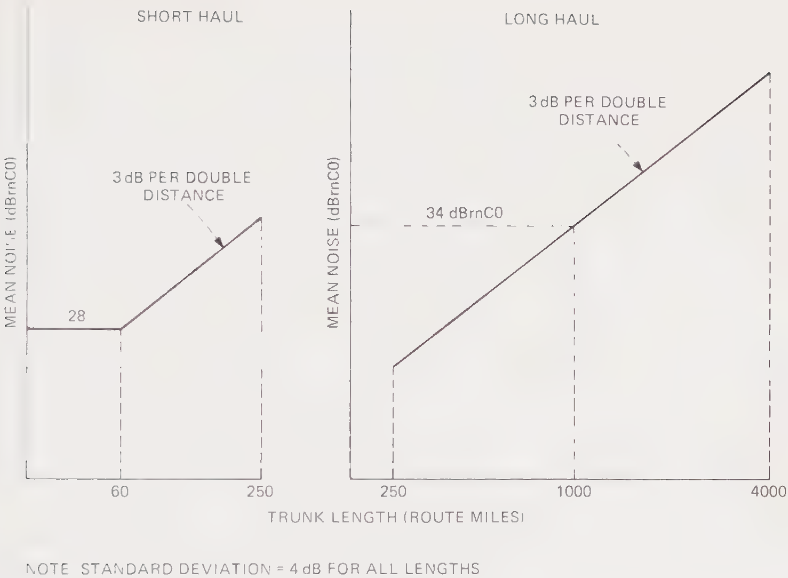


Fig. 17-4. Length Dependence of Mean Values of Carrier Noise Objectives

carrier systems, respectively. The mean noise objectives for systems of other lengths can be obtained from Fig. 17-4.

The division of noise between short-haul and long-haul systems was based upon the noise performance of the types of systems under development and the economics of noise reduction in those systems. A different pairing of the objectives also could give the desired grade of service, but would not result in the most economical solution.

Objectives have also been set for such transmission parameters as impulse noise, frequency response, echo, loss, and crosstalk. The rationale for setting these objectives is analogous to that described for telephone circuit noise. Transmission objectives are used by Bell Laboratories engineers to serve as a guide in the design and layout of equipments and systems and by AT&T engineers to serve as a guide in setting operation and maintenance requirements for telephone company personnel.

17.2.3 LESS TRACTABLE PARAMETERS

Objectives must also be set for such network performance parameters as percent dial tone delayed, percent blocking on trunk groups, and percent switching equipment irregularities. These objectives serve as a guide for Bell Laboratories designers who need to determine the reliability required of switching equipment and for operating company personnel who need to determine the number of trunks and the amount of switching equipment to provide for anticipated traffic loads.

Setting objectives for these parameters tends to be more difficult than for transmission parameters. One reason is that traffic-related parameters are strongly time-dependent. For example, the probability that a trunk in a particular group will be available for a call will vary depending on whether one considers the fixed busy hour, bouncing busy hour, high day, ten high day, or weekly peak load associated with the group. Furthermore, it is more difficult to design controlled human factors experiments that relate meaningfully to such parameters; hence, it is more difficult to specify $P(R \| X)$ functions for them. A higher degree of qualitative judgment and intuition has been involved in establishing overall objectives for these parameters.

It is interesting to observe the contrast between objective setting for the parameters mentioned in this section and for the parameters of Section 17.2.2. However, analogies that exist are also of interest. For example, apportioning traffic economically between direct and alternate trunk routes for any given level of blocking is analogous to apportioning noise economically among the facilities contributing to the total noise of a connection.

One final point warrants mention. The parameters discussed in this section are undergoing reexamination to determine if objectives that relate more quantitatively to customer satisfaction can be established. More will be said of this in Section 17.5.

17.3 BELL SYSTEM INDEX PLANS

For some time, the Bell System has used index plans to monitor uniformity of performance throughout the Bell System and to monitor performance relative to the level of a base period. Each index plan is established to monitor a particular portion of Bell System plant (such as switching systems) or facet of telephone service (such as billing). Index plans of interest in this chapter involve one or more parameters of network transmission, traffic, or switching. The trunk transmission maintenance index plan, for example, monitors the performance of trunks and involves three transmission parameters: noise, loss, and balance.

For each parameter involved in an index plan, an index table is used to convert the raw performance measurement (such as percent calls blocked) to an index score. The index table for each parameter is generated by determining the performance of appropriate network elements during a base period and then rank-ordering the elements. A network element as used in an index plan is, for example, a No. 1 Electronic Switching System, the loops associated with a wire center, or the trunks associated with a wire center. Three index points—100, 97, and 90—are specified; 100 is the index score given to a performance level exceeded by only 2-1/2 percent of the network elements during the base period; 97 is the score given to the median performance level; and 90 is the score given to the performance level exceeded by 97-1/2 percent of the network elements. A curve which passes through these three specified points is generated, using a mathematical fitting program available through the Statistics and Operations Research Analysis Group of AT&T. The index table, which relates any measured performance level to a corresponding index score between 0 and 100, is based on the fitted curve.[5] An index in the range of 99-100 is considered excellent, in the range of 96-98 is fully satisfactory, in the range of 90-95 is fair to mediocre, and below 90 is unsatisfactory.

The mechanics of setting up an index table are more straightforward[6] for some parameters than for others. To establish a table for percent overflows or percent equipment irregularities, for example, the performance levels (that is, the percent overflows or irregularities experienced) for network elements can be simply rank-ordered at a particular point in time, the key index points can be picked, and a fitted curve generated. Other parameters pose more difficulties. Transmission performance index curves, for example, are based on percentages of loops, trunks, or connections exceeding specified noise or loss-variation limits. For these parameters, technical considerations must go into setting the limits before percentages are determined and the elements rank-ordered. Similarly, the dial tone speed index curve is based on the percentage of busy-hour calls for which dial tone delay exceeds 3 seconds; thus, the 3-second limit must be specified before the elements are rank-ordered.

For convenience, the index score achieved for a particular parameter is simply called the index achieved. When an index plan includes several components, the overall index is determined as a weighted sum of the component indices. The trunk transmission maintenance index (score), for example, is determined as the weighted sum of the noise, loss, and balance (echo and singing return loss) component indices. The index plan specifies how the weight is to be apportioned.

Once an index plan has been established, it provides a measure of how well telephone company subdivisions (districts, divisions, etc.) are controlling the parameters indexed.

Since results are reported to virtually all levels of management, achieving satisfactory index scores is of considerable interest in the operating companies.

17.3.1 CURRENT TRANSMISSION INDEX PLANS

The following three transmission index plans are presently in use:

(1) *Connection Appraisal Index Plan*

Connection appraisals, which are administered by the operating company engineering department, consist of transmission observations on connections dialed from a central office. Because these calls in-

5. These fitted curves are typically S-shaped; examples of derived index tables are provided in Tables 17-1 through 17-3.

6. Even in the most straightforward cases, a suitable population of network elements must be specified for rank-ordering.

clude all of the components of plant used in a telephone call except customer loops and stations, they are indicators of the transmission performance of trunks in connections. The method of sampling is designed to produce meaningful indices for divisions and areas within a company, as well as for a complete company.

Local Component—Fifty loss observations and 50 noise observations are made from each sampled office. These measurements are made to test loss and noise on circuits in local offices reached on a free or message-unit basis.

Toll Component—Fifty loss observations and 50 noise observations are made from each sampled office. These measurements are made to test loss and noise on circuits in called offices that are selected to represent the calling pattern of the customers served by the sampled office.

(2) *Trunk Transmission Maintenance Index Plan*

The trunk transmission maintenance index is based on routine maintenance loss and noise measurements and sampling surveys to determine toll office balance, all conducted by the plant department. The index is developed as a weighted combination of loss, noise, and balance components.

(3) *Subscriber Plant Transmission Index Plan—Noise Component*

The noise component is currently the only component of this index plan. It is based on summaries of noise surveys, usually made by the plant department. The noise surveys are made in the central office, on lines with all stations on-hook. The results are summarized quarterly. The survey results are combined to develop area and company component indices that provide a picture of the general level of noise performance.

To see how an index is calculated in practice, the local component of the connection appraisal index (CAI) will be considered. Although this index is being revised, it is a useful example of how an index is calculated; note, however, that the formulation and numerical values, including the associated tables, are subject to change. The loss portion of the local component of the CAI will be considered first. An effort is made to keep loss on local connections within a specified range of values. If this effort is successful, more than 80 percent of the connections will have less than 5.5 dB loss, and fewer than 2 percent will have more than 8 dB loss. The index score provides a measure of how well loss has been controlled. Performance is rated by considering the 5.5- and 8-dB points on the loss distribution curve and by awarding index points on the basis of:

Percent calls with loss ≥8 dB (less is better) (20 percent weighting)

Percent calls with loss <5.5 dB (more is better) (30 percent weighting)

The associated index tables are given in Tables 17-1 and 17-2. Suppose, for example, that one of the 50 loss observations exceeded 8 dB and that 41 of the 50 were less than 5.5 dB. Tables 17-1 and 17-2 indicate that the local loss component index of the CAI would then be 19.2 + 29.1 = 48.3.

TABLE 17-1
CONNECTION APPRAISAL INDEX
LOCAL COMPONENT
LOSS—UPPER REFERENCE

PERCENT STEP	SUB-COMP. INDEX	COMP. POINTS	PERCENT STEP	SUB-COMP. INDEX	COMP. POINTS
0.0-0.1	100	20.0	6.5- 6.6	86.0	17.2
0.2-0.3	99.5	19.9	6.7- 6.8	85.0	17.0
0.4-0.6	99.0	19.8	6.9- 7.1	83.0	16.6
0.7-0.9	98.5	19.7	7.2- 7.5	81.0	16.2
1.0-1.2	98.0	19.6	7.6- 7.8	79.0	15.8
1.3-1.4	97.5	19.5	7.9- 8.1	77.0	15.4
1.5-1.7	97.0	19.4	8.2- 8.5	74.0	14.8
1.8-1.9	96.5	19.3	8.6- 8.9	71.0	14.2
2.0-2.2	96.0	19.2	9.0- 9.2	68.0	13.6
2.3-2.5	95.5	19.1	9.3- 9.5	64.0	12.8
2.6-2.8	95.0	19.0	9.6- 9.9	60.0	12.0
2.9-3.0	94.5	18.9	10.0-10.3	55.0	11.0
3.1-3.3	94.0	18.8	10.4-10.7	50.0	10.0
3.4-3.5	93.5	18.7	10.8-11.1	45.0	9.0
3.6-3.8	93.0	18.6	11.2-11.6	40.0	8.0
3.9-4.1	92.5	18.5	11.7-12.1	35.0	7.0
4.2-4.3	92.0	18.4	12.2-12.6	30.0	6.0
4.4-4.6	91.5	18.3	12.7-13.2	25.0	5.0
4.7-4.9	91.0	18.2	13.3-13.9	20.0	4.0
5.0-5.1	90.5	18.1	14.0-15.0	15.0	3.0
5.2-5.4	90.0	18.0	15.1-17.1	10.0	2.0
5.5-5.6	89.5	17.9	17.2-19.8	5.0	1.0
5.7-5.8	89.0	17.8	Over 19.8	0.0	0.0
5.9-6.1	88.0	17.6			
6.2-6.4	87.0	17.4			

TABLE 17-2
CONNECTION APPRAISAL INDEX
LOCAL COMPONENT
LOSS—LOWER REFERENCE

PERCENT STEP	SUB-COMP. INDEX	COMP. POINTS	PERCENT STEP	SUB-COMP. INDEX	COMP. POINTS
Over 97	100	30.0	45.1-46.6	90.0	27.0
95.5-97.0	99.7	29.9	43.5-45.0	89.7	26.9
93.8-95.4	99.3	29.8	41.8-43.4	89.3	26.8
92.1-93.7	99.0	29.7	40.1-41.7	89.0	26.7
90.4-92.0	98.7	29.6	38.0-40.0	88.4	26.5
88.7-90.3	98.4	29.5	36.0-37.9	87.8	26.3
86.9-88.6	98.1	29.4	34.0-35.9	87.0	26.1
85.0-86.8	97.7	29.3	32.0-33.9	86.2	25.9
83.2-84.9	97.3	29.2	30.0-31.9	85.2	25.6
81.4-83.1	97.0	29.1	28.1-29.9	84.2	25.3
79.6-81.3	96.7	29.0	26.5-28.0	83.2	25.0
77.8-79.5	96.4	28.9	25.0-26.4	82.4	24.7
76.0-77.7	96.1	28.8	23.5-24.9	81.4	24.4
74.1-75.9	95.7	28.7	22.0-23.4	80.4	24.1
72.3-74.0	95.3	28.6	20.5-21.9	79.4	23.8
70.6-72.2	95.0	28.5	19.1-20.4	78.4	23.5
69.0-70.5	94.7	28.4	17.7-19.0	77.4	23.2
67.4-68.9	94.4	28.3	16.3-17.6	76.4	22.9
65.7-67.3	94.1	28.2	14.9-16.2	75.4	22.6
63.9-65.6	93.7	28.1	13.5-14.8	74.0	22.2
62.1-63.8	93.3	28.0	12.0-13.4	72.7	21.8
60.2-62.0	93.0	27.9	10.5-11.9	71.4	21.4
58.3-60.1	92.7	27.8	9.0-10.4	70.0	21.0
56.5-58.2	92.3	27.7	7.6- 8.9	68.7	20.6
54.7-56.4	92.0	27.6	6.2- 7.5	67.4	20.2
53.0-54.6	91.7	27.5	4.9- 6.1	66.0	19.8
51.3-52.9	91.3	27.4	3.6- 4.8	64.7	19.4
49.7-51.2	91.0	27.3	2.3- 3.5	63.4	19.0
48.2-49.6	90.7	27.2	1.1- 2.2	62.0	18.6
46.7-48.1	90.3	27.1	0.0- 1.0	60.7	18.2

For the noise portion of the local component of the CAI, performance is rated as a function of the percent of calls exceeding a reference of 25 dBrnC. The associated index table is given in Table 17-3. Assume that 3 of the 50 noise observations exceeded 25 dBrnC; Table 17-3 indicates that the local noise component index of the CAI would be equal to 48.2.

TABLE 17-3
CONNECTION APPRAISAL INDEX
LOCAL COMPONENT
NOISE

PERCENT STEP	SUB-COMP. INDEX	COMP. POINTS	PERCENT STEP	SUB-COMP. INDEX	COMP. POINTS
0.0-1.1	100	50.0	18.6-19.1	86.6	43.3
1.2-1.7	99.6	49.8	19.2-19.7	85.6	42.8
1.8-2.3	99.2	49.6	19.8-20.3	84.6	42.3
2.4-2.9	98.8	49.4	20.4-20.9	83.6	41.8
3.0-3.5	98.4	49.2	21.0-21.5	82.4	41.2
3.6-4.1	98.0	49.0	21.6-22.1	81.0	40.5
4.2-4.7	97.6	48.8	22.2-22.7	79.4	39.7
4.8-5.3	97.2	48.6	22.8-23.3	77.8	38.9
5.4-5.9	96.8	48.4	23.4-23.9	76.2	38.1
6.0-6.5	96.4	48.2	24.0-24.5	74.6	37.3
6.6-7.1	96.0	48.0	24.6-25.1	72.6	36.3
7.2-7.7	95.6	47.8	25.2-26.3	70.0	35.0
7.8-8.3	95.2	47.6	26.4-27.5	65.0	32.5
8.4-8.9	94.8	47.4	27.6-28.7	60.0	30.0
9.0-9.5	94.4	47.2	28.8-29.9	55.0	27.5
9.6-10.1	94.0	47.0	30.0-31.1	50.0	25.0
10.2-10.7	93.6	46.8	31.2-32.3	45.0	22.5
10.8-11.3	93.2	46.6	32.4-33.5	40.0	20.0
11.4-11.9	92.8	46.4	33.6-34.7	35.0	17.5
12.0-12.5	92.4	46.2	34.8-36.3	30.0	15.0
12.6-13.1	92.0	46.0	36.4-37.9	25.0	12.5
13.2-13.7	91.6	45.8	38.0-39.9	20.0	10.0
13.8-14.3	91.2	45.6	40.0-42.7	15.0	7.5
14.4-14.9	90.8	45.4	42.8-49.1	10.0	5.0
15.0-15.5	90.4	45.2	49.2-56.3	5.0	2.5
15.6-16.1	90.0	45.0	Above 56.3	0.0	0.0
16.2-16.7	89.4	44.7			
16.8-17.3	88.8	44.4			
17.4-17.9	88.2	44.1			
18.0-18.5	87.6	43.8			

Accordingly, for this example, the local component index of the CAI would be 48.2 + 48.3 = 96.5.

17.3.2 SWITCHING SERVICE INDEX PLAN

The local dial-line index plan[7] administered by the operating company's traffic division, is intended to monitor local dial central office switching service. The components of the index and their weights are as follows:

(1) Equipment irregularities—misdirected calls, no-ring conditions (Panel and Step-by-Step, 30 percent; Crossbar and ESS, 25 percent).

(2) No circuit/reorder signal (overflow)—intraoffice or interoffice all-paths-busy conditions (Panel and Step-by-Step, 35 percent; Crossbar and ESS, 25 percent).

(3) Dial tone speed—percent of business day busy-hour calls experiencing dial tone delay greater than 3 seconds (35 percent).

(4) Incoming matching loss—business day busy-hour incoming calls encountering failures to match an incoming trunk with an available called line (Crossbar and ESS, 15 percent; Panel and Step-by-Step, 0 percent).

Data for components (3) and (4) are obtained from traffic registers. Data on the remaining components of the local dial-line index are based on service observations of a small sample of calls at the originating central office. The service observer monitors each call only long enough to get the needed information; the privacy of telephone communications is strictly maintained in accordance with Bell System policy and federal and state statutes. Connectors (called "shoes") are used to bridge customer lines to a service observer. In a 30,000-line office, there would be about 60 shoes. The shoes are assigned at random and are moved each week. When one of the observed lines goes off-hook, it is connected to the observer, provided the link to the observer is idle. The observer records the dialed digits, certain timing information, and the final disposition of the call (e.g., complete, busy, reorder) and then drops the call, thus becoming free to observe another call. The service observing cards are summarized, and various statistics are computed. Typically, 300 observations per month are obtained in a central office. Three-month rolling averages of the service observing results are used to calculate the local dial-line index.

The quota of dial-line service observations for the purpose of indexing is on the order of 900 initial attempts classified as local for each originating central office. The quota may be obtained monthly or by accumulating two or three months of observations. The percentage of observations taken in various periods of the day should be in proportion to the traffic handled in those periods. Raw results are converted to indices using tables as described in Section 17.3.1.

Service observation also provides information on equipment irregularities, no-trunk conditions, and reorders for DDD service. This information is ob-

7. For this plan, local calls are those that are dialed within the same NPA to an NNX that is 25 miles or less from the originating NNX.

tained primarily from incoming trunk and outgoing trunk service observation. However, some data also are obtained from dial-line service observation of DDD calls. The number of dial-line observations of DDD calls is quite variable since there is no quota; DDD calls are simply observed as they are offered in the course of obtaining the quota of dial-line observations on local calls. The information gained is used to provide an indication of the quality of DDD traffic service.

17.3.3 OTHER INDEX PLANS

Numerous other index plans are in effect in the Bell System; they relate to such service aspects as repair, installation, maintenance, operator assistance, billing, collection, etc. While no attempt has been made to present all these index plans here, the general discussion of index plan philosophy applies to all plans, and the selected index plans that have been described are typical.

17.3.4 REMARKS ON INDICES

The emphasis placed by index plans on providing service uniformity over space and time is important because many customers are sensitive primarily to variations in service, which they perceive as they change community of interest or as time passes. Still, it must be realized that indices are not direct measures of customer satisfaction. It is important, therefore, to ensure that index plans properly reflect customer expectations to the fullest extent practicable. For this reason, it is desirable to have a means of monitoring customer attitudes on a continuing basis, both to detect possible changes that are warranted in index plans and to keep a finger on the pulse of customer opinion. This point will be pursued in Sections 17.5 and 17.6.

17.4 SURVEYS AND TREND ANALYSES

17.4.1 BELL LABORATORIES TRANSMISSION SURVEYS

Bell Laboratories has conducted a number of system-wide transmission surveys since 1959[8]. These surveys employ sampling techniques that permit estimation of transmission performance parameters for the total population of connections and also permit quantitative measurement of the possible error in these estimates.

Surveys made in 1959, 1962, 1966, 1969-70, and 1972 concentrated on the transmission performance of toll connections[9]. Other surveys examined the performance of specific equipments or portions of the telephone network[10].

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8. References 3 and 4 review these surveys. Much of Section 17.4.1 is taken from these references.

9. References 3 and 5 through 8.

10. References 9 through 11.

Finally, one report provided information on the characteristics of customer loop plant[11].

Over the period covered by these surveys, the switched telecommunications network has experienced substantial growth and change. Many additional facilities have been placed in service, newly designed transmission and switching equipment has been introduced, and data transmission considerations have played a greater part in the overall design, operation, and maintenance of the switched network. Successive surveys have therefore provided valuable updated information on the status of transmission performance. Reference 3, published in 1971, reported specific comparisons with past surveys. These comparisons indicated a trend toward improved transmission performance. Substantial improvement was observed with respect to phase jitter. Relative envelope delay distortion, attenuation distortion, slope, and 1000-Hz loss also showed improvements. Reference 3 also reported on new measures of impairments that had been made for the first time on a system-wide basis for toll connections. They included peak-to-average voltage ratio (PAR)[12], frequency offset, level tracking, and nonlinear distortion. Other surveys conducted by Bell Laboratories provide information on error rates observed when data are transmitted over the switched network. These surveys are covered in References 4 and 5 and 13 through 17.

As previously mentioned, the parameter characterization provided by all these transmission surveys is needed to set realistic objectives and to determine whether transmission performance is adequate for anticipated voice and data uses.

17.4.2 OTHER TREND ANALYSES

Operating companies take peg count, overflow, and traffic usage readings on a continuing basis to measure traffic volume in terms of total and toll messages, facility usage in CCS, etc. (see Section 14.8). This information is useful in identifying network weak spots or pockets of substandard service and also for planning facility installations, trunk group sizes, and the like. Also, service observing provides an indication of the frequency of equipment irregularities and of blocking levels encountered on local and DDD calls. Finally, network call completion data are gathered monthly on an NPA-by-NPA basis, so that NPAs with low completion rates can be investigated to determine how their completion rates can be improved. These programs provide continual feedback on network performance from a traffic standpoint.

11. Reference 12.

12. A specific test of pulse response.

17.5 CUSTOMER ATTITUDE MEASUREMENTS

17.5.1 TELEPHONE SERVICE ATTITUDE MEASUREMENT (TELSAM) PROGRAM

The TELSAM program was launched by AT&T in 1971. The purpose of this program is to determine the customer's opinion of Bell System service. Five TELSAM questionnaires have been prepared, covering (1) installation services, (2) repair services, (3) business office services, (4) operator services, and (5) dial calling services (including coin telephone service). Each customer called is asked to respond to one of these questionnaires.

Each telephone company participating in the TELSAM program selects its own sample of customers to be called. Operating company clerks select telephone numbers at random from an appropriate population of customers. For example, the population of customers having a recent contact with a business office is appropriate for the business office questionnaire, whereas the population of residence and non-PBX customers is used for the dial services questionnaire. No subscriber is interviewed more than once in a 6-month period for any questionnaire.

Interviews are conducted by outside research firms. An attempt is made to complete at least 50 interviews per telephone company district per month for each type of questionnaire. Results are stored on computer tape for processing; such storage greatly facilitates handling of results.

As of the second quarter of 1975, 4 interview centers, talking with approximately 150,000 customers per month, were serving all companies except Southwestern Bell and Michigan Bell.

The dial calling services questionnaire is of most direct interest for this chapter. Briefly, each customer is asked:[13]

(1) To rate the overall quality of his telephone service as poor, fair, good, or excellent. If service is rated fair or poor, the customer is asked whether the rating is due to (a) no ring-through, (b) poor transmission, (c) no dial tone, (d) being cut off, (e) wrong outgoing calls, (f) wrong incoming calls, (g) needing operator assistance, or (h) other reasons.

(2) Whether he received dial tone promptly on the last local call made from his telephone.

(3) Whether the last local call dialed went through the first time and, if not, whether the difficulty was (a) busy signal, (b) no answer, (c) wrong number, (d) got dial tone again, (e) got recording, (f) got operator, (g) nothing happened, or (h) other.

(4) Whether he had any trouble hearing or being heard on his last local call and, if so, whether the trouble was: (a) noises, (b) tones, (c) oth-

13. Questions asked the customer about recorded messages and coin telephone services are not listed here.

er voices on the line, (d) echo, (e) distortion, (f) difficulty hearing, (g) fading, or (h) other.

(5) Whether he placed any toll or long distance calls that he dialed himself within the last month. If he has, questions (3) and (4) are asked regarding his most recent such call.

All TELSAM results are available on a telephone company district basis and are also summarized for divisions, areas, and complete companies. These results provide direct feedback from large numbers of customers (approximately 30,000 per month respond to the dial calling services questionnaire) regarding what they think about their service.

17.5.2 CUSTOMER TROUBLE REPORT ANALYSIS PLAN (CTRAP)

CTRAP is designed to provide manual and mechanized procedures for:

(1) Recording trouble reports and developing trouble histories regarding the service of individual customers.

(2) Accumulating statistics and providing broad-gauge trouble report trend data concerning customer service.

A customer trouble report is defined to be any oral or written notice that indicates one or more of the following conditions:

(1) Difficulty or dissatisfaction with the performance of telephone plant or telephone employees.

(2) Improper functioning of telephone company equipment or associated customer-owned auxiliary equipment.

(3) Defect in or dissatisfaction with the physical condition, location, or appearance of a plant item.

Trouble reports are collected for all classes of service, including residence, business, coin, PBX, mobile, etc. The reports are categorized into eight types:

(1) Cannot call, no dial tone—includes reports of slow receipt of dial tone and reports of inability to get dial tone to originate a call.

(2) Cannot call, other—the customer hears dial tone, but cannot originate or complete a call.

(3) Transmission, noise—includes reports of cannot hear, cannot be heard, distortion, garbled copy, cutoffs, momentary interruptions, and noise.

(4) Cannot be called—customer has trouble receiving calls.

(5) Custom calling services failure—customer reports trouble with calling service features such as speed calling, call transfer, etc.

(6) Data failure—customer cannot send or receive data.

(7) Physical condition—customer reports worn, damaged, loose, or missing equipment, etc.

(8) Miscellaneous—any trouble report not included in the other seven types.

Customer trouble reports result in telephone company action to discover the source of and to clear the trouble. Trouble report tickets also are used by the repair service bureaus to analyze patterns or trends of trouble and to detect any weak spots that may be observed. A "customer trouble reports per 100 stations" index is determined for various telephone company subdivisions and classes of service so that progress in holding trouble reports to a minimum can be monitored. This index is an important component of the exchange maintenance service results plan.

It can be seen that, in a general way, customer trouble reports provide an additional means of measuring customer opinion. Efforts have been undertaken to determine whether trouble report volume tracks opinion fluctuations recorded by TELSAM, especially for trouble report categories that correspond well with TELSAM opinion categories. Results from special TELSAM studies suggest a correlation between customer opinion on transmission quality and the customer's actual trouble report history.

17.5.3 CUSTOMER OPINION MEASUREMENTS VERSUS HUMAN FACTORS EXPERIMENTS

TELSAM and CTRAP provide measures of customer opinion for various administrative subdivisions of telephone companies. It is interesting to contrast these customer attitude measures with the human factors experiments discussed in Section 17.2.

In the human factors experiments, controlled levels of stimuli are presented to subjects; detailed knowledge of the experimental conditions to which the subjects are reacting is therefore available. The problems with such experiments are:

(1) One can never be certain of the fidelity with which real-world conditions are being reproduced.

(2) Limited numbers of subjects are involved, and the extent of which these subjects are truly representative of the total population of telephone subscribers cannot be known fully.

(3) It is difficult to design controlled laboratory experiments to study subjective reactions to parameters such as percent equipment irregularities, percent network blocking, etc.

With TELSAM and CTRAP, on the other hand, broad cross sections of Bell System customers are registering their opinions of the service delivered to them. It is not completely clear, however, what parameters or even extraneous stimuli (hostility to institutions in general, for example) are prompting customer reactions.

Thus, both the controlled experiments discussed in Section 17.2 and the broad customer attitude measurements of this section have advantages and disadvantages. The extent to which they can be used to complement one another is under investigation.

17.6 INTERRELATIONSHIPS

The intent of this chapter has been to provide an overview of the processes involved in evaluating services and operations and to discuss the relationship between service evaluation and specification of network performance objectives. The purpose of this final section is to emphasize the interactive and continuing nature of the work described in Sections 17.2 through 17.5.

The interrelationships of interest are depicted in Fig. 17-5. The solid lines with arrowheads represent relations that are more or less traditional. Characterization surveys and controlled human factors experiments have long been used to set performance objectives; the objectives and surveys in turn influence the Bell Laboratories equipment and system design processes, the performance measurements employed by the operating companies[14], and the performance improvement programs launched for particular parameters.

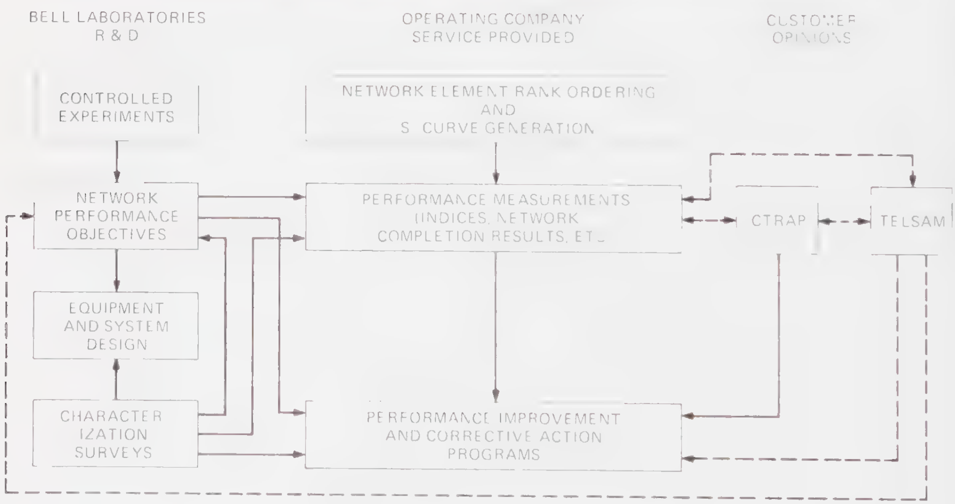

Fig. 17-5. Interactions in Setting Service Objectives and in Evaluating Performance

Index plans are strongly influenced by the network element rank-ordering and index table generation process. Performance improvement and corrective

14. They may be used, for example, to select the performance limit with respect to which elements are rank-ordered for an index plan.

action programs undertaken by the operating companies are largely guided by index results and trouble report analyses.

The dotted lines with arrowheads in Fig. 17-5 represent nontraditional relations being investigated to better characterize the extent to which objectives, performance measurements, and performance improvement programs are synchronized with customer viewpoints. Part of this effort, as discussed in Section 17.5, is directed toward studying whether trouble report and TELSAM opinion fluctuations are correlated and also toward studying whether TELSAM results can be used profitably to supplement the results of controlled human factors experiments in setting objectives for network performance.

Efforts are under way to determine the extent of correlation between customer attitude variations and variations in performance indicators (such as indices) over periods of time for the various subdivisions of the Bell System. One particular study is analyzing the possibilities for:

(1) Revising certain index plans to better reflect the customer's view of service.

(2) Revising TELSAM to provide more useful indications of customer opinion.

(3) Developing a methodology for optimally using customer opinion and performance measurement feedback to improve service.

All aspects of the service objective and evaluation process must undergo continual reexamination as new technologies emerge, new economies become realizable, new facilities are put into service, and customer expectations change. To provide economical, satisfactory service, such reexamination requires continuous close interaction between Bell Laboratories and AT&T Operations personnel involved in the cost / service-objective / service-evaluation triangle, as measurements, feedback loops, and analysis techniques evolve. The questions listed at the beginning of this chapter accordingly provide a continuing and evolving challenge to Bell System engineers.

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18 Glossary

ABD

See *Average Business Day.*

Access Arrangement

An alternate name for a *protective connecting arrangement.* Access arrangement is normally used in reference to the interconnection of customer-provided data modems or automatic calling units in which data access arrangement (DAA) service includes the provision of a data access arrangement with appropriate loop conditioning (including adjustments for loop loss) to meet data requirements.

ACD

See *Automatic Call Distributor.*

ACH

See *Attempts per Circuit per Hour.*

Actual Work Time (AWT)

The average time an operator requires to handle a call. This corresponds to the expected value (mean value) of the holding time distribution used in the Erlang C model.

Adaptive Transversal Equalizer

A transversal filter that automatically adjusts its characteristics to compensate for linear distortion. Adaptive equalizers are particularly important in data modems where their use has permitted voiceband data rates to be increased from approximately 3000 bits per second to approximately 10,000 bits per second.

Address

(1) A sequence of numbers that identifies the telephone to which a call is directed. The address is usually a 7- or 10-digit number, depending on whether the destination is inside or outside the numbering plan area where the call originated. Also called *Destination Code.*

(2) Digital information (a combination of bits) that identifies a location in a storage device or equipment unit.

Address Signals

Signals used to convey call destination information, such as telephone station code, central office code, and area code. Some forms of address signals are called *pulses*; e.g., dial pulses, multifrequency pulses.

Administration

In operating companies, dial or network administration is a number of related functions with the objective of ensuring the overall provision of service by a switching system. It includes assignment of lines and trunks to switching system terminals, collection of traffic data, analysis of troubles and customer complaints, and requests for additions and modifications to switching systems.

AFT

See *Analog Facility Terminal.*

AIC

See *Automatic Intercept Center.*

AIS

See *Automatic Intercept System.*

Alerting (Alerting Signal)

A signal sent to a customer, PBX, or switching system to indicate an incoming call. A common form is the signal that rings a bell in the telephone set being called.

All-Number Calling (ANC)

The system of telephone numbering that uses all numbers and replaces the 2-letter plus 5-number (2L + 5N) numbering plan. ANC offers more usable combinations of numbers than the 2L + 5N numbering plan and is becoming the nationwide standard.

Alternate Routing

A means of selectively distributing traffic over a number of routes ultimately leading to the same destination.

AM

Amplitude modulation.

AMA

See *Automatic Message Accounting.*

American Standard Code for Information Interchange (ASCII)

A 7-bit code for providing as many as 128 different characters. An eighth bit can be added as a parity check for error detection purposes.

Analog Facility Terminal (AFT)

A voice-frequency facility terminal that performs signaling and transmission functions and includes analog channel banks. It interfaces between an analog carrier system and a switching system, a metallic facility, a digital facility terminal, or another analog facility terminal.

Analog Signal

A signal that varies in a continuous manner, such as voice or music. An analog signal may be contrasted with a digital signal which represents only discrete states. The signal put out by a data set has both analog and discrete characteristics.

ANC

See *All-Number Calling.*

ANI

See *Automatic Number Identification.*

Answer Delay

The time from the beginning of ringing until the called station answers.

Apparatus

A standardized unit of hardware, such as a relay or capacitor, that is generally small and performs a single function. In some cases rather complex assemblies, such as a telephone set or a data set, are classified as apparatus. Apparatus is not likely to be repaired or modified while installed in its service location. Western Electric does not keep detailed records for Western Electric furnished apparatus, but does for equipment. See *Equipment.*

Area Transfer

The process of assigning a group of customers to a new wire center.

ASCII

See *American Standard Code for Information Interchange.*

Asynchronous Data Transmission

Data transmission in which there is no predetermined time interval for signal elements. The data channel may provide an extra state to separate in time the signal elements that carry the "payload" information. In a TOUCH-TONE telephone, this state is no tone at all. If the main data channel consists of several parallel binary subchannels, the signal on one of these can be used to inform the receiver when a new set of signal elements is arriving. On a single binary channel, a popular mode of operation is "start-stop", in which the start of a character can come at any time (character asynchronous), but the following elements of the character come at specific times with respect to the start element.

Attempts per Circuit per Hour (ACH)

An indication of calling pressure. See *Connections per Circuit per Hour.*

Attenuation Constant

The real part of the propagation constant of a transmission line (the imaginary part is the phase constant). It is a ratio equal to the decrease (attenuation) in amplitude of a sinusoidal wave as it traverses a unit length of a transmission line.

Attenuation Distortion

The change in attenuation with frequency relative to the attenuation at a reference frequency; for example, the change in attenuation with frequency within a voiceband relative to the attenuation at 1 kHz.

Attestation

A program designed to allow direct electrical connection to the public telephone network of certain types of customer-provided equipment having a low potential for network harm. The program requires the manufacturer to attest that his products, such as headsets and nonpowered conferencing devices, meet requirements published by AT&T in Technical References. Tariff provisions allow equipment covered by the attestation program to be connected without protective connecting arrangements.

Automatic Call Distributor (ACD)

A system for automatically providing even distribution of incoming calls to operator or attendant positions; calls are served in the approximate order of arrival and are routed to positions in the order of their availability for handling a call.

Automatic Equalization

The process of automatically compensating for linear distortion. This is generally accomplished by an adaptive transversal equalizer.

Automatic Intercept Center (AIC)

A centrally located set of equipments that is a part of an Automatic Intercept System and provides arrangements, having stored program control, whereby the calling customer is automatically advised, by means of either recorded or electronically assembled announcements, of the prevailing situation that prevents completion of connection to the called number.

Automatic Intercept System (AIS)

A type of Traffic Service System consisting of one or more automatic intercept centers and a centralized intercept bureau for handling intercept calls.

Automatic Message Accounting (AMA)

The automatic collection, recording, and processing of information relating to calls for billing purposes.

Automatic Number Identification (ANI)

The automatic identification of a calling station, usually for automatic message accounting.

Automatic Ringdown

A technique for supervision alerting on a nondial trunk in which the application of a 2-second burst of ringing at the originating end results in a supervisory signal at the terminating manual PBX. See *Ringdown.*

Automatic Voice Network (AUTOVON)

A private voiceband network serving the Department of Defense. AUTOVON employs automatic switching and handles both voice and data traffic. It is worldwide; the continental United States portion is known as CONUS AUTOVON.

AUTOVON

See *Automatic Voice Network.*

Average Business Day (ABD)

Denotes the average of the parameter in question over the business days during the period considered; for example, busy-hour traffic. Business days include Mondays through Fridays but exclude holidays. See *Peak Load.*

AWT

See *Actual Work Time.*

Balance

(1) To distribute traffic over the line terminals at a central office as uniformly as possible. Without load balancing, a portion of the switching equip-

ment may become overloaded even though the total capacity of the system has not been exceeded.

(2) To adjust the impedance of circuits and balance networks to achieve specified return loss objectives at junctions of 2-wire and 4-wire circuits.

Balance Network

An adjustable impedance used to terminate one port of a hybrid such that the hybrid characteristics approach the ideal when used to provide 2-wire to 4-wire conversion.

Baseband

The frequency band occupied by one or more information signals that either modulate a carrier or are transmitted at baseband frequency over a suitable medium.

Baseband Channel

Because they differ in properties and availability, a distinction should be made between baseband channels and non-baseband (passband) channels. The simplest example of a baseband channel is a pair of wires; it transmits direct current and has no impairments such as phase offset or frequency offset that would destroy waveform. No modulation is needed to send pulse streams or visual signals. The Bell System uses such channels as segments of built-up channels, but, with one or two exceptions, does not offer such channels to the public. Even if such a channel is transformer-coupled so that it does not transmit direct current, it still deserves the name baseband in that pulse patterns or waves that have no dc component can be transmitted faithfully without modulation. Customer-to-customer voiceband channels in an exchange area may be of this type. Customer-to-customer television channels are designed to simulate this type of baseband channel. In contrast, the name *passband channel* connotes that modulation is used in the structure of the channel, as in a carrier system. The usual consequence is phase or frequency offset. When a voiceband channel is made up of baseband loops and carrier trunks in tandem, the carrier portion dominates the channel characteristics in the sense that digital or visual signals cannot be transmitted directly but require modulation in the station.

Baud

A unit of digital signaling rate. The signaling rate in bauds is equal to the reciprocal of the length in seconds of the signal element when all signal elements have equal length. If signal elements are not of equal length, as in "start-stop" character asynchronous operation, the signaling rate in bauds is expressed as the reciprocal of the length of the shortest signal element. The information rate in bits per second may be greater than the baud rate because one signal element can represent more than one bit.

BCS

See *Business Communications Systems.* See *Business Customer Services.*

Bell System Practice (BSP)

A document in a comprehensive series prepared to disseminate detailed technical information and operating methods within the Bell System. Certain series of BSPs cover manufacturing, installation, and equipment performance requirements; these are primarily of interest to Western Electric. Other series are instructions for the engineering, operation, maintenance, and repair of the telephone plant; these are primarily of interest to operating companies. Certain others are prepared for the instruction and training of telephone company personnel.

Most BSPs are prepared by Western Electric. Bell Laboratories prepares certain BSPs and is responsible for accuracy of technical content of all BSPs. AT&T authorizes the preparation and release of all BSPs.

Bell System Repair Specification (BSRS)

A Bell System document that specifies detailed repair procedures for apparatus- and equipment-coded units. These documents are not for standard field maintenance purposes, but rather for detailed major repairs usually performed at a Western Electric service center.

Binder Group

A group of cable pairs within a cable sheath that are twisted and bound together during cable construction.

Bipolar Signal

A digital signal technique that uses either a positive or a negative excursion (always alternating) for one state and ground for the other state.

BIS

See *Business Information Systems.*

BISCUS/FACS

See *Business Information System Customer Services—Facility Assignment and Control System.*

Bit

(1) An abbreviation of binary digit. A bit can be one of the two binary characters, 1 or 0.

(2) A unit of information. One bit of information is sufficient to specify one of two equally likely possibilities.

Bits per Second (b/s)

Digital information rate expressed as the number of binary information units transmitted per second. See *Symbol.* If a channel produces errors, the information rate (as defined by Shannon) will be lower than the figure noted above, but this lower figure is rarely used. Typically, a data channel is described as having a stated bit rate and a stated expected error rate.

Blocking

The inability of the calling party to be connected to the called party because either (a) all suitable trunk paths are busy or (b) a path between a given inlet and any suitable free outlet of the switching network of a switching system is unavailable.

Bridged Tap

A cable pair connected in parallel with a customer loop. The connection (tap) may occur at the central office or at some point along a cable route.

BSP

See *Bell System Practice.*

BSRS

See *Bell System Repair Specification.*

BTE

See *Business Terminal Equipment.*

Buried Service Wire

A buried wire pair connecting the customer's premises to a pair in the distribution cable.

Business Communications Systems (BCS)

Systems, such as key telephones, private branch exchanges, automatic call distributors, and telephone answering systems, that are used to fill the communication needs of business customers. Because BCS has become a term used by other companies, the term is being replaced by *Customer Switching Systems* (CSS).

Business Customer Services (BCS)

Refers to a class of services generally used by business customers, including private branch exchange service, key telephone service, automatic call distribution service, and telephone answering service.

Business Information Systems (BIS)

A collection of computer-based systems for performing voluminous business and administrative operations associated with the provision of telephone service by operating companies.

Business Information System Customer Services—Facility Assignment and Control System (BISCUS/FACS)

One of the Business Information Systems developed at Bell Laboratories. BISCUS/FACS is used to assign cable facilities, cable terminations, telephone numbers, and central office line equipment to service orders.

Business Office

The part of the telephone company that a customer contacts regarding initial requests for service, subsequent changes in service, and questions relating to billing.

Business Service

Telecommunications service used in a business environment.

Business Terminal Equipment (BTE)

Refers to the terminal equipment used by business customers including teletypewriter machines, data sets, key telephone systems, PBXs, etc.

Busy Hour

That hour during which the portion of the telephone network in question carries the most traffic. Traffic peaks caused by holidays or special events are not considered. Switching systems and trunk groups are normally sized for the busy hour. See *Peak Load.*

Busy Hour, Bouncing

See *Busy Hour.* The highest load may not occur at the same hour on all days. If the highest load is selected for each day without regard to the hour in which it occurs, the average of these loads is said to occur in the bouncing busy hour. Traffic measurements are usually made over the five working days of each week.

Busy Hour, Fixed

See *Busy Hour.* When the hourly loads are averaged across days for each hour of the day, the maximum of these averages defines the fixed busy hour, also called the *time consistent busy hour.* Traffic measurements are usually made over the five working days of each week.

Busy Tone

An audible signal indicating a call cannot be completed because the called line is busy. The tone is applied 60 times per minute.

Cable Fill

The percentage of pairs in a cable sheath actually assigned and used.

Cable Vault

An area, generally on the lower level of a telephone company building, where cables enter the building.

Call Forwarding

One of the custom calling services. When call forwarding is activated by a customer, all calls to that line are automatically routed to another line designated during activation.

Call Store

The equipment unit of an Electronic Switching System that provides temporary memory storage of information pertaining to call processing and maintenance.

Call Waiting

The custom calling service that provides a tone burst to a customer on an established call when a second call has been directed to that line. The notification tone is heard only by the called customer, whereas the incoming caller hears regular audible ringing. The customer can place the existing call on hold, connect to the calling party, and then repeat the procedure to reestablish the original connection. The operation of changing the talking connection can be repeated indefinitely.

CAMA

See *Centralized Automatic Message Accounting.*

CAMA-ONI

See *Centralized Automatic Message Accounting—Operator Number Identification.*

Carried Load

The average number of calls that are in progress. The unit, one call, is an Erlang.

Carrier System

A system for transmitting one or more channels of information by processing and converting to a form suitable for the transmission medium used by the system. Many information channels can be carried by one broadband carrier system. Common types of carrier systems are frequency-division, in which each information channel occupies an assigned portion of the frequency spectrum, and time-division, in which each information channel uses the transmission medium for periodic assigned time intervals.

Carterfone Decision

A decision made by the Federal Communications Commission in 1968 to the effect that telephone company customers should be permitted to connect their own equipment (e.g., data modems) to the public telephone network provided that this interconnection does not adversely affect the telephone companies' operations or the utility of the telephone system to others. Prior to this decision, only telephone company provided equipment could be connected to the network.

CCH

See *Connections per Circuit per Hour.*

CCIS

See *Common Channel Interoffice Signaling.*

CCITT

See *International Telephone and Telegraph Consultative Committee.*

CCS

See *Hundred Call Seconds.*

CCSA

See *Common-Control Switching Arrangement.*

CDO

See *Community Dial Office.*

Central Office (CO)

A switching system that connects lines to lines and lines to trunks. The term is sometimes used loosely to refer to a telephone company building in which a switching system is located and to include other equipment (such as transmission system terminals) that may be located in such a building.

Central Office Code

A 3-digit identification under which up to 10,000 station codes are subgrouped. Exchange area boundaries are associated with the central office code which accordingly has billing significance. Note that several central office codes may be served by a central office. Also called *NNX code.*

Central Office Work Order

An order for work to be done in the operating company to make or change equipment assignments for switching system line or trunk access.

Centralized Automatic Message Accounting (CAMA)

A process using centrally located equipment, including a switchboard or a traffic service position, associated with a tandem or toll switching office, for automatically recording billing data for customer-dialed extra-charge calls originating from several local central offices. A tape record is processed at an electronic data processing center.

Centralized Automatic Message Accounting—Operator Number Identification (CAMA-ONI) Operator

An operator located at a position that is connected temporarily on a customer-dialed station-to-station call. The operator secures the calling number from the customer and keys the number into the centralized automatic message accounting equipment.

Centralized Intercept Bureau (CIB)

That type of bureau that is part of an Automatic Intercept System and is associated with one or more automatic intercept centers. It provides facilities whereby operators situated at auxiliary service positions furnish assistance to calling customers whose calls have been intercepted and who require help beyond that furnished by an automatic intercept center.

Centrex

A service for customers with many stations that permits station-to-station dialing, one listed directory number for the customer, direct inward dialing to a particular station, and station identification on outgoing calls. The switching functions are performed in a central office.

Channel

A transmission path between two points. The term channel may refer to a one-way path or, when paths in the two directions of transmission are always associated, to a 2-way path. It is usually the smallest subdivision of a transmission system by means of which a single type of communication service is provided, i.e., a voice channel, teletypewriter channel, or data channel.

Channel Bank

Channel terminal equipment used for combining (multiplexing) channels on a frequency-division or time-division basis. Voice channels are combined into 12- or 24-channel groups.

Channel Busy Tone

An audible signal indicating that a call cannot be completed because of trunk or switching system blocking. The tone is applied 120 times per minute. Also called *fast busy* or *reorder tone.*

CIB

See *Centralized Intercept Bureau.*

Circuit

(1) A communication path between two or more points.

(2) A network of circuit elements, such as resistors, inductors, capacitors, semiconductors, etc., that performs a specific function.

(3) A closed path through which current can flow.

Circuit Order

The document used to transmit engineering design of a public telephone network trunk or special-service circuit to the department that implements the design.

Class 5 Office

A local central office that serves as the network entry point for station loops and certain special-service lines. Also called *end office.* Other offices, classes 1, 2, 3, and 4, are toll offices in the telephone network.

CO

See *Central Office.*

Code

(1) Any of a wide variety of schemes for representing information such as a color code for values of resistors, Morse code for telegraphy, and a ZIP code for a mail address.

(2) A system of rules for representing information by digital signals such as teletypewriter code. See *ASCII.*

(3) A numbering system for telephone addresses. See *Central Office Code, Station Code,* and *Number Plan Area.*

(4) A set of standard abbreviations for equipment and facility names. See *Common Language Code.*

(5) A set of rules for representing the amplitude of a signal sample by digital signals. See *Pulse Code Modulation.*

Coded Ringing

A form of semiselective ringing. The customer is required to identify his own code by the number of rings and/or their duration.

Coherent

Refers to a fixed phase relationship that provides certain advantages in signal detection.

Coherent Modulation System

A modulation system that requires a carrier, either transmitted or locally derived and having the same frequency and phase as that associated with the received signal, for recovering the original modulating signal.

Coherent Phase-Shift Keying (CPSK)

Modulation techniques for transmitting digital information in which that information is conveyed by selecting discrete phase changes of the carrier relative to a reference. See *Coherent Modulation System.*

Coin-First Service

Coin telephone service in which an initial rate deposit is required to obtain dial tone. Coin-first service is being replaced by dial-tone-first, an improved service requiring additional functions in the station and in the switching system.

Coin Relay

A relay in a coin telephone that collects or returns the coins under the control of the central office.

Common Channel Interoffice Signaling (CCIS)

A signaling system, developed for use between stored program switching systems, in which all of the signaling information for a group of trunks is transmitted over a dedicated high-speed data link, rather than on a per-trunk basis. CCIS can reduce call setup time and save money compared with individual trunk signaling.

Common Control

An automatic arrangement in which items of control equipment in a switching system are shared; they are associated with a given call only during the periods required to accomplish the control functions. All Bell System Crossbar and Electronic Switching Systems have common control.

Common-Control Switching Arrangement (CCSA)

An arrangement in which switching for a private network is provided by one or more common-control switching systems. The switching systems may be shared by several private networks and also may be shared with the public telephone network.

Common Language Code

Codes used to ensure uniform abbreviation of equipment and facility names, place names, etc.

Communications Satellite Corporation (COMSAT)

Created by authorization of Congress in the Communications Satellite Act of 1962. This private corporation (not an agency of the United States Government, although subject to governmental regulation) was created primarily to provide for the establishment, operation, and management of a commercial communications satellite system. COMSAT presently acts as manager for INTELSAT and also represents the United States in INTELSAT.

Community Dial Office (CDO)

A small automatic switching system that serves a separate exchange area having its own numbering plan and ordinarily having no operating or maintenance force located in its own building; operation is handled and maintenance is directed from a conveniently located point referred to as an *operator office.*

Compandor

An abbreviation for compressor—expandor. A device used to compress the range of talker volumes at the input to a carrier system (in particular, to increase low-level talker volumes) and to expand the received volumes at the output of the carrier system (to provide the complementary function and to make the transmission system transparent). This technique improves the signal-to-noise ratio for low-level talkers and provides a substantially reduced received noise level during the so-called quiet intervals.

Compandor Mistracking

Mistracking refers to the failure of the expandor characteristic of a compandor to complement exactly the compressor characteristic, thereby causing signal distortion.

COMSAT

See *Communications Satellite Corporation.*

Concentration

(1) Applies to a switching network (or portion of one) that has more inputs than outputs.

(2) In a traffic network, combining calls arriving on many lines or trunks to transmit them more efficiently in a trunk group.

(3) Locating as much equipment as possible at a given place to achieve economies in such things as building costs, power arrangements, and maintenance.

Connecting Arrangement

The implementation for connecting arrangement service. A connecting arrangement consists of an interconnecting unit, a Technical Reference, and a tariff offering.

Connecting Arrangement Service

A service providing electrical connection to the public telephone network of customer-provided equipment. This service, which is usually denoted by a uniform service order code (USOC), is offered by tariff and is implemented with an interconnecting unit and a Technical Reference.

Connection

(1) A point where a junction of two or more conductors is made.

(2) Generally, a telephone connection is a 2-way voiceband circuit completed between two points by means of one or more switching systems. It contains two loops and may contain one or more trunks.

Connections per Circuit per Hour (CCH)

An indication of holding time of calls. Under normal circumstances, $ACH=CCH\approx 6$ in the busy hour for trunk groups excluding high-usage groups.

Connector

In Step-by-Step switching systems, a 2-motion electromechanical switch that operates on the last two digits of the telephone number to connect from a selector to any one of 100 customer loops. The connector performs the following functions:

(1) Tests for busy.

(2) If busy, returns busy tone.

(3) If idle, rings the called party and returns ringback tone to the calling line.

(4) Provides a supervisory signal indicating that answer has occurred and trips ringing.

(5) Provides talking battery to the calling line on intraoffice calls and to the called line.

(6) Disconnects when the customer hangs up.

Construction Program

A detailed plan of placement, removal, and rearrangement of facilities to modernize and expand the capacity of the facilities network.

Conversion (Converting)

In signaling, the substitution of one, two, or three digits for received digits for the purpose of directing the call through the next office.

Coordinate Network

A switching network consisting of incoming and outgoing talking paths arranged at right angles to each other with fine-motion or electronic switching elements at intersections.

CORNET Network

A private telephone network serving Western Electric and Bell Laboratories; CORNET is a contraction of corporate network. This network uses common-control switching arrangements (CCSA).

Country Code

The 1-, 2-, or 3-digit number that, in the world numbering plan, identifies each country or integrated numbering plan in the world. The initial digit is always the world-zone number. Any subsequent digits in the code further define the designated geographic area (normally identifying a specific country). On an international call, the country code is dialed before the national number.

Coupler

An alternate name for an *interconnecting unit.*

CPSK

See *Coherent Phase-Shift Keying.*

Crossbar Switch

The basic element of any Crossbar System. A crossbar switch is a relay mechanism consisting of 10 horizontal paths and 10 or 20 vertical paths. Any horizontal path can be connected to any vertical path by means of magnets. A 2-stage operation is used to close any crosspoint. First, a selecting magnet shifts all selecting fingers in a horizontal row, then a holding magnet shifts a vertical actuating card to close the selected contacts.

Crosspoint Array

An arrangement of switching elements used in some switching networks, characterized by incoming and outgoing talking paths arranged at right angles to each other, with switching elements at intersections.

Crosstalk

Undesired power coupled into a communications circuit from other communications circuits. Telephone crosstalk may be either intelligible or unintelligible.

CTRAP

See *Customer Trouble Report Analysis Plan.*

Custom Calling Services

A group of four services provided by Electronic Switching Systems to business and residence customers: 3-way calling, speed calling, call forwarding, and call waiting.

Customer-Premises Equipment

Equipment normally installed on the customer's premises, such as telephone sets, key telephones, PBXs.

Customer Switching System

A switching system that provides service for a customer, typically a business customer. Systems in this category include key telephone systems, private branch exchanges, automatic call distributors, and telephone answering systems. The term is replacing business communications system.

Customer Trouble Report Analysis Plan (CTRAP)

A plan that provides manual and mechanized procedures for recording troubles reported by customers and analyzing the reports to obtain statistical data regarding customer service.

DA

See *Directory Assistance.*

Data Communications

In telephone company terminology, data communications refers to end-to-end transmission of any kind of information other than sound (including voice) or video. Data sources may be either digital, such as a computer, or analog, such as an electrocardiogram transmitter. Data transmission should not be confused with digital transmission. Data transmission refers to transmission of information from a data source, whereas digital transmission refers to a particular kind of transmission facility implementation.

Data Communication Terminal

See *Data Terminal.*

DATAPHONE Service

A service in which calls are placed over the public telephone network in the normal manner or automatically, and, after a connection is established, data terminals are connected at both ends for exchange of data. The term applies to private-line service as well.

DATAPHONE 50 Service

DATAPHONE 50 service is a 50-kilobit-per-second switched data network service. Five dedicated wideband switching systems are located across the nation. These switching systems are tied together by wideband trunks, dedicated to the DATAPHONE 50 network. Subscribers to the service are given private-line access to the switching system nearest them.

Data Set

Equipment for performing the conversion between signals from data processors or terminals (usually digital) and signals suitable for transmission over telephone lines, and for control of the connection. Data sets can be either transmitters or receivers, or both. That portion of a data set that converts the terminal signals for transmission (modulator) and the received line signals for delivery to the terminal (demodulator) is called a *modem*, a contraction for modulator/demodulator. In common usage, the terms data set and modem are often used interchangeably, although strictly speaking a data set has control functions in addition to modulation and demodulation.

Data Terminal

A device, associated with a computer system for data input and output, that may be at a location remote from the computer system, thus requiring data transmission. For example, a teletypewriter is a data terminal and so is a magnetic tape reader. The term also applies to devices for terminal-to-terminal communications.

Data Under Voice (DUV)

An arrangement for transmitting 1.544-megabit-per-second data streams in the bandwidth available underneath the portion of the baseband used for voice channels on existing microwave systems. DUV will be the primary long-haul transmission facility used in the early years of the Digital Data System.

dB (decibel)

A logarithmic measure of the ratio between two powers.

$$dB = 10 \log_{10} \frac{P_2}{P_1}.$$

dBm

A logarithmic measure of power with respect to a reference power of 1 milliwatt.

$$dBm = 10 \log_{10} \frac{P}{1\ milliwatt}.$$

dBrnC

A power level in dB relative to a noise reference of -90 dBm, as measured with a noise meter, weighted by a special frequency function called *C-message weighting* that expresses average subjective reaction to interference as a function of frequency.

dBrnC0

Noise measured in dBrnC and referred to the 0 transmission level point.

DC Signaling

Refers to a variety of techniques for transmitting signaling information using direct current over metallic circuits; for example, loop-reverse-battery, loop-start, or duplex (DX) signaling. DC signaling is a subset of out-of-band signaling.

DDD

See *Direct Distance Dialing.*

DDS

See *Digital Data System.* Also used for DATAPHONE digital service.

Decoder

A device that converts information from one form to another. In a Panel switching system, the decoder converts address digits to an identification of the appropriate trunk group to be used. The term *translator,* or *route translator,* is associated with devices in other switching systems that perform a similar function.

Delta Modulation

Conversion of an analog signal, such as voice, to a digital format in which the amplitude difference between successive samples of the analog signal is represented by a set of digits coded to express the quantized amplitude difference. In its simplest form, the quantized magnitude of the amplitude difference can have only one value other than zero.

DESIGN LINE

A series of telephone sets having special decorative housings. The housings are sold to customers; the internal mechanism remains the property of the Bell System.

Destination Code

The sequence of numbers that identifies the destination of a call.

DFT

See *Digital Facility Terminal.*

Dial

A device that is part of a customer's telephone set and is used to generate a coded signal to control the central office switching equipment in accordance with the digits dialed. It may be either a rotary device or a pushbutton (TOUCH-TONE) device. The term is sometimes used as an adjective as in "dial administration," the process of short-term rearrangements and monitoring of performance in a central office switching system.

Dial Long Line Circuit

A circuit, usually located in a central office, that extends the dialing, supervision, and other signaling range of a loop.

Dial Pulsing

A means of signaling consisting of regular momentary interruptions of a direct or alternating current path at the sending end in which the number of interruptions corresponds to the value of a digit or character. The interruptions are usually produced by a rotary telephone dial, but may be produced by a sender in a switching system.

Dial Repeating Trunks

PBX tie trunks used with terminating PBX equipment capable of handling PBX station signaling information without attendant assistance.

Dial Tone

An audible tone sent from an automatic switching system to a customer to indicate the equipment is ready to receive dial signals.

Dial Tone Delay

A measure of time required to provide dial tone to customers. This measures one aspect of the performance of a switching system.

Dial-Tone-First Coin Service

A coin service that allows customers to obtain dial tone before money is deposited into the coin telephone. Some service codes, such as 911, may be dialed without a coin. This service contrasts with postpay operation, which sets up a connection before coin deposit and does not provide coin return, and with coin-first operation, which requires coin deposit for all calls.

Dial Transfer

A service available with some PBXs that enables a station receiving a call to transfer it to another station in the same group without the assistance of an attendant. Also called *call transfer.*

Differential Delay

The difference in the delays experienced by two sinusoids of different frequencies in passing through a communications channel.

Differential Phase-Shift Keying (DPSK)

Modulation techniques for transmitting digital information in which that information is conveyed by selecting discrete phase changes of the carrier. Phase changes are detected by comparing the phase of each signal element with the phase of the preceding signal element.

Digital Data System (DDS)

A nationwide private-line synchronous data communications network formed by interconnecting digital transmission facilities and providing special maintenance and testing capabilities. Customer channels operate at 2.4, 4.8, 9.6, 56, or 1544 kilobits per second.

Digital Facility

A switching or transmission facility designed specifically to handle digital signals.

Digital Facility Terminal (DFT)

A voice-frequency facility terminal that performs signaling and transmission functions and includes digital banks. It interfaces between a digital carrier system and a switching system, a metallic facility, an analog facility terminal, or another digital facility terminal.

Digital Inquiry—Voice Answerback (DIVA)

A data communications system in which data are entered by means of a TOUCH-TONE dial and in which the answer comes back in the form of a computer-controlled audio response.

Digital Signal

A signal that has a limited number of discrete states prior to transmission. This may be contrasted with an analog signal which varies in a continuous manner and may be said to have an infinite number of states.

Digital Transmission

A mode of transmission in which all information to be transmitted is first converted to digital form and then transmitted as a serial stream of pulses. Any signal—voice, data, television—can be converted to digital form.

Digroup

A digitally multiplexed group of 24 channels. Digroup usually refers to the T1 carrier line signal of 1.544 megabits per second; however, the term also is used to refer to the digital channel bank that provides the 24-channel multiplexing function.

Direct Distance Dialing (DDD)

The automatic establishment of toll calls in response to signals from the dialing device of the originating customer.

Direct Distance Dialing (DDD)Network

Strictly, the telephone network over which a customer can dial all calls to which toll charges are applicable. Because of the widespread availability of DDD service and because exchange area calls can be dialed directly using the same facilities, the term DDD is sometimes applied to the whole traffic network that provides public telephone service.

Direct Progressive Control

The mode of operation of an automatic telephone switching system in which the dial pulses from the calling telephone directly control the switches that establish the desired connection.

Direct Trunk

A trunk between two class 5 offices.

Directory Assistance (DA)

A service in which a customer will be connected to an operator at a directory assistance bureau by dialing the proper service code or number and will be told the directory number of the customer whom he desires to call, provided that the customer's number is, or will be, published (listed) in the telephone directory. (Formerly called *information service.*)

Directory Assistance Bureau

A bureau in which directory assistance service is rendered to customers. The operators in attendance obtain the desired telephone numbers from telephone directories or similar media. (Formerly called *information bureau.*)

Directory Assistance Operator

A person who handles directory assistance calls.

Dispatch

The process of sending a craftsperson to an equipment location such as an outside plant location or to a customer's premises for maintenance or trouble diagnostic purposes.

Distributing Frame

A main distributing frame is a connection system that interfaces between loop cable pairs and switching equipment. Other distributing frames are used to interconnect other equipments within an office.

Distribution

In a switching network, distribution refers to the capability of connecting an input to any one of several outputs. In a traffic network, distribution refers to separating calls on incoming trunk groups at a toll or tandem office and recombining them on other outgoing trunk groups.

Distribution Cable

Part of the outside cable plant connecting feeder or subfeeder cables to drop wires or buried service wires that connect to the customer's premises. Distribution cable usually contains fewer than 300 twisted wire pairs.

DIVA

See *Digital Inquiry—Voice Answerback.*

Diversity

(1) A method of radio transmission and or reception in which a single information channel is derived or selected from a plurality of received channels. Diversity may take the form of frequency diversity, the use of more than one frequency; polarization diversity, the use of more than one polarization for transmission; space diversity, the use of two or more antennas at different locations at the transmitter and/or receiver; and angle diversity, antennas pointed in slightly different directions.

(2) A method of transmitting a single information channel over separate geographic routes to provide a high degree of service continuity.

DPSK

See *Differential Phase-Shift Keying.*

Drop Wire

A relatively short pair of wires connecting an aerial distribution cable pair to a customer's premises.

DSBAM

Double sideband amplitude modulation.

DUV

See *Data Under Voice.*

DX Signaling

A facility signaling system and range extension technique for long metallic trunks that uses bridge-type detection of small dc changes.

EADAS

See *Engineering and Administration Data Acquisition System.*

Echo

An attenuated signal derived from a primary signal by reflection at one or more impedance discontinuities and delayed relative to the primary signal.

Echo Suppressor

A device that detects speech signals transmitted in either direction on a 4-wire circuit and introduces loss in the opposite direction of speech transmission for suppressing echoes. In the public telephone network, echo suppressors are used typically in trunks longer than 1850 miles.

Echo, Talker

An echo of a talker's voice that is returned to the talker. When there is delay between the original signal and the echo, the effect is disturbing unless the echo is attenuated to a tolerable level.

Economy of Scale

As the need for increased capacity in switching and transmission facilities develops, due either to growth or concentration, the cost per unit of capacity may decrease because of two factors:

(1) Fixed start-up costs that are spread over an increasing number of units.

(2) Technological advantages that can be achieved when designing for large capacity.

Electronic Switching System (ESS)

A class of modern switching systems in which the control functions are performed principally by electronic devices. There are two types in use: time-division and space-division.

Electronic Translator

The equipment in No. 4A/ETS toll switching systems that translates the called codes, by means of electronic circuitry and stored program control information, into information required by the system to select an available route toward the central office of the called customer.

E&M Lead Signaling

A specific form of interface between a switching system and a trunk in which the signaling information is transferred across the interface via 2-state voltage conditions on two leads, each with ground return, separate from the leads used for message information. The message and signaling information are combined (and separated) by a signaling system appropriate for application to the transmission facility. The term E&M lead signaling is used also in some special-service applications.

End Office

A local switching office where loops are terminated for purposes of interconnection to each other and to trunks. End offices are designated class 5. See *Toll Hierarchy.*

End-to-End Signaling

A mode of network operation in which the originating central office (or station) retains control and signals directly to each successive central office (or PBX) as trunks are added to the connection. This contrasts with operation in which each office takes control in turn, called *link-by-link signaling.*

Engineered Capacity

The highest load level for a trunk group or a switching system at which service objectives are met. In general, for a switching system, carried load is equal to offered load below engineered capacity, but is less than offered load above engineered capacity.

Engineering, Communications or Telephone

An activity that applies the principles of electrical communications to the solution of practical communication problems. A common use of the term refers to operating company functions, such as the final planning and sizing of trunk groups, central office equipment, and transmission facilities, or the end-to-end transmission design of loops and trunks.

Engineering and Administration Data Acquisition System (EADAS)

A system in which traffic data are measured at switching systems by electronic devices, transmitted to a centrally located minicomputer, and recorded on magnetic tape in a format that is suitable for computer processing and analysis.

Engineering, Planning, and Analysis Systems (EPLANS)

Software systems used by operating telephone company engineering and related personnel to support their planning, record keeping, implementation, scheduling, ordering, network performance evaluation, network characterization, and other similar activities. The programs are Western Electric products and are offered as time-share or batch-run computer services by Western Electric or, in some cases, are run in telephone company data centers.

Engineering Work Order

An order for work to be done in an operating company to add, remove, or change outside plant facilities in the inventory.

Envelope Delay Distortion

Departure from a constant value of the envelope delay versus frequency characteristic. Envelope delay is the derivative with respect to frequency of the phase characteristic of the transfer function and should not be confused with differential delay which is the difference in delay at two frequencies.

EPLANS

See *Engineering, Planning, and Analysis Systems.*

Equalization

The procedure applied to transmission media or channels in order that the amplitude and phase (or envelope delay) characteristics of a signal to be transmitted are preserved at the receiving end of the connection. (If a channel introduces phase or frequency offset, equalization does not preserve the waveform of the signal.)

Equipment

A unit of hardware, typically including apparatus units as components, that may have options to alter its function and may have changes made on the telephone companies' premises to improve existing characteristics, to correct undesirable conditions, or to provide new operating features. Western Electric maintains detailed records indicating quantity, features, location, and changes for most Western Electric furnished equipment units.

Equipment Charge

A monthly non-usage-sensitive charge, based on the amount and type of installed telephone equipment or apparatus.

Erlang

A dimensionless unit of traffic intensity used to express the average number of calls under way or the average number of devices in use. One Erlang corresponds to the continuous occupancy of one traffic path. Traffic in Erlangs is the sum of the holding times of paths divided by the period of measurement. The term Erlang can be used to express the capacity of a system; for example, a trunk group of 30 trunks, which in a theoretical peak sense might carry 30 Erlangs of traffic, would have a typical capacity of perhaps 25 Erlangs averaged over an hour.

Erlang B

One of the basic traffic models and related formulas used in the Bell System. The assumptions are Poisson input, negative exponential holding time, and blocked calls cleared. Used for trunk engineering.

Erlang C

One of the basic traffic models and related formulas used in the Bell System. This is the queuing model with assumptions of Poisson input, negative exponential holding times, and blocked calls delayed. The queuing discipline may be arbitrary but is usually approximately first come, first served. Used for common-control engineering.

Error Rate

A measure of the performance of a digital transmission system. It can be specified as a bit error rate (the probability of error per bit transmitted), as a block error rate (the probability of one or more errors in a specified-length block of bits), or in other forms such as percent error-free seconds.

ESS

See *Electronic Switching System.*

Exchange Area

An area within which there is a single uniform set of charges for telephone service. An exchange area may be served by a number of central offices. A call between any two points within an exchange area is a local call.

Exchange Area Facilities

Transmission facilities within an exchange area used for loops, trunks, and special-service circuits. The term commonly refers to facilities used for trunks between class 5 offices, between tandems and class 5 offices or other tandems, and between class 5 offices and toll offices over distances up to approximately 100 miles. T1 carrier is an example of an exchange area facility.

Expansion

The term applied to a switching network (or portion of one) that has more outputs than inputs.

Facilities Network

The aggregate of transmission systems, switching systems, and station equipment; it supports a large number of traffic networks.

Facility

Any one of the elements of physical telephone plant that are needed to provide service. Thus, switching systems, cables, and microwave radio transmission systems are examples of facilities. Facility is sometimes used in a more restricted sense to mean transmission facility.

Facility Management

A concept of overall efficient transmission system (facility) utilization, including concepts such as the use of protection channels, temporary setups for television specials, etc. These uses are in addition to normal utilization for maintenance and restoration purposes.

Facility Work Order

An order to rearrange facilities on working services, or those for which service order work is in progress.

FADS

See *Force Administration Data System.*

FCC

See *Federal Communications Commission.*

Federal Communications Commission (FCC)

A board of seven commissioners, appointed by the President of the United States under the Communications Act of 1934, having the power to regulate interstate and foreign communications originating in the United States by wire and radio.

Feedback Amplifier

An amplifier in which a portion of the output signal is fed back and combined with the input signal. By proper negative feedback (opposite phase) design, the gain of an amplifier can be made essentially independent of the active elements (transistors, etc.) in the amplifier circuit. The gain can therefore be made very controllable and stable, as can input and output impedance as well as linear and nonlinear distortion.

Feeder Cable

A large pair-size loop cable emanating from a central office and usually placed in an underground conduit system with access available at periodically placed manholes.

Feeder Route

A network of loop cable extending from a wire center into a segment of the area served by the wire center.

Feeder Section

A segment of a feeder route that is uniform throughout its length with respect to facility requirements and facilities in place.

Ferreed Assembly

A component consisting of two or four miniature glass-enclosed reed switches that are operated or released by controlling the magnetization of two adjacent plates. The magnetization of the plates is controlled by two windings. When both windings are energized, the reeds close and remain closed. When only one winding is energized, the reeds open.

Ferrod

A current-sensing device (ferrite rod) used in scanners for supervisory and other purposes.

Final Group

A trunk group that acts as a final route for traffic. Traffic can overflow to a final group from high-usage groups that are busy. Traffic cannot overflow from a final group.

FIT

A unit for expressing reliability in terms of failure rate.

$$1 \text{ FIT} = 1 \text{ failure in } 10^9 \text{ component operating hours}$$

Flip-Flop

A 2-state device that assumes one state or the other, depending upon the polarity of the pulse used to drive it or upon the terminal to which the drive is applied.

FM

Frequency modulation.

FNPA

See *Foreign Numbering Plan Area.*

Focused Overload

Abnormal calling from many points to one particular point; for example, after an earthquake or in response to a radio station give-away offer.

Force Administration Data System (FADS)

A system that provides basic telephone traffic data from which additional data may be derived to assist in arranging the most effective manning of attendant or operator positions and in calculating work force performance.

Forcing

The managerial function of providing the proper number of operators (half-hourly) to serve demand. The goal is to satisfy the service objectives while controlling expense. The functions are forecasting demand, scheduling tours to cover this demand, allocating the tours to offices in multioffice systems, assigning individual operators to specific tours, and making corrections in real time as required.

Foreign Area Translation

The translation of the office codes of a foreign area for routing purposes when there is more than one trunk route available for entry into the foreign area or for other selective treatment.

Foreign Exchange (FX) Service

A service providing a circuit connecting a subscriber's main station or private branch exchange with a central office of an exchange other than that which normally serves the exchange area in which the subscriber is located.

Foreign Numbering Plan Area (FNPA)

Any NPA outside the boundaries of the home NPA.

Four-Wire Circuit

A circuit using two one-way transmission paths, one for each direction of transmission. It may be two pairs (four wires) of metallic conductors or two channels as in a carrier system.

Frame

(1) A segment of a signal, analog or digital, that has a repetitive characteristic in that corresponding elements of successive frames represent the same things. Examples are a television frame, which represents a complete scan of a picture, or a telemetry frame, which represents values of a number of parameters in a specific order. In a time-division multiplex system, a frame is a sequence of time slots, each containing a sample from one of the channels served by the multiplex system; the frame is repeated at the sampling rate, and each channel occupies the same sequence position in successive frames.

(2) An assembly of equipment units.

Framing

The process of establishing a reference so that time slots or elements within the frame can be identified.

Frequency Division

A method of serving a number of simultaneous calls by means of a common transmission path with a different frequency band for the transmission of each call.

Frequency Frogging

The practice of changing the relative positions of channels in a common spectrum periodically along a transmission path to reduce intermodulation noise or crosstalk.

Frequency Offset

A frequency shift that occurs when a signal is sent over an analog carrier facility in which the modulating and demodulating frequencies are not identical. A channel with frequency offset does not preserve the waveform of the transmitted signal. DATAPHONE sets are designed to tolerate frequency offsets of up to +5 Hz.

Frequency-Shift Keying (FSK)

A modulation technique for transmitting digital information having two or possibly more discrete states. Each of the discrete states is represented by an associated frequency. The most common form is binary FSK which uses two frequencies to represent the two states.

FSK

See *Frequency-Shift Keying.*

Full-Duplex Transmission

A method of operating a communications circuit so that each end can simultaneously transmit and receive.

Full Group

A trunk group, other than a final trunk group, that does not overflow calls to another trunk group. Enough trunks are provided to give an acceptable blocking probability.

FX

See *Foreign Exchange Service.*

Generic Program

A set of instructions for an Electronic Switching System that is the same for all offices using that type of system. Detailed differences for each individual office are listed in a separate parameter table.

Grade of Service

(1) An estimate of customer satisfaction with a particular aspect of service (such as noise or echo). It combines the distribution of subjective opinions of a representative group of people with the distribution of performance for the particular aspect being graded. For example, with a specified distribution of noise, 95 percent of the people may judge the noise performance to be good or better; the noise grade of service is then said to be 95 percent good or better.

(2) The proportion of calls, usually during the busy hour, that cannot be completed due to limits in the call-handling capability of a component in a network. For example, service objectives are defined on a per-link (per-trunk-group) basis for the last-choice groups in a traffic network. See *Service Objective.*

Ground Start

A supervisory signal given at certain coin telephones and PBXs by connecting one side of the line to ground.

Half-Duplex Transmission

A method of operating a communications circuit so that each end can transmit or receive, but not both simultaneously. Thus, normal operation is alternate, one-way-at-a-time, transmission.

Hamming Code

A form of code that will permit the correction of some errors and detection of most other errors in digital data transmission.

Hardware Tariffs

Tariffs filed on the basis of providing service with an explicit type of serving equipment.

Harmonic Distortion

The result of nonlinearities in the communication channel that cause harmonics of the input frequencies to appear in the output. The same effect produces spurious frequencies, such as sum and difference frequencies, from interaction of input frequencies.

HCMTS

See *High-Capacity Mobile Telecommunications System.*

Held Order

(1) A service order that is not completed within a specified period of time.

(2) A service order requiring rearrangement or reinforcement of outside plant.

HIC

See *Hybrid Integrated Circuit.*

High-Capacity Mobile Telecommunications System (HCMTS)

A mobile system featuring a cellular pattern of base transmitters and receivers and frequent reuse of radio channels. One large advantage of HCMTS over earlier systems is that higher quality service would be available to a much larger number of subscribers than is possible today.

High-Usage Group

A trunk group that is the primary direct route between two switching systems. The group is designed for high average occupancy. To provide an overall acceptable probability of blocking, an alternate route must be provided for overflow traffic.

HNPA

See *Home Numbering Plan Area.*

Home Numbering Plan Area (HNPA)

The NPA within which the calling line appears at a local (class 5) switching office.

Hub

A point or piece of equipment where a branch of a multipoint network is connected. In a telegraph network, signals appear as dc pulses at the hub. A network may have a number of geographically distributed hubs or bridging points.

Hub Layout

In voiceband multipoint networks, a hub layout is one in which each branch, or leg, serving a particular station is routed to a common central location for appropriate bridging and test access. The central location is generally known as a serving test center (STC).

Hundred Call Seconds (CCS)

A unit of traffic used to express the average number of calls in progress or the average number of devices in use. Numerically it is 36 times the traffic expressed in Erlangs.

Hybrid

A network having four ports and designed so that when the ports are properly terminated, the signal input to any particular port splits equally between the two adjacent ports with essentially no signal coupled to the opposite port. Hybrids are used to couple 4-wire circuits to 2-wire circuits.

Hybrid Integrated Circuit (HIC)

The term usually refers to an electronic circuit that contains both silicon integrated circuits and circuitry fabricated by film deposition techniques.

IDDD

See *International Direct Distance Dialing.*

Improved Mobile Telephone Service (IMTS)

Mobile telephone service on a completely dial basis. Mobile units can dial into the public telephone network and can be reached from the network without operator assistance. This is in contrast with original mobile service which was on an operator-handled basis for both incoming and outgoing traffic. (To be distinguished from High-Capacity Mobile Telecommunications Service.)

Impulse Noise

Short bursts of high-level noise such as that resulting from the coupling of transients into a channel. Typical sources of such noises are lightning and transients from switching systems. Impulse noise, which sounds like a click, is not particularly detrimental to voice communications, but it can be detrimental to data communications. Some of the older switching systems, such as the Panel type, create so much impulse noise that DATAPHONE service is not handled by central offices of this type.

IMTS

See *Improved Mobile Telephone Service.*

Inband Signaling

Signaling that uses the same path as a message and in which the signaling frequencies are in the same band used for the message.

Independent Telephone Company

A telephone company not affiliated with the Bell System and having its own "independent" territory. There were over 1600 independent telephone companies in the United States in 1975.

Index Plan

A method used in the Bell System to calculate an index of performance. There are a number of index plans in use, each of which takes into account statistical data for a particular parameter or combination of parameters of plant performance or service. Examples are connection appraisal index plan, trunk transmission maintenance index plan, and local dial-line index plan.

Individual Line Service

Refers to the provision of a nonshared access line to the central office as part of either business or residence telephone service.

Input/Output

(1) The information entering or leaving a system across a system boundary (alternatively, information entering or leaving a subsystem within the system boundary).

(2) The process of transmitting information from an external source to a system or from a system to an external destination.

Insertion Loss

The insertion loss of a transmission system (or component of the system) inserted between two impedances, Z_1 (transmitter) and Z_N (receiver), it is the ratio of the power measured at the receiver before the insertion of the transmission system to the power measured after insertion. Insertion loss is normally expressed in decibels (dB).

Installation Charge

A one-time charge, due upon installation of customer-premises equipment, that is used to help recover the actual expenditures.

Integrated Circuit, Silicon

An electronic circuit, fabricated on a silicon substrate, that contains a number of active and passive circuit elements in a small area.

Intelligible Crosstalk

Crosstalk sufficiently understandable under prevailing circuit and room noise conditions so that meaningful information can be obtained.

INTELSAT

See *International Telecommunications Satellite Consortium.*

Intercept Operator

A person who provides intercept service at an intercept position of a switchboard or at an auxiliary services position of a centralized intercept bureau.

Intercept Service

A service in which a telephone call directed to an improper telephone number is redirected to an operator or to a recording. The caller is informed why the call could not be completed and, if possible, is given the correct number.

Intercom Service

An optional service with key telephone equipment that provides intercommunications among stations in a key telephone system over facilities distinct from CO facilities. Calls are made using an abbreviated dialing plan.

Interconnecting Unit

An interface device on the telephone company side of the interface used for connecting arrangement service. In addition to providing appropriate interfacing functions, the interconnecting unit serves as a protection device.

Interface

A common boundary between two systems or pieces of equipment where they are joined.

Interface Device

A device that meets the interface specifications on one side of an interface. The term is usually applied to a device through which a system or equipment works to meet interface specifications.

Interface Specification

A set of technical requirements that must be met at an interface.

International Direct Distance Dialing (IDDD)

The automatic establishment of international calls by signals from the calling device of either a customer or an operator.

International Telecommunications Satellite Consortium (INTELSAT)

An international organization established in 1964 to govern a global commercial communications satellite system to provide communications between many countries. Membership is in excess of 80 countries. The Communications Satellite Corporation (COMSAT) acts as manager for INTELSAT and also represents the United States.

International Telephone and Telegraph Consulatative Committee (CCITT)

One of two committees that support the International Telecommunications Union (ITU) by conducting studies on technical and operating questions and recommending standards; the other is the International Radio Consultative Committee (CCIR). The ITU, a specialized agency of the United Nations, was created to encourage international cooperation in the development and use of communications by radio, telegraph, cable, telephone, and television.

Interstate Communications Services

Communications services across state boundaries, e.g., private-line service from New Jersey to New York. Interstate services are regulated by the Federal Communications Commission.

Intersymbol Interference

In an ideal digital transmission system, the detection of a symbol is not affected by preceding or following symbols. When the transmission system departs from ideal (e.g., insufficient bandwidth), errors may be caused by energy from preceding or following symbols affecting the detection of the desired symbol.

Intertoll Trunk

A trunk between two toll offices.

Intrastate Communications Services

Communications services confined within a single state, e.g., a local call placed within a town. Intrastate services are regulated by state regulatory bodies.

Intrastate Toll

Traffic within state boundaries that is charged at toll rather than local rates.

Inward Wide Area Telecommunications Service (INWATS)

A reverse-charge direct distance dialing service to a specific directory number (see *WATS*). Bulk rates based on measured time are charged.

INWATS

See *Inward Wide Area Telecommunications Service.*

Jumper

A pair of wires used in establishing a connection through a distributing frame.

Junctor

Within a switching system, a connection or circuit between inlets and outlets of the same or different switching networks. An intraoffice trunk.

Key Telephone Set

A telephone set with buttons or keys located on or near the telephone. It is used with associated equipment to provide features such as call holding, multiline pickup, signaling, intercommunication, and conferencing.

Key Telephone Systems

An arrangement of key telephone stations and associated circuitry, located on a customer's premises, providing combinations of certain voice communications arrangements such as multiline pickup, call line status lamp signals, and interconnection among stations without the need for connections through the central office or PBX facilities.

Keypulsing Signal

In multifrequency signaling, a signal, keyed by the operator, that is used to prepare the distant equipment for receiving digits.

LAMA

See *Local Automatic Message Accounting.*

LBO

See *Line Build-Out Network.*

Line

(1) A pair of wires carrying direct current between a central office and a customer's terminal. A line is the most common type of loop. See *Loop.*

(2) In carrier systems, the portion of a transmission system that extends between two terminal locations. The line includes the transmission media and associated line repeaters.

(3) Also used to indicate the side of a piece of central office equipment that connects to or toward the outside plant; the other side of the equipment is called the *drop side.*

(4) A family of equipments or apparatus designed to provide a variety of styles, a range of sizes, or a choice of service features.

Line Build-Out (LBO) Network

Amplifiers (repeaters) in a cable transmission system may be designed to compensate for distortion of a specific length of cable. When the length of cable between amplifiers is less than that for which the amplifier is designed, one or more line build-out networks are used to bring the distortion to approximately the design level.

Line Equipment

Equipment located in a central office and associated with a particular line. Includes a line relay or equivalent that is activated when the customer's telephone is off-hook.

Line Finder

A switching mechanism that finds a calling line in a group of 100 or 200 in a Step-by-Step System or in a group of 300 or 400 in a Panel System and connects it to an intraoffice circuit, usually to a local first selector.

Line Link Pulsing

An arrangement that permits a Crossbar office to transmit dial-pulse information to a PBX for switching direct-inward-dialed calls to the indicated station.

Linear Distortion

Distortion resulting from a channel having a linear filter characteristic different from an ideal linear low-pass or bandpass filter; in particular, amplitude characteristics that are not flat over the passband and phase characteristics that are not linear over the passband.

Link-by-Link Signaling

A mode of network operation in which each office along the route of a call acts autonomously, forwarding all of the information required to complete the call to the next office in the chain. Contrasts with *End-to-End Signaling.*

Load Balancing

The process of assigning customers to line equipment so as to maintain a proper distribution of traffic in a switching system. Load balancing also is done at other places in switching equipment, such as on incoming selectors in Step-by-Step Systems.

Load Coil

An inductor used to increase the effective distributed inductance of a transmission pair, thereby improving its transmission characteristics.

Loaded Line

A cable pair having load coils placed periodically along its length.

Local Automatic Message Accounting (LAMA)

A process using equipment located in a local office for automatically recording billing data for message rate calls (bulk billing) and for customer-dialed station-to-station toll calls.

Local Service, Local Exchange Service

Public telephone service to points within the designated local service area (exchange area) for a station. The local service area for a central office is usually defined in the telephone directory; it typically includes customers served by other nearby central offices. Service is charged at a flat monthly rate or by the amount of usage; calls are not billed individually.

Local Switching Facilities

Switching systems that perform end office (class 5 office) functions. Switching systems to which loops or lines are connected.

Long-Route Design

A codification of design practices used to plan customer loops that exceed the resistance design limit of the serving central office.

Longitudinal Balance

A measure of the conversion of equal induced noise-to-ground voltages to metallic current (loop current) in a 2-wire transmission pair. When the balance is good, the metallic current is relatively small.

Longitudinal Induction Noise

Noise induced into a cable pair as metallic (loop) current because of pair imbalance or the unequal coupling of the noise source into the wires of a pair.

Loop

(1) A channel between a customer's terminal and a central office. The most common form of loop, a pair of wires, is also called a line.

(2) Also used to mean a 2-wire ungrounded connection between pieces of equipment (as distinguished from a one-wire and ground connection).

Loop-Reverse-Battery

A method of signaling over interoffice trunks in which dc changes, including directional changes associated with battery reversal, are used for supervisory states. This technique provides 2-way signaling on 2-wire trunks; however, a trunk can be seized at only one end—it cannot be seized at the office at which battery is applied. Also called *reverse battery signaling.*

Loop Signaling

A method of signaling over dc circuit paths that utilizes the metallic loop formed by the line or trunk conductors and terminating circuits.

Loop-Start

A supervisory signal given at a telephone or PBX in response to completing the loop current path.

Loudness Loss

A measure used to express the loss of communication paths in a manner that reflects loudness perception. For partial and overall telephone circuits, loudness loss is the ratio of suitably weighted output signal levels to input signal levels. (The signals may be electric or acoustic.)

Main Distributing Frame (MDF)

A distributing frame used to interconnect cable pairs and line and trunk equipment terminals on a switching system.

Make-Busy

Conditioning a circuit, a terminal, or a termination to be unavailable for service. When unavailable, it is generally necessary that it appear busy to circuits that seek to connect to it.

Marker (Crossbar)

The heart of common-control Crossbar central office equipment. It performs the following functions in a No. 5 Crossbar switching system: (a) determines terminal locations of calling lines, incoming trunks bidding for service, called lines, and outgoing trunks in the equipment, (b) determines the proper route for the call, establishes the connection within the office, and passes routing information to the senders, (c) determines the calling line class of service, and provides charge classification, (d) recognizes line busy, trouble, intercept, and vacant line conditions, and (e) calls in a trouble recorder when necessary.

MDF

See *Main Distributing Frame.*

Measured (or Message Rate) Service

Telephone service for which a charge is made in accordance with a measured amount of usage, referred to as message units.

Media

In transmission systems, the structure or path along which the signal is propagated, such as wire pair, coaxial cable, waveguide, optical fiber, or radio path.

Message

(1) In telephone communications, a successful call attempt that is answered by the called party and followed by some minimum period of connection.

(2) In data communications, a set of information, typically digital and in a specific code such as ASCII, to be carried from a source to a destination. A header, with address and other information regarding handling, may be considered part of or separate from the message.

Message Circuit Noise

(1) The short-term average noise level as measured with a 3A noise measuring set or its equivalent. This set includes frequency weighting and time constants to make the set most sensitive to noise that will impair transmission quality in telephone circuits used for speech.

(2) The noise occurring in a voiceband channel due to electronic thermal effects, random crosstalk, and intermodulation activity.

Message Switching Network

A type of traffic network in which the sources provide messages and, for each, the address(es) of one or more destinations; the traffic network then delivers the messages to their various destinations. Typically a message is in digital form and is stored digitally at one or more points in the network; the storage time may be long (days) or short (microseconds). This contrasts with a line switching network in which an unbroken channel is provided from source to destination and the absence of storage means that the format of the information is relatively unconstrained. Message switching services have long been offered by the Bell System in the telegraph field. These have been implemented with private traffic networks, but common-user networks are possible.

Message Telecommunication Service (MTS)

Service that uses in whole or in part the public telephone network. Examples include public telephone service, mobile radio-telephone service, air-to-ground service, etc. Private-line services are not included.

Metallic Facility Terminal (MFT)

A voice-frequency facility terminal combining voice-frequency transmission and signaling functions into one unit. It interfaces a metallic facility (wire) with a switching system or with another metallic facility. Channel bank equipment is not involved.

MF

See *Multifrequency Pulsing.*

MFT

See *Metallic Facility Terminal.*

Mobile Telephone Services

A class of services that utilizes radio channels to provide telephone service. Mobile telephone services include:

(1) Land mobile telephone service.

(2) BELLBOY service.

(3) Air/ground service.

(4) VHF maritime service.

(5) Coastal harbor service.

(6) High-seas maritime radio-telephone service.

(7) High-speed train service.

Modem

A contraction of the words modulator and demodulator, signifying an equipment unit that performs both of these functions.

Modular Telephone

A concept in station set design whereby the handset and line cord connect into their mating parts by plug and jack rather than by permanent wiring. The plug-in design is intended to reduce maintenance costs and to allow more flexibility in introducing new operating concepts, such as the PhoneCenter.

MTS

See *Message Telecommunication Service.*

Multifrequency Pulsing (MF)

An inband interoffice address signaling method in which ten decimal digits and five auxiliary signals are each represented by selecting two frequencies out of the following group: 700, 900, 1100, 1300, 1500, and 1700 Hz.

Multiple

Terminals or jacks connected and grouped so that a circuit is made available at a number of points, e.g., a switchboard multiple.

Multiplex

The process or equipment for combining a number of individual channels into a common spectrum or into a common bit stream for transmission.

Mutual Pair Capacitance

The capacitance per unit length between the conductors of a twisted wire pair.

NAP

See *Network Access Pricing.*

Network

(1) The facilities network is the aggregate of transmission systems, switching systems, and station equipments; it supports a large number of traffic networks.

(2) A traffic network is an arrangement of channels, such as loops and trunks, associated switching arrangements, and station equipments, designed to handle a specific body of traffic. A traffic network is a subset of the facilities network.

(3) An electrical/electronic circuit, usually packaged as a single piece of apparatus or on a printed circuit pack. Examples are a transformer network and an equalization network.

(4) The switching stages and associated interconnections of a switching system are collectively called the switching network.

Network Access Pricing (NAP)

A tariffing concept whereby the rate for a service would be strongly influenced by the cost of network elements (e.g., stations, loops, etc.) used to provide that service. Contrasts with the tariffing concept based on the value of service.

Network Management

A set of procedures, equipment, and operations designed to keep a traffic network (the public telephone network, for example) operating near maximum efficiency when unusual loads or equipment failures would otherwise force the network into a congested, inefficient state.

Network Port(s)

In a network (in the sense of a localized circuit), ports are the interfaces with facilities or circuits outside the network, e.g., the input port and output port of an amplifier. In certain multiport networks, the combination of an input terminal and output terminal, associated with a particular direction or side, is collectively referred to as a port, e.g., the six ports on a 6-way, 4-wire multipoint bridge. A point of connection between a computer and a communications system is sometimes called a port.

Noise

An unwanted disturbance introduced in a communications circuit. It may partially or completely obscure the information content of a desired signal. On telephone circuits, noise may be an annoyance during quiet intervals as well as when speech is present.

Nonassociated CCIS

A network of CCIS data links and signal transfer points (STPs) intended to make CCIS economical for small trunk groups. The signals are routed via two or more shared data links in tandem and are processed and forwarded through one or more STPs. The route followed by the signals may be geographically different from that for the connection to be established.

Noncoherent Modulation System

A modulation system not requiring a source of carrier, either generated at the receiving terminal or transmitted separately, that has the same frequency and phase as that associated with the received signal for recovering the original modulating signal.

Nondial Trunks

PBX tie trunks that require attendant assistance for verbal transmission of address information.

Nonintelligible Crosstalk

Crosstalk that cannot be understood but that is subjectively more annoying than thermal noise because of its syllabic nature.

Nonlinear Distortion

Amplitude distortion caused by nonlinearities in a communication channel.

NPA

See *Numbering Plan Area.*

Number Group

In Crossbar switching systems, an arrangement for associating equipment numbers with main-station codes. A form of translator.

Number Service

Service to provide information necessary for call placement; includes information provided by directory assistance, intercept, and rate and route bureaus.

Number Service Operator

A person who provides any of several services relating to telephone numbers, such as directory assistance for both customers and toll service operators and interception of calls to unassigned or changed numbers.

Numbering Plan Area (NPA)

In North America, a geographic division within which telephone directory numbers are subgrouped. A 3-digit, N0/1X or NXX code is assigned to each NPA, where

N = any digit 2 through 9
0/1 = 0 or 1
X = any digit 0 through 9

Occupancy

The fraction of time that a circuit or an equipment is in use, expressed as a decimal. Numerically, it is the Erlangs carried and is equal to the CCS carried divided by 36. As measured, occupancy includes both message time and setup time.

Off-Hook

Station switchhook contacts closed, resulting in line current, or whatever supervisory condition is indicative of the in-use or request-for-service state.

Offered Load in Erlangs

The average number of calls that would have been in progress if there had been no delay or blocking.

On-Hook

Station switchhook contacts open or whatever supervisory condition is indicative of the equipment-idle state.

One-Way Trunk

A trunk that can be seized at only one end. See *Seize.*

Operating Company, Operating Telephone Company

A regulated telephone company whose primary business is providing telephone service to customers. There are 24 operating companies in the Bell System and over 1600 non-Bell operating companies in the United States. These together provide service to the entire country.

Operating Force

Those employees primarily engaged in service relating to telephone operators and their associated clerical and supervisory personnel. This includes personnel in operator training but does not include personnel engaged in the observation of the handling of operator traffic or personnel at attended pay stations.

Operator Services

A variety of services normally performed by operators. These include completing or helping customers to complete toll calls and assistance calls; preparing billing inputs on those calls; providing directory assistance; intercepting and helping customers with calls to changed or nonworking numbers; providing special services, such as person-to-person, coin, credit card, collect, PICTUREPHONE, mobile, and conference calls; and giving on-the-job consultation to business customers.

Operator Trunk

A type of toll-connecting trunk that provides access from class 5 offices to toll assistance operators.

Out-of-Band Signaling

A method of signaling that uses the same path as voice-frequency transmission and in which the signaling is outside the band used for voice frequencies.

Outside Plant

The part of the telephone system that is located physically outside of telephone company buildings. Includes cables, supporting structures, and certain equipment items such as load coils. Microwave towers, antennas, and cable system repeaters are not considered as outside plant.

Outstate T1

T1 carrier implemented according to special engineering rules that allow it to serve areas in excess of the normally recommended 50-mile T1 carrier limitation.

Overflow

A count of all calls offered to a trunk group that are not carried (see *Peg Count*). Usually measured for an hour.

Pair Gain

The number of customers served by a communication system less the number of wire pairs used by that system. Pair gain can be achieved by multiplexing and by concentration.

PAM

See *Pulse Amplitude Modulation.*

Parity Bit

A bit attached to a word to make the total 1s, including the parity bit, odd (or even). Used to detect single bit errors.

Parity Check

A check on the validity of a binary word by determining whether the number of 1s in the word is odd (or even).

Party-Line Service

Refers to the provision of a shared line to the central office as part of either business or residence telephone service. Two, four, eight, or more customers may share a party line.

PBX

See *Private Branch Exchange.*

PBX Attendant

A person situated at a position of a switchboard, desk, or console on a customer's premises to assist in establishing telephone connections between or with stations served by a PBX and who may perform various auxiliary functions associated therewith. Not an employee of the telephone company.

PBX Tie Trunk

A trunk between two PBXs.

PBX Trunk

A line that connects a PBX and a central office. Sometimes called a PBX line in central office terminology.

PCM

See *Pulse Code Modulation.*

Peak Load

Denotes a higher-than-average quantity of traffic; usually expressed for a one-hour period and as any of several functions of the observing interval, such as peak hour during a day, average of daily peak hours over a 20-day interval, maximum of average hourly traffic over a 20-day interval. See *Busy Hour.* Note that significantly higher peak loads occur infrequently as a result of catastrophes and on Mother's Day and Christmas.

Peg Count

A count of all calls offered to a trunk group, usually measured for an hour. As applied to units of common-control switching systems, peg count or carried peg count means the number of calls actually handled.

Per-Trunk Signaling

A method of signaling in which the signals pertaining to a particular call are transmitted over the same trunk that carries the call. Interoffice signaling other than CCIS falls into this category.

Permanent Signal

A sustained off-hook supervisory signal, originating outside a switching system and not related to a call in progress. Permanent signals can occupy a substantial part of the capacity of a switching system.

Person-to-Person Service

The service in which the person originating the call specifies to an operator a particular person to be reached or a particular station, department, or office to be reached through a PBX attendant.

Personnel Subsystem

The people, and their supporting methods and procedures, training aids, etc., who work in conjunction with a hardware (and software) configuration to achieve system objectives.

Phase Constant

The phase shift of a sinusoidal wave as it traverses a unit length of a transmission line.

Phase Jitter

Phase variations arising in a channel and caused by incidental frequency modulation of signals transmitted over the channel. This occurs when the carrier supply frequencies in a frequency-division-multiplexed carrier system are not perfectly constant. For example, in L carrier, the carrier frequencies are obtained by generating harmonics from a 4-kHz signal. A small amount of noise (usually power frequency and its harmonics) on this signal can result in sizable frequency deviations in the higher harmonics.

Phase-Shift Keying (PSK)

Modulation techniques for transmitting digital information in which that information is conveyed by selecting discrete phase changes of the carrier. See *Coherent Phase-Shift Keying* and *Differential Phase-Shift Keying*.

PhoneCenter

A store in which a customer may select telephones to be brought home and plugged into prewired connectors. Modular telephones are required in a PhoneCenter area.

PIC Cable

Cable whose conductors are individually insulated with a polyethylene (plastic) covering.

PICTUREPHONE Service

A service that combines voice telephone service and a television-like picture. This service is available in a few metropolitan areas.

Poisson

In traffic theory, Poisson refers to a distribution or a process resulting in a distribution of events such that the intervals between adjacent events are independent random variables that are members of identical exponential distributions. Under certain conditions, the arrival of telephone calls to be routed over a trunk group can be approximated by a Poisson distribution. Named after a 19th century French mathematician.

Polar Signal

A digital signal technique in which positive and negative excursions represent the two binary states.

Position

(1) A location or piece of equipment at which a person works, e.g., that portion of a manual switchboard that is normally provided for the use of one operator.

(2) A unit of manual work that must be assigned and performed as a whole. For example, the work of a toll operator at a switchboard would be said to involve about 20 units or "positions" of work.

Post-Dialing Delay

The elapsed time from the end of dialing to the start of ringing at the called end of a connection.

Postpay

Coin telephone service in which coins are deposited after the called party answers. The simplest form of coin service, this always requires additional attention from the operator on toll calls and lacks features such as coin return.

Power Density Spectrum

The relative proportion of total signal power distributed as a function of frequency.

Prefix

Any dialed digit input prior to the destination address. Prefixes are used to place an address in proper context, to indicate service options, or both. Examples: prefix 1, to indicate a toll call; prefix 0, to request the services of an operator.

Prepay

Coin telephone service in which an initial rate deposit is required before the connection is established on chargeable calls. Prepay service is provided either by coin-first or dial-tone-first service.

Primary Center

A class 3 office in the hierarchy of toll switching offices. See *Toll Office.*

Principal City

The principal city for an NPA is the toll office farthest down the routing ladder to which all codes for that area can be routed by destination-type codes. It need not be physically located within the NPA served.

Private Branch Exchange (PBX)

A private switching system, either manual or dial, usually serving an organization such as a business company or a government agency and usually located on the customer's premises. Telephones served by the PBX are called stations. Calls from one station to another may be handled manually or automatically depending on the type of PBX. Calls between stations and an external network, for example, the public telephone network, are normally handled manually by the PBX attendant. Direct inward dialing and automatic identified outward dialing service (formerly called centrex-CU) can be provided by some PBXs. Tie trunks between PBX systems of a single customer are commonly used.

Private Line

A circuit leased by a customer for his exclusive use, connecting two or more terminal equipments only to each other and working independently of any central office switched interconnections; it may be used for voice, data, television, etc.

Private-Line Service

A service in which the customer leases a circuit, not interconnected with the public telephone network, for his exclusive use. The private line may be used for transmission of voice, teletypewriter, data, television, etc.

Private Voiceband Network

A network that is made up of voiceband circuits, and sometimes switching arrangements, for the exclusive use of one customer. These networks can be nationwide in scope and typically serve large corporations or government agencies.

Progressively Controlled Network

A switching network consisting of large-motion switches, such as step-by-step or panel, in which calls are set up by making a series of connections, one at a time.

Propagation Constant

In transmission line theory, the complex number whose real part is the attenuation constant and whose imaginary part is the phase constant.

Protection Channel

The broadband channel of a carrier system that is utilized as a spare and can be switched into service in the event of failure of a normal working broadband channel.

Protection Span

A section of a carrier transmission system, including repeatered line and in some cases terminal equipment, within which a broadband protection channel can be substituted for a working broadband channel in the event of equipment or line failure in the working channel.

Protector Frame

A frame, usually part of the main distributing frame, that serves as termination for loop cables and contains electrical protection devices that normally provide conducting paths but will break down and electrically isolate a loop from the switching equipment when an abnormally high voltage occurs as may result from lightning or contact between a power line and a telephone line.

Provisioning

Provisioning of service consists of the operations necessary to respond to service orders, trunk orders, and special-service circuit orders and to provide the resources necessary to fill these orders. It includes forecasting, planning, construction and installation of facilities, preparing and responding to orders, and maintenance of facilities.

PSK

See *Phase-Shift Keying.*

PTN

See *Public Telephone Network.*

PTS

See *Public Telephone Service.*

Public Coin Telephone Service

Coin telephone service provided where a public need exists, such as at an airport lobby, at the option of the telephone company with the agreement of the owner of the premises or space. There is no directory listing.

Public Telephone Network (PTN)

The traffic network that provides public telephone service.

Public Telephone Service (PTS)

Ordinary telephone service in which a customer has a connection to a central office and can be connected to any other customer of the service. Sometimes called *plain old telephone service* (POTS).

Public Utility

A business organization performing some public service and subject to special government regulation. Telephone companies and electric power companies are public utilities.

Public Utility Commission

An agency charged with regulating communications services, as well as other public utility services, usually within a state.

Pulp-Insulated Cable

Cable whose conductors are individually insulated with paper pulp.

Pulse Amplitude Modulation (PAM)

A modulation technique in which the amplitude of each pulse is related to the amplitude of an analog signal. Used, for example, in time-division multiplex arrangements in which successive pulses represent samples from the individual voiceband channels; also used in time-division switching systems of small and moderate size.

Pulse Code Modulation (PCM)

Conversion of an analog signal, such as voice, to a digital format, ordinarily in terms of binary-coded pulses representing the quantized amplitude samples of the analog signal.

QAM

See *Quadrature Amplitude Modulation.*

Quadrature Amplitude Modulation (QAM)

A modulation system in which two independent signals are impressed on carriers of the same frequency that are 90 degrees out of phase with respect to one another. QAM is attractive for high bandwidth utilization in data communication.

Quantizer

A component of a digital communications system whose function is to assign one of a discrete set of values to the amplitude of each successive sample of a signal. The discrete set of values corresponds to a discrete set of contiguous nonoverlapping intervals covering the dynamic amplitude range of the signal.

Quantizer Noise

The error that results from ascribing a finite number of levels to a continuous signal.

Range Extender

A device that permits a central office to serve a line whose resistance exceeds the normal limit for signaling. A range extender does not extend transmission range. Range extenders are also used in special-service circuits.

Range Extender With Gain (REG)

A unit that provides range extension in a loop for both signaling and transmission.

Rate Center

A geographically specified point used for determining mileage-dependent rates. The rate center of an exchange is generally a point centrally located within the exchange area.

Rate and Route Operator

An operator who provides information to the toll operator, such as special operator routing codes, rate information, and lists of numbers that are coin lines.

Ready-Access Terminal

A class of unsealed terminals that are used to make connections of customer drop wires to wire pairs in a distribution cable.

REG

See *Range Extender With Gain.*

Regenerator

A repeater or amplifier that reshapes, by local generation, line signals used in digital transmission systems. Takes advantage of the fact that the general characteristics of the received signal, such as repetition rate, are known. Contrasts with a linear amplifier used in analog systems.

Regional Center

A class 1 office in the hierarchy of toll switching offices; the highest level toll office. See *Toll Office.*

Register

A part of an automatic switching system that receives and stores signals from a calling device or other source for interpretation and action, some of which is carried out by the register itself.

Regulated Public Utility

A firm that supplies an indispensable service under essentially noncompetitive conditions, with governmental regulation of prices, rate of return, and service quality.

Remote Trunk Arrangement (RTA)

An arrangement whereby the trunks from a number of small end offices are concentrated for efficient service by a single Traffic Service Position System (TSPS) base unit. This enables a TSPS RTA complex to serve an area over 100,000 square miles.

Reorder Tone

A tone applied 120 times per minute that indicates all switching paths are busy, all toll trunks are busy, equipment blockages, unassigned code dialed, or incomplete registration of digits at a tandem or toll office. Also called *Channel Busy* or *Fast Busy Tone.*

Repeater

(1) Analog or nonregenerative: an amplifier inserted in a transmission medium to compensate for the attenuation and distortion introduced by the medium.

(2) Digital or regenerative: a device inserted in a transmission medium to regenerate a digital signal sent over the medium; see *Regenerator.*

Resistance Design

A design method for customer loops in which an attempt is made to employ cable having the highest gauge (smallest wire) that will ensure a loop resistance less than the signaling limit of the central office serving the loop.

Restoration

The process of making good a failed transmission system section by patching in a spare or low-usage system.

Return Loss

The ratio of the incident wave to the reflected wave at the terminal of a transmission line or circuit; if the terminating impedance is exactly equal to the characteristic impedance of the transmission line or the circuit impedance, there is no reflection and the return loss is infinite. Also, where a 4-wire circuit is connected to a 2-wire circuit through a hybrid, return loss is the ratio of the wave entering the hybrid on one side of the 4-wire circuit to the reflected wave leaving the hybrid on the other side of the 4-wire circuit. Note that there can be a number of reflections along a telephone circuit; the reflection having lowest return loss usually occurs at a central office where a loop is connected to a trunk.

Revertive Pulsing

A method of signaling between switching systems in which information is conveyed from system A to system B by B sending a sequence of pulses to A which A counts; A signals B when the correct number has been received.

Ring Conductor

One conductor of a customer line (tip and ring). Use of the names *tip* and *ring* has extended throughout the plant.

Ring Trip

The process of removing the ringing signal at the central office when the called telephone is lifted from the switchhook.

Ringdown

A method of alerting an operator whereby ringing is sent over the line to operate a device or circuit to produce a steady indication (normally a visual signal).

Ringer

A device, usually part of a telephone set, that responds to a 20-Hz signal to produce a ringing sound. Ringers separate from the associated telephone sets are sometimes installed.

Ringer Isolator

A device that disconnects the ringer when ringing voltage is not present; used when ringers are connected in an unbalanced configuration (one side grounded) to achieve greater circuit balance during transmission.

Ringing

The process of alerting the called party by the application of an intermittent 20-Hz signal to the appropriate line; this produces a ringing sound at the called telephone set. When the ringing signal is applied to the called line, an intermittent signal called audible ringing is sent to the calling telephone to indicate that ringing is taking place.

RTA

See *Remote Trunk Arrangement.*

SAM

See *Service Attitude Measurement.*

Sectional Center

A class 2 office in the hierarchy of toll switching offices. See *Toll Office.*

Seize, Seizure

An action of a switching system in selecting an outgoing trunk or other component for a particular call.

Selective Ringing

A means of ringing only the desired party on a multiparty line.

Selector

In Step-by-Step switching systems, an automatic switching mechanism actuated by dc pulses to select one of ten groups of intraoffice circuits, after which it hunts and connects to an idle circuit in the group.

Semipublic Coin Telephone Service

Coin telephone service provided where there is a combination of general public and specific customer need for the service, such as at a gasoline station. A directory listing is provided with this service.

Semiselective Ringing

Party-line ringing in which the ringers of only two of the main stations respond simultaneously, the differentiation being by the number of rings, either one long or two short. This provides for 8-party service.

Sender

Equipment in a switching system used to transmit and/or receive the called number to or from a distant office; usually arranged for transmitting on a multifrequency or dial-pulse basis. Under certain conditions of trouble, a sender may remain connected to a trunk without performing its intended function; this is known as a stuck sender.

Sender Attachment Delay

The interval between request for service (off-hook signal) and attachment of a sender, register, or receiver at a switching system. Normally, attachment time is very short, but it can be substantial under certain traffic conditions. Since attachment delay is a mechanism by which congestion spreads in an overloaded network, it is of importance to network management.

Service Attitude Measurement (SAM)

A program in which attitudes of telephone customers toward various services are solicited. A questionnaire relating to a specific type of service is mailed to a selected sample of customers. Similar to TELSAM in which the sample of customers is contacted by telephone rather than by mail.

Service Circuit

An auxiliary circuit connected through the switching network of a switching system to lines or trunks as required. It performs a specialized function such as dial-pulse reception.

Service Code

A code, typically of the N11 series, such as 411 (directory assistance) and 911 (emergency), that defines a connection for a service rather than a connection to a customer.

Service Objective

A statement of the quality of service that is to be provided to the customer; for example, no more than 1.5 percent of customers should have to wait more than 3 seconds for dial tone during the average busy hour, or the busy-hour blocking on a last-choice trunk group should not exceed 1 percent.

Service Observing

A direct measurement of service provided to the customer, obtained by sampling actual calls. The observers do not listen to conversations.

Service Order

An order prepared in the commercial department of an operating company at the request of a customer to establish a service, to change an existing service, or to terminate a service. The resultant document contains all the information required to meet the customer's needs.

Service Representative

An individual in the business office of a telephone company who typically deals with customers.

Service Tariffs

Tariffs filed primarily on the basis of value of service provided and secondarily on the cost of serving vehicles. For example, local exchange rates are usually based on the number of telephones in the exchange area rather than on the type of switching system serving the particular exchange area.

The rates will, of course, reflect total investment in switching equipment and other facilities within the state.

Serving Area

A geographic region including all customers served by a given wire center.

Serving Test Center (STC)

An office that serves as an access and testing point for switched and nonswitched special-service circuits routed through the STC for this purpose. An STC also can perform the overall plant control function for specific circuits.

SF

See *Single-Frequency Signaling.*

Sidetone

The portion of the signal from a telephone transmitter that appears at the receiver of that telephone excluding delayed echo. Some sidetone appears to be desirable to assure the customer that the telephone is working.

Signal

A wave used to convey information such as voice, television, data, or information for network control.

Signal Distributor (SD)

Equipment in Electronic Switching Systems to deliver signals from a central control to other circuits. It converts the central control output to high-power, long-duration pulses to operate relays.

Signal Element

In digital transmission, a signal within a time interval during which the intended state, or symbol, is recognized (i.e., distinguished from other possible symbols). In a band-limited channel, this time interval has a lower bound that must be met to detect the proper symbol without interference from other signal elements. Systems designed to make efficient use of channel bandwidth typically use a signal element occupying an interval of just this length. See *Symbol.*

Signal Processor (SP)

An equipment unit for Electronic Switching Systems for use in larger offices to perform repetitive time-consuming input-output tasks for central control.

Signal Transfer Point (STP)

In CCIS, a message switching system that permits signaling messages to be sent from one switching system to another by way of one or more other offices at which STPs are located. It reduces the number of CCIS data links required to serve a network.

Signaling

The transmission of address (pulsing), supervision, or other switching information between stations and switching systems and between switching systems, including any information required for billing.

Simplex Transmission

(1) A method of operating a communications circuit so that transmission is in only one direction.

(2) A method of deriving a conductor by using the conductors of a pair in parallel. Normal use of the pair is retained.

Singing

A continuous whistle or howl caused by oscillation in a telephone circuit. It occurs when the sum of the gains in the circuit exceeds the sum of all the circuit losses. In a 4-wire circuit, the sum of the losses includes the losses from input port to output port of the hybrids. Provision of adequate margins in transmission objectives has made this a rare occurrence.

Single-Frequency (SF) Signaling

A method of conveying dial-pulse and supervisory signals from one end of a trunk or line to the other, using the presence or absence of a single specified frequency. A 2600-Hz tone is commonly used.

Six-Digit Translation

The operation of interpreting six digits, commonly comprising a 3-digit numbering plan area code followed by a 3-digit central office code, as routing control for the switching of calls.

Skewed Overloads

Abnormal loads that greatly exceed average business day demands and are usually distributed quite differently geographically; for example, snowstorm calling between city and suburbs.

Slip

An alteration of a digital information stream consisting of an advance or delay of all following signal elements by an amount equal to or greater than a signal element. This causes one or more signal elements to be missed or to be repeated.

SOST

See *Special Operator Service Traffic.*

SP

See *Signal Processor.*

Span

A collection of span lines between two offices. The term is also used to refer to the collection of all span lines in a particular cable, all span lines on a particular route, or all span lines between two offices.

Span Line

A repeatered T1 line section between two central offices (not necessarily contiguous offices). A T1 Carrier System is made up of a tandem combination of span lines, plus a digital channel bank at each terminal.

Special Assembly

Refers to services provided on a special, nontariffed basis. The rate for these special assemblies is based directly on the cost to provide the service. A frequently provided special assembly is a candidate for a tariff filing.

Special Operator Service Traffic (SOST)

Traffic handled by operators primarily because of their unique accessibility at all times; examples include providing emergency manual service, opening doors, discharging plant alarms.

Special Service

Any of a variety of switched services, nonswitched services, or special-rate services that are either separate from public telephone service or contribute to certain aspects of public telephone service. Examples are PBX service; WATS; foreign exchange service; and private-line services such as circuits for burglar alarms, data, teletypewriter, and television.

Special-Service Circuit

A circuit used to provide a special service to a specific customer.

Speed-of-Answer Index

One of the service indexes for operator services, the speed-of-answer index gives an indication of the delay an arriving call will experience before being served by an operator.

Speed Calling

One of the custom calling features, speed calling allows station users to assign abbreviated codes to selected called numbers. This permits the use of fewer digits than are required normally to dial these selected numbers.

SSB AM

Single-sideband amplitude modulation.

Spurt Signaling

Short-duration signaling information transfer where the receiving circuit must provide for the necessary state memory.

ST

See *Start Signal.*

Start (ST) Signal

In multifrequency pulsing, a signal used to indicate that all digits have been transmitted.

Start-Stop

A timing and framing technique used in data transmission systems, especially teletypewriter systems. Data are transmitted in the form of serial characters, each composed of a start element, information bits, and a stop element, with fixed timing of all of these. Characters are sent asynchronously.

Station Code

The final four digits of a standard 7- or 10-digit address. These digits define a connection to a specific customer's telephone(s) within the larger context of an NPA and central office code. The term *main station code* is an equivalent expression. In the past, a line number and a party letter often were combined to provide station identification. With the discontinuance of party letters, the four numerics have assumed the role of station identification.

Station-to-Station Service

The service in which the person originating the call specifies to an operator only the destination code. Includes station-to-station service originating at a public or semipublic coin telephone.

Step-by-Step (SXS) System

An automatic switching system in which a call is extended progressively step-by-step to the desired terminal under direct control of pulses from a customer's dial or from a sender.

STP

See *Signal Transfer Point.*

Subfeeder Cable

A cable that connects feeder cables to distribution cables; usually buried without conduit and containing between 300 and 900 twisted pairs.

Subscriber Sender

Equipment in No. 1 Crossbar and Panel switching systems that receives address information from a customer.

Supervision

The function of monitoring and controlling the status of a call by means of supervisory signals. See *Supervisory Signals.*

Supervisory Signals

Signals used to indicate or control the states of circuits involved in a particular connection. A supervisory signal indicates to equipment, to an operator, or to a customer that a particular state in a call has been reached and may signify the need for action to be taken.

Switchhook Flash

A brief on-hook signal produced by momentarily depressing the telephone switchhook button (or equivalent). Must be long enough to be recognized, but not so long as to be interpreted as a disconnect signal.

Switching

(1) Designates a field of work, such as system development, planning, or engineering, involving the application of switching technology in telecommunications networks.

(2) Refers to the process of connecting together appropriate lines and trunks to form a desired communication path between two station sets. Included are all kinds of related functions, such as sending and receiving signals, monitoring the status of circuits, translating addresses to routing instructions, alternate routing, testing circuits for busy condition, and detecting and recording troubles.

(3) In a more restricted sense, switching is the technology of making and breaking electrical circuits. Sometimes used to describe any circuit that operates discretely, particularly logic and memory.

Switching Equipment Irregularities

Malfunctions in switching equipment or associated signaling that result in wrong numbers or the absence of appropriate call progress indications to the call originator. Sometimes loosely called *equipment irregularities.*

Switching Network

Switching stages and their interconnections within a switching system.

Switching System

An electromechanical or electronic system for connecting lines to lines, lines to trunks, or trunks to trunks. A single switching system may handle several central office codes. The term includes PBX switching systems (manual and automatic), local switching systems, and toll switching systems. See *Switching*.

SXS

See *Step-by-Step System.*

Symbol

In digital transmission, a recognizable electrical state associated with a signal element. In binary transmission, a signal element is represented as one of two possible states or symbols. See *Signal Element.*

Synchronous Data Transmission

Data transmission in which the nominal signal element spacing is fixed. This is called "synchronous transmission" because the receiver must be in synchronism with the time pattern of the incoming symbols. Contrasts with asynchronous data transmission.

System Code

A 3-digit code of the form 0/1XX available to operators or automatically associated with certain toll calls to modify routing or call-handling logic. Customers are prevented from using system codes by constraints in the format of signals accepted by switching systems.

Talkoff

False operation of inband signaling receivers caused by customer speech simulating the supervisory tone for a sufficiently long interval (usually more than 150 ms) to cause accidental release of the connection.

Tandem Office

In general, an intermediate switching system for interconnecting local and toll offices. All toll offices are tandem offices. A more specific meaning of local tandem or metropolitan tandem office is an office that connects class 5 offices to other class 5 offices or to other tandem offices within a metropolitan area.

Tariff

The published rates, regulations, and descriptions governing the provision of communications services.

TAS

See *Telephone Answering Service.*

Task Oriented Plant Practice (TOPP)

A Bell System Practice (BSP) concept whereby the complete step-by-step procedures necessary to perform a complete task are available in one unified (and often flow-charted) document.

Technical Reference

A publication that gives additional description and technical details to supplement a tariff. One use is to provide interface guidelines for non-Western Electric manufactured customer-premises equipment.

Telegraph

Refers to transmission systems, switching systems, testboards, stations, and services that are oriented toward narrowband, private-line data services at speeds up to 150 bits per second. The most common service of this type is teletypewriter. Channels provided under Series 1000 tariff are sometimes called telegraph channels.

Telephone Answering Service (TAS)

A service provided by firms who specialize in answering, at central locations called bureaus, the telephones of their clients. The Bell System provides telephone answering systems to these bureaus.

Telephone Service Attitude Measurement (TELSAM)

A program in which attitudes of telephone customers relating to various services are solicited. Selected samples of customers are called by telephone and asked to reply to a questionnaire. There are questionnaires for installation services, repair services, business office services, operator services, and dial calling services. Similar to SAM, in which the questionnaires are mailed to customers.

Telephone Set

The terminal equipment on the customer's premises for voice telephone service. Includes transmitter, receiver, switchhook, dial, ringer, and associated circuits.

Teletraffic Theory

A mathematical treatment of call flow in a communications network.

Teletypewriter

An electromechanical typewriter device that generates from a keyboard a coded signal corresponding to the typed character. This electrical signal may be passed over appropriate transmission facilities and used to control a similar teletypewriter at a distance.

Teletypewriter Exchange Service (TWX)

A service in which a customer's teletypewriter is connected to a TWX switching system and can be connected to any other customer of the same service. This service was formerly offered by the Bell System, but was sold to the Western Union Telegraph Company in 1971.

TELSAM

See *Telephone Service Attitude Measurement.*

Terminal

(1) Equipment at the end of a communication circuit. User terminals include telephone sets and teletypewriters.

(2) Carrier terminals include the modulation and demodulation equipment and the multiplex equipments used to combine and separate individual channels at the ends of a transmission system.

(3) A point at which an electrical connection can be made to a device, circuit, or equipment. It is usually characterized by some means for securely fastening a wire or cable.

Termination

(1) An item that is connected to the terminals of a circuit or equipment.

(2) An impedance connected to the end of a circuit being tested.

(3) The points on a switching network to which a trunk or a line may be attached.

Termination Charge

A charge due if and when certain types of telephone service (e.g., large PBX service) are prematurely discontinued. The termination charge is typically a decreasing function of time that reduces to zero in 2 to 4 years.

Three-Way Calling

One of the custom calling features, 3-way calling enables a customer to add (by dialing) a third party to an existing connection so that all three parties can communicate. When the third party answers, private 2-party conversation can be held before bridging the connection for a 3-party conversation.

Tie Line

See *Tie Trunk.*

Tie Trunk

A special-service circuit connecting two private branch exchanges or equivalent switching systems.

Time Division

A method of serving a number of simultaneous channels over a common transmission path by assigning the transmission path sequentially to the various channels, each assignment being for a discrete time interval.

Time-Sharing

The use of a facility or equipment for more than one purpose or function or for repetition of the same function within the same overall time period. This is accomplished by interspersing or interleaving the required actions in time.

Timing Jitter

In digital carrier systems, an accumulative relative timing discrepancy between digital signal elements. The most common causes are transmission media with nonuniform delay-versus-frequency characteristics and imperfect timing recovery in digital line regenerators.

Timing Recovery

The process of determining the appropriate sampling times for a synchronous data stream.

Tip Cable

A small (usually 100-pair) cable connecting terminals on a distributing frame to cable pairs in the cable vault.

Tip Conductor

One conductor of a customer line (tip and ring).

Tip and Ring Conductors

The two conductors associated with a 2-wire cable pair. The terms *tip* and *ring* derive their names from the physical characteristics of an operator's cordboard plug, in which these two conductors terminated in the days of manual switchboards. Use of the names tip and ring has extended throughout the plant. The cordboard plug also had a *sleeve,* and the name is occasionally used for a third conductor associated with tip and ring.

Tip, Ring, Ground

The conductive paths between a central office and a station. The tip and ring leads constitute the metallic pair of wires that carry a balanced speech or data signal. The ground path in combination with the conductor is used occasionally for signaling.

TIRKS

See *Trunks Integrated Records Keeping System.*

TLP

See *Transmission Level Point.*

Toll

A term describing service that is a part of public telephone service but under a tariff separate from the exchange area tariff. Also used to describe components of the facilities network that are used principally for toll service.

Toll Center

A class 4 office in the hierarchy of toll switching offices; the lowest level toll office. See *Toll Office.*

Toll-Connecting Trunk

A trunk between an end office and a toll office.

Toll Hierarchy

The ordered structure established among toll offices of the United States and Canadian public telephone network to provide systematic switched routing of calls. Four hierarchical classes apply to toll offices, whereas local, or end, offices are designated class 5.

Toll Office

A switching office where trunks are interconnected to serve toll calls. Toll offices are arranged in a hierarchical structure as follows:

Regional Center—Class 1
Sectional Center—Class 2
Primary Center—Class 3
Toll Center—Class 4

Toll Service

Public telephone service with points outside the designated local exchange service area for a station and for which calls are billed individually. Includes service through the toll switching hierarchy.

Toll Service Operator

A person who provides any of a variety of services relating to toll calls, such as billing functions associated with coin, collect, or person-to-person calls, identifying the calling number where necessary, and assisting customers.

TOPP

See *Task Oriented Plant Practice.*

TOUCH-TONE

The Bell System's designation for a station set signaling technique that encodes digits as multifrequency tone pairs. The frequencies are chosen to make unlikely the simulation of any pair by a human voice.

TOUCH-TONE Dial

A pushbutton pad and associated oscillator circuitry used to transmit address (or end-to-end data) signals from customer stations by means of in-band tones. Each decimal digit, plus a maximum of six additional signals, is uniquely represented by selecting one frequency from each of two mutually exclusive groups of four. The dial is ordinarily powered from the central office.

Traffic Network

An arrangement of channels, such as loops and trunks, associated switching arrangements, and station equipments designed to handle a specific body of traffic; a subset of the facility network.

Traffic Service Position

A cordless console that is associated with either a Crossbar Tandem office or a Traffic Service Position System, equipped so that operators can provide assistance if needed on station-to-station calls, special toll calls, coin distance dialing calls, and all local and toll assistance traffic. The operators provide assistance in completing these calls and ensure that correct data are recorded in the centralized automatic message accounting equipment or in the Traffic Service Position System equipment. The operators also supervise coin deposits for calls originating at coin stations. The position is arranged for automatic display of both the calling and called numbers, as well as certain other information.

Traffic Service Position System (TSPS)

That type of Traffic Service System, having stored program control, that provides for the processing and recording of special toll calls, coin station toll calls, and other types of calls requiring operator assistance. It includes traffic service positions arranged in groups called traffic offices where operators are automatically connected in on calls to perform the functions necessary to process and record the calls correctly.

Traffic Usage Recorder (TUR)

A device that scans trunks periodically and counts the number busy. At the end of an hour, the TUR provides a measure of usage based on the sampled values.

Transhybrid Loss

The transmission loss between opposite ports of a hybrid network, i.e., between the 4-wire input and output terminal ports. The transhybrid loss is ideally very large, a condition that is approached when the hybrid is properly terminated.

Translation

The operation of converting information from one form to another. In switching systems, the process of interpreting all or part of a destination code to determine the routing of a call.

Translator

A device that converts information from one form to another. In switching systems, a translator converts address digits to an identification of the appropriate trunk group to be used.

Transmission

(1) Designates a field of work, such as equipment development, system design, planning, or engineering, in which electrical communication technology is used to create systems to carry information over a distance.

(2) Refers to the process of sending information from one point to another.

(3) Used with a modifier to describe the quality of a telephone connection: good, fair, or poor transmission.

(4) Refers to the transfer characteristic of a channel or network in general or, more specifically, to the amplitude transfer characteristic. One sometimes hears the phrase, "transmission as a function of frequency."

Transmission Deviations

Departures from a flat response in the gain-frequency and delay-frequency characteristics of channels or transmission media.

Transmission Facility

An element of physical telephone plant that performs the function of transmission; for example, a multipair cable, a coaxial cable system, or a microwave radio system.

Transmission Level Point (TLP)

A specification, in dB, of the relative level at a particular point in a transmission system as referred to a zero transmission level point (0 TLP). Note that the TLP value does not specify the absolute power that will exist at that point, and the unit of TLP specification is not dBm.

Transmission Objectives

Electrical performance characteristics for communication circuits, systems, and equipments based on both economic and technical considerations of telephone facilities and on reasonable estimates of the performance desired. Characteristics for which objectives are stated include: loss, noise, echo, crosstalk, frequency shift, attenuation distortion, envelope delay distortion, etc.

Traveling Class Mark

A unique "label" that identifies a call as it is routed through the network; e.g., an indication that the call originated from a coin telephone. Traveling class marks are not presently used, but will be possible with CCIS. It will then become possible to use the same transmission facility in several different traffic networks, each identified by a traveling class mark.

Trunk

A communication channel between two switching systems. The term "switching system" includes central office types, toll switching systems, PBXs, key telephone systems, manual and automatic switchboards, concentrators, etc.

Trunk Circuit

A circuit, part of a switching system, associated with the connection of a trunk to the switching system. It serves to convert between the signal formats used internally in the switching system and those used in the transmission circuit, and it performs logic and sometimes memory functions associated with supervision.

Trunk Group

A number of trunks that can be used interchangeably between two switching systems.

Trunk Order

A document (or data system equivalent) used in an operating company to request a change to a trunk group.

Trunks Integrated Records Keeping System (TIRKS)

Part of the overall Business Information System used to maintain the inventory and assignment of the facilities and equipment used to establish trunks of all kinds.

TSPS

See *Traffic Service Position System.*

TUR

See *Traffic Usage Recorder.*

Twisted Pair

A pair of wires used in transmission circuits and twisted about one another to minimize coupling with other circuits. Paired cable is made up of a few to several thousand twisted pairs.

Two-Tier Tariffs

A tariff structure providing for a decrease in monthly equipment charges after a contracted period. The initial and decreased monthly charges are functions of capital costs and administration and maintenance charges.

Two-Way Trunk

A trunk that can be seized at either end.

TWX

See *Teletypewriter Exchange Service.*

UL

See *Underwriters' Laboratories.*

Underwriters' Laboratories (UL)

A private testing laboratory concerned with electrical and fire hazards of equipment. In general, Western Electric telephone equipment is approved within Bell Telephone Laboratories or Western Electric; in some cases, items of telephone equipment have been approved by UL.

Unigauge Design

A design method for customer loops that provides for the exclusive use of 26-gauge cable on all loops within 30 kilofeet of the central office. Requires range extension equipment developed specifically for the Unigauge system.

Unipolar Signal

A digital signal technique that uses a positive (or negative) excursion and ground as the two binary signal states.

Usage

(1) A measure of trunk or equipment occupancy expressed in Erlangs or CCS.

(2) A measure of local service in "message units" that may depend on both distance and duration of calls and may be defined differently in different localities.

Vacant Code

An unassigned numbering plan area, central office, or station code. Upon recognition, a call placed to a vacant code is normally directed to a vacant code announcement.

Vertical Services

Service over and above what is required for basic communications capability; e.g., deluxe telephone station sets or custom calling services.

Vestigial Sideband Modulation (VSB)

A form of amplitude modulation, lying between double sideband and single sideband, in which one sideband and a small vestige of the other sideband are transmitted. Vestigial sideband modulation is attractive for data transmission because it uses less bandwidth than double sideband and preserves the waveform of the signal.

VFFT

See *Voice-Frequency Facility Terminal.*

V-H Coordinates

Numerical coordinates that define the location of a rate center. A simple calculation using the V-H coordinates for two rate centers gives the airline mileage between the two points for use in determining charges for toll calls and private lines.

Via Net Loss (VNL)

A loss objective for trunks, the value of which has been selected to obtain a satisfactory balance between loss and talker echo performance. The numerical value of a particular VNL is equal to a constant, 0.4 dB, plus a prescribed component that is proportional to delay.

VNL

See *Via Net Loss.*

Voice-Frequency Facility Terminal (VFFT)

A terminal equipment concept that combines transmission (including channel banks), signaling, and test access functions in a modular bay, eliminating or minimizing the need for intermediate distributing frames. There are three types of VFFTs: analog, digital, and metallic.

VSB

See *Vestigial Sideband Modulation.*

WATS

See *Wide Area Telecommunications Service.*

Wide Area Telecommunications Service (WATS)

WATS permits customers to make (OUTWATS) or receive (INWATS) long distance voice or DATAPHONE calls and to have them billed on a bulk rather than individual call basis. The service is provided within selected service areas, or bands, by means of special private-access lines connected to the public telephone network via WATS-equipped central offices. A single access line permits inward or outward service, but not both.

Wire Center

The location of one or more local switching systems. A point at which customer loops converge.

Wire Centering

The process of determining the location and timing of new wire centers.

Word

An ordered set of characters expressing information. (The term word may be prefixed by an adjective describing the nature of the characters, such as binary words.)

Index

A

B

F

M

N

O

P

Q

R

S

T

U

V

W