Optical Fiber System Design for TelMex

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Telefonos de Mexico (TelMex) has embarked on a program to modernize its telecommunications network. At the heart of this modernization is a 13,500-kilometer optical fiber backbone that uses state-of-the-art technology. AT&T will provide about 60 percent of the required network for TelMex using dispersion-shifted fibers that operate at 1550 nanometers. The network will be installed to run at 565 megabits per second, with future upgrades possible to synchronous digital hierarchy optical network rates of 2.5 gigabits per second. The total turnkey system provided by AT&T includes optical fiber cable, splicing, installation, terminals, repeaters, training, maintenance, and documentation. This effort, which represents a collaboration among AT&T Network Systems–U.S.A., AT&T Network Systems International–Netherlands, AT&T Network Systems–España, and AT&T Mexico, is also the first example of AT&T–España and AT&T working together to satisfy the rigorous requirements of TelMex. When completed, this will be the largest long distance network in the world using dispersion-shifted fibers.

Introduction

In today's telecommunications environment, the rapid change in fiber-optic technologies and transmission standards makes any equipment purchase a complex decision for the buyer. Customers must analyze existing products and configurations and develop economically and technically sound plans for introducing new technologies.

Developing nations, such as Mexico, are making significant capital investments to modernize and expand their telecommunications infrastructures, that is, the number of phone lines for a particular population size. Figure 1 shows the trend of phone lines per 100 people for various countries. Highly developed countries, such as Sweden, Denmark, Canada, and the United States, for example, have about 50 lines per 100 people, while less developed countries may have 10 lines, or fewer, per 100 people. This index of lines per 100 people is a useful measure of how accessible the phone system is to the general population.

Mexico ranks 13th in the world's economy, but 83rd in phone lines per 100 people.[1] With about 5.6 lines per 100 population, about one-half the phone density of the former Soviet Union, Mexico has started a program to upgrade its telecommunications network. Although only 5 million lines are currently in operation and just 13 percent of these are digital, TelMex has set a goal of 20 million lines in place by the year 2000, a growth rate of 10 percent per year. Improved telecommunications is a major element of the Mexican government's plan for infrastructure development, and it plans to increase phone lines by 12 percent each year through 1994. For 1992, line growth should reach 14 percent, which is above the government's goal.

A key element in the modernization of the long distance network is the implementation of a network with a fiber-optic backbone. This network will cover over 13,000 kilometers (km) during a two-year period (1992–1994); it will include links to 54 long distance nodes and have a complementary digital radio network for route diversity. (Route diversity ensures that an alternate is available to complete a phone call should the primary system incur a problem.) AT&T is

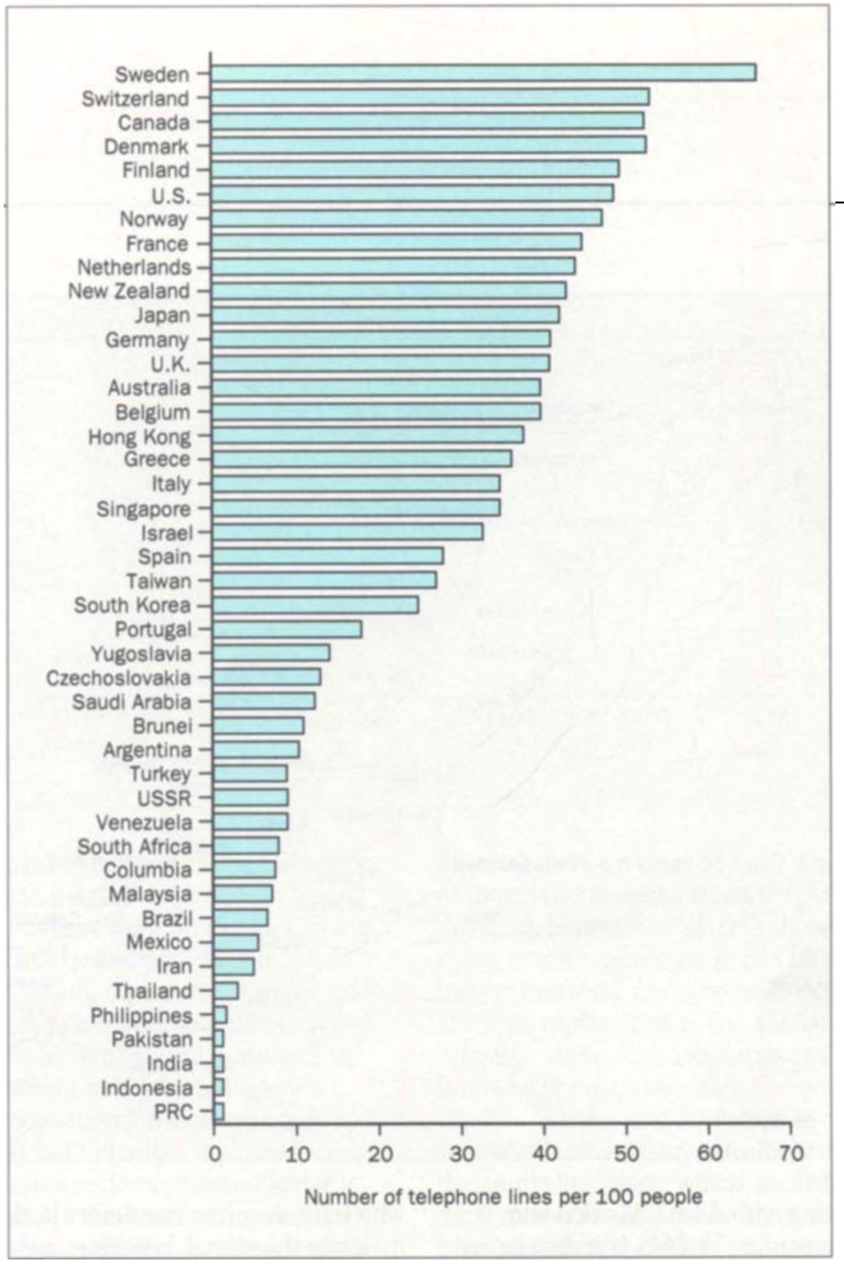


Figure 1. The trend of telephone density for various countries, derived from 1988 data cited by AT&T International Marketing (see Reference 1).

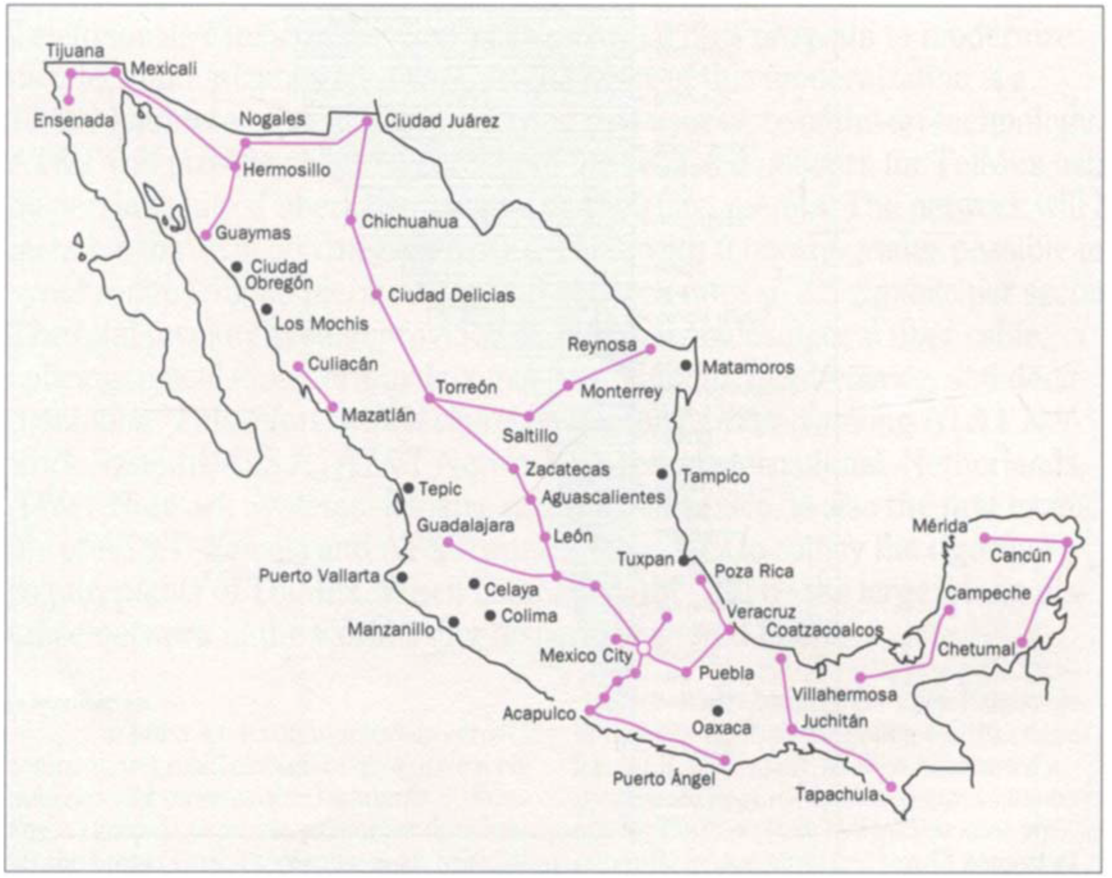
supplying about 36 (60 percent) of the long distance nodes, or fiber-optic links, which will require about 45 terminals and 60 repeaters for the AT&T Mexico routes. A repeater is an amplifier for the optical signal; because it has no interactive capability, it may be located in a remote site in the countryside. A terminal is a repeater that an engineer can program for particular functions; it is located in an office site such as a switching center.

Optical Fiber Network

AT&T is providing TelMex with a complete turnkey system. The project encompasses engineering, equipment provision, and construction of a fiber-optic network throughout Mexico, including 8000 km of optical fiber cable. This system will contain 36 fiber-optic links, each with one or more regenerator sections. (A link is a length of cable that contains one or more regenerator sections to boost the signal.) Figure 2 shows the portion of the network being provided by AT&T.

The engineering and provisioning of equipment for the TelMex project is a global effort, combining the talents of several international partners. AT&T Network Cable Systems in Atlanta, Georgia, is manufacturing the optical fiber cable, which includes dispersion-shifted fibers, and related apparatus, such as connectors, interconnection equipment, splices, and closures. AT&T Network Systems–España, in Madrid, Spain, is providing the project's 565-megabit-per-second (Mb/s) terminal and regeneration equipment, as well as the power equipment. AT&T Outside Plant Systems in Mexico City, Mexico, the focal point for this project, is responsible for route engineering, construction, and activation of each of the

Figure 2. The portion of the TelMex network being provided by AT&T.



36 fiber-optic links. Working with AT&T Mexico and each of the AT&T business units, TelMex has developed technical specifications for equipment, construction guidelines, and performance requirements. TelMex and its international AT&T partners are responsible for building the world's largest dispersion-shifted optical fiber network. AT&T Network Cable Systems, which provides all passive optical components, will deliver about 165,000 fiber km of dispersion-shifted fibers in the 8000 km of AT&T Lightguide Express Entry (LXE) cable. (A cable one kilometer in length contains 24 fibers and, therefore, 24 kilometers of fiber.)

Optical Fiber Design Choice

One important parameter to be considered when designing an optical transmission system is the repeater spacing that is possible using existing technology. The signal in the optical fiber decreases as the length of the fiber increases. If the signal is reduced to a point below which the receiver can detect it, the signal is lost. To maintain the signal, repeaters are placed in the optical path to convert the optical signal to an electrical signal, which is used as input to another laser to transmit the signal again, at the original power level. Thus, repeaters are highly complex and expensive. Reducing the use of repeaters by using the lowest loss fiber decreases the number of repeaters required for a network.

In the proposed architecture, AT&T has provided a solution that meets the TelMex requirements by deploying a 565-Mb/s optical line system operating at 1550 nanometers (nm) with a distributed feedback (DFB) laser and dispersion-shifted optical fiber. DFB lasers are laser diode devices that have been modified to reduce the spectral distribution reflected from the rear face of the laser. This narrow-frequency reflection confines the laser output to a single oscillation path within the laser. Thus, DFB lasers may also be referred to as single-frequency lasers, single-mode lasers, or single-line lasers.

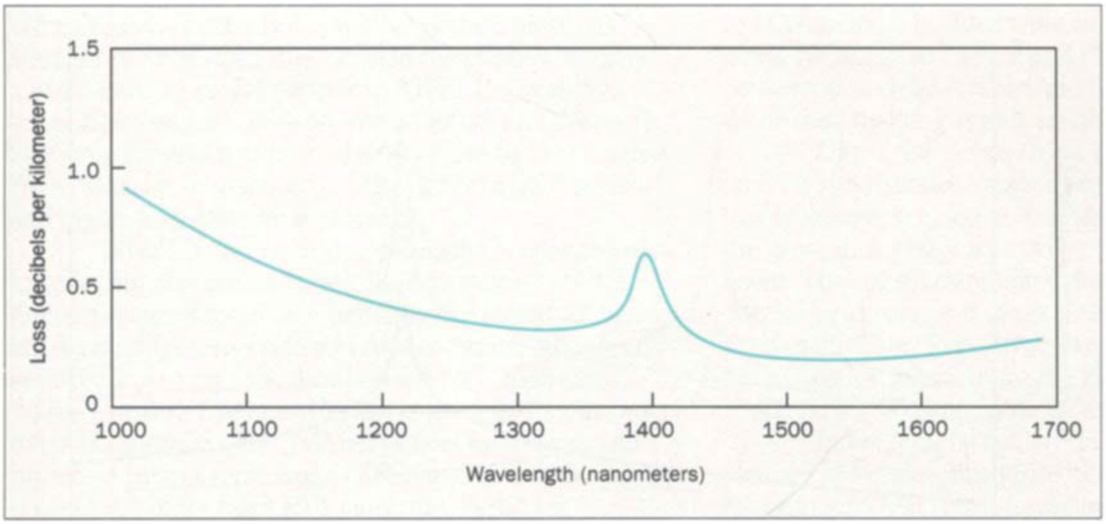


Figure 3. A typical optical attenuation for a germania-doped fiber measured from 1000 to 1700 nm.

To achieve the maximum transmission distance with the least loss of signal, a lightwave system should operate at the wavelength where fiber attenuation is the lowest. For today's germania-doped optical fibers, this occurs in the region of 1550 nm, where the attenuation is constant for high-quality, single-mode fiber and is about 0.2 decibel per kilometer (dB/km), slightly more than half as large as the attenuation at 1310 nm. Figure 3 shows a typical optical attenuation for a germania-doped fiber measured from 1000 to 1700 nm.

At 1550 nm, the most serious system barrier is fiber dispersion. Dispersion is the broadening (in time) of a light pulse because of material and waveguide properties in the optical fiber. When a pulse broadens to the extent that it overlaps an adjacent time slot, an error occurs. Pulse broadening limits the maximum usable bit rate and results in a power penalty for the system. Thus, a lightwave system using a conventional laser would suffer a dispersion-limited bit-rate-distance product of less than or equal to 18 gigabits per second per kilometer (Gb/s–km), which is far worse than the 88 Gb/s–km possible at 1310 nm. We present two solutions to this problem: controlled dispersion fibers and single-frequency lasers.

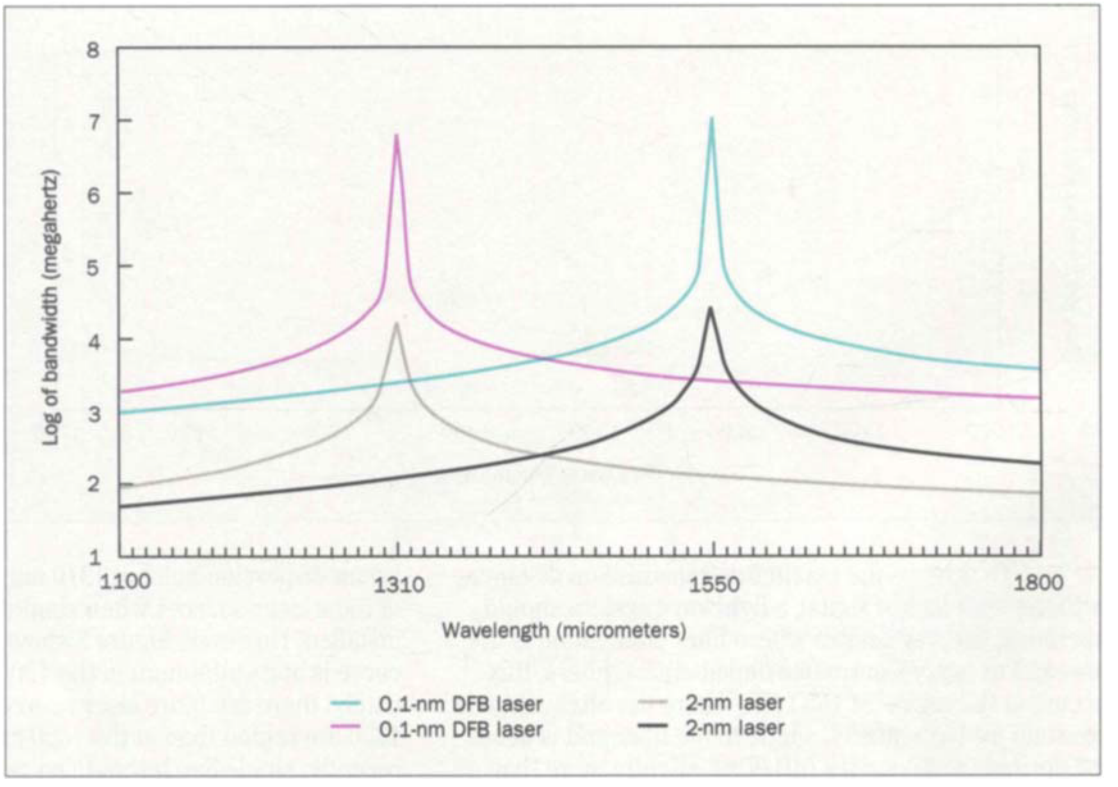
With the proper choice of fiber parameters, waveguide and material dispersion can cancel each other. In the resulting fiber, often called a dispersion-shifted fiber, attenuation and dispersion are minimized at the same wavelength. Most optical fibers used in today's telecommunications are single-mode fibers with a minimum dispersion point at 1310 nm, the wavelength of most laser sources when single-mode fiber was first installed. However, Figure 3 shows that the attenuation curve is at its minimum in the 1500-nm region. Unfortunately, there are more laser sources available in the 1300-nm region than in the 1550-nm region, and, until recently, single-line lasers (also called single-frequency lasers) were not available.

In the second solution to dispersion at 1500 nm, we use a laser with an extremely narrow spectral width, the single-line laser, which oscillates in only one longitudinal mode. Lasers whose semiconductor cavities have been modified to obtain single-frequency operation have performed best in system demonstrations. As we mentioned earlier, the DFB laser uses a periodically perturbed waveguide to provide frequency-selective feedback, resulting in single-frequency operation.

By adjusting the waveguide properties of the fiber, the zero-dispersion wavelength can be moved to 1550 nm. This type of fiber is usually called a dispersion-shifted fiber to distinguish it from a nondispersion-shifted fiber, whose zero dispersion wavelength is 1310 nm. The dispersion-shifted fiber was initially proposed for use in the 1550-nm region with conventional multi-line lasers operating at 1550 nm. However, this combination has about the same bit rate capacity as the unshifted fiber in the 1310-nm region and the multi-line laser operating at 1310 nm.

TelMex's requirement to have the highest bit-rate-distance product prompted AT&T to consider using

Figure 4. The bandwidth curves for shifted and unshifted optical fibers using both multi-line and single-line laser sources for an arbitrary span length of 70 km.



dispersion-shifted fiber. By combining dispersion-shifted fibers with single-line lasers in the 1550-nm region, we are able to achieve the highest bit rate over the longest distance. Some of the repeater sections are 70–100 km long, and it is desirable to transmit over this distance without repeaters to avoid the expense of building and maintaining repeater huts in remote locations. In the future, we will be able to upgrade the initial 565-Mb/s system to synchronous digital hierarchy (SDH) bit rates of 2.5 Gb/s. Dispersion-shifted fibers and single-line lasers fulfill this requirement. Figure 4 shows the bandwidth curves for shifted and unshifted optical fibers using both multi-line and single-line laser sources for an arbitrary span length of 70 km. (For additional information about optical fibers and optical fiber systems, see References 2 and 3.)

Cable Design

TelMex has selected two types of LXE cables, each appropriate for a different terrain. To protect TelMex cables from service-affecting attacks, such as from rodents or lightning, rodent lightning (RL) stainless-steel-armored cables (LXE-RL) will be used on direct buried routes known to be infested with gophers. This steel-sheathed cable increases the reliability of the optical fiber cable. Cables placed in conduit or other protected areas will be armored with mild steel. We are using AT&T's second-generation ST® optical connector, and AT&T's Enhanced Rotary Mechanical Splice, which offers the lowest available attenuation to this loss-limited, dispersion-shifted network.

Transmission and Protection Equipment

In July 1991, AT&T Network Systems–España signed a contract with TelMex to supply transmission and power equipment for Mexico. AT&T Network Systems–España submitted the completed proposal for transmission equipment relating to the Long-Distance Fiber-Optic Network Project for TelMex, using AT&T Network Systems Mexico as its agent in Mexico. This is the first combined bid of AT&T and AT&T Network Systems–España, a joint venture in Spain between AT&T Network Systems International and the Spanish company Amper. AT&T Network Systems–España, a three-yearold company, is already a major telecommunications supplier to Telefonica (the Spanish telephone company and a 6-percent equity partner in AT&T Network Systems International). In September 1990, AT&T Network Systems–España inaugurated a new plant in Tres Cantos (near Madrid) to manufacture the 5ESS® digital switch and digital transmission equipment.

AT&T Network Systems–España is charged with introducing new technologies, implementing new production systems capable of handling the increased Spanish demand for telephone and data communications, and contributing to the globalization of AT&T. Currently, AT&T Network Systems–España is participating in two overseas contracts, the TelMex project in Mexico, and a project in Indonesia to supply 5ESS digital switch systems to the Indonesian PTT company, Perumtel.

The TelMex project is a classic example of what it means to be a global telecommunications supplier. The AT&T Network Systems–España contract with TelMex includes:

- A 565-Mb/s optical line system 8TR 695
- A line protection switch 8TR 636
- Power generation, including batteries and air conditioning
- Installation and testing
- Training
- Spare equipment, including transmitters, multiplexers, receivers, etc., for the optical line system
- Measurement equipment
- Documentation
- Financing.

The 8TR 695 is AT&T's newly developed 565-Mb/s optical line system, designed as high-capacity digital links for trunk networks as well as the supervision and functionality required for the junction and local network. The new electronics includes the 140/565 multiplexer and provides simultaneous access for four bit streams of 140 Mb/s each. It multiplexes four electrical 140-Mb/s tributary input signals into an optical 565-Mb/s line signal. The line code used has an additional transmission capacity of up to 8 Mb/s for maintenance and supervisory functions or additional channels for data communications. The system operates at a wavelength of 1550 nm with a distributed feedback laser in the transmitter and an avalanche photodiode in the receiver. The standard available power budget for the equipment is 28 dB. AT&T's optical fiber cables allow distances of up to 113 km to be bridged without using repeaters. This newly designed 565-Mb/s optical system reduces power consumption considerably, and the resulting low thermal dissipation makes it highly reliable.

Office regenerators are also part of the product line. The intermediate station equipment is a regenerator that is located in an office (rather than being buried in the ground) for easy access if service problems should occur. The regenerator takes the incoming data signal, checks for errors, and sends a regenerated optical signal back to the fiber. Regenerators are an essential part of the network equipment for the 8000-km network for which AT&T is responsible in Mexico.

In long, high-capacity links, such as the ones planned in Mexico, line protection solves the long traffic interruptions that result from line or equipment failures. Whenever equipment failure triggers an alarm, the system must restore the communication by rerouting the data to a protection line. The 8TR 695 system supports line protection. The Mexico link will use 1+1 line protection (one regular line and one protection line to transmit the 565 Mb/s data stream) in addition to the high-capacity 565-Mb/s transport channel. The 8TR 695 has several auxiliary channels. Channels of 2 (2x), 16 (1x), 64 (1x) and 210 (3x) kilobits per second (kb/s) can be used for maintenance and supervision purposes, as well as for an engineer's order wire connection (normally the telephone channel used to communicate between stations).

For medium-capacity information transmission, an 8-Mb/s channel is available. Another medium-capacity option would be a system equipped with a 2/8 multiplex circuit pack that makes available four 2-Mb/s data streams instead of one 8-Mb/s channel. This increases the flexibility in the application of the 8-Mb/s channel. The system has been designed for minimum power consumption and size, achieved with full integration of the main functions using surface-mount device and submicrometer complementary metal-oxide semiconductor circuits. Each 450-mm-wide electronics rack can hold up to five terminals.

To simplify maintenance and provide flexibility in applications, a newly designed supervision system primarily supervises the local equipment in both terminal and intermediate stations. Remote supervision can then be configured. The system can supervise different types of equipment, e.g., primary or higher-order multiplex equipment. A work station can be connected to the system to improve and simplify maintenance, and to make it more user friendly.

System Upgrades

With a 565-Mb/s link installed, the capacity of the optical link is about 9000 telephone channels per optical fiber. Nevertheless, capacity requirements are continually increasing, and future options for upgrading the installed equipment are important. Two potential upgrades are worth mentioning.

First, installed equipment can be functionally upgraded when it is converted from plesiochronous digital hierarchy (PDH-based) to SDH-based equipment. (Plesiochronous signals are made up of data streams generated by different clocks running at slightly different rates. To synchronize them, they must be brought up to the same uniform clock rate. SDH solves this by using one master clock for the network.) The recently defined SDH hierarchy is intended to be a world standard for transmission interfaces. Especially in larger networks, more functions can be added to SDH systems.

Second, the transition from PDH to SDH automatically upgrades the system. In the PDH hierarchy, the highest bit rate defined is 565 Mb/s (4 x 140 Mb/s), while in SDH the highest bit rate defined is 2.5 Gb/s (STM-16). (This synchronous transmission module [STM] has sixteen 140-Mb/s building blocks.) The latter increases capacity by a factor of four. A 2.5 Gb/s transport system can carry more than 30,000 telephone channels simultaneously. In the Mexico network, both options for a system upgrade may be used if needed.

Alternatively, we can smoothly upgrade parts of the total system rather than the entire network. The reason for this smooth transition lies in the definition of SDH, whose logical scheme multiplexes different PDH signals and puts them in an SDH frame. (A frame is a segment of a signal that has a repetitive characteristic in that corresponding elements of successive frames represent the same things. For example, a television frame represents the complete scan of a picture.) Each piece of equipment supports a different subset of possibilities. Therefore, PDH systems could be gradually augmented by SDH-based systems, such as the AT&T SDH-based SLM-2000 product line, which includes terminals, add/drop multiplexers, and regenerators at both STM-4 (622 Mb/s) and STM-16 (2.5 Gb/s) levels. (STM-4 has four 140-Mb/s building blocks.) This flexibility allows the capacity and functionality of systems such as the Mexico network to evolve.

Line protection switch 8TR 636

For TelMex, the 8TR 636 protective switching system is configured to switch at the interface of 140 Mb/s in a 1+1 mode that can be upgraded easily to a 1 + n mode, where n can be up to 11. This system can grow to the full capacity of the optical cables in this project. Although only end-to-end systems are requested for TelMex's initial project layout, expansions might call for drop/insert and through-connected traffic, configurations that this protective switching system can also handle. The 159 8TR 636 systems will contain equipment manufactured in the AT&T plant in The Netherlands. AT&T Network Systems–España will supply, install, and place into service the following equipment needed to supply power to the transmission equipment: 60-hertz diesel generators, 2000-watt rectifiers, 200 ampere-hour batteries, 24,000 British thermal unit (BTU) air conditioners, a continuous current distribution panel, and an alternate current distribution panel.

This generator-powered automatic equipment has been used for emergencies in places where the commercial power supply frequently fails, or where the current supply is unstable. In the TelMex installation, 82 power plants will be supported with equipment manufactured in Spain.

In addition to line protection schemes, AT&T is working with TelMex to develop self-healing schemes based on wideband cross-connects and a network management system. In SDH technology, a wideband cross-connect provides for rerouting of the data streams. For example, any of four input data streams running at 140 Mb/s can be routed to any of four other output data lines. If a problem occurs, the self-healing feature detects and switches (reroutes) the data stream to minimize service interruptions.

Installation and Testing

The installation of the TelMex optical fiber network is a monumental task. Working locally with Fabricaciones Ingeniera & Montajes, S. A. (FIMSA), a Mexican engineering and construction company, AT&T has deployed ten complete installation crews that are working their way southward and northward concurrently.

These crews are housed in self-contained mobile camps, each of which provides its own maintenance and product warehouse facilities. Four of the crews plow in the cable, four are engaged in splicing and testing the cables, and two crews install and test the terminal and repeater equipment.

The routes for the optical fiber cables follow, where practical, existing highway rights of way throughout Mexico. Only five percent of the routes will be placed on railroad rights of way. The major consideration for choosing the highway routes is accessibility for both installation and maintenance. Along the construction route, AT&T will build about 60 repeater huts, using traditional building materials in keeping with local architecture.

To cope with the rough terrain of Mexico, each plowing crew will be equipped with two each of the following: Caterpillar D8N tractors, cable plows, ripping plows, and rock saws. This will ensure that they can meet the tight construction schedule required by TelMex. A good example of this installation challenge is the link connecting Poza Rica with Tulancingo. AT&T has allocated one crew a full seven months to install its 157-km link through some of the roughest terrain in Mexico.

Training

AT&T has established a training center for the network cable and transmission systems offered in Mexico. It will provide licensing and certification for two TelMex training instructors, who will establish an in-house program in which they will train maintenance and engineering personnel on the following topics:

- Optical fiber cable, splicing, connectorization, and outside plant system restoration
- The 8TR 695 optical system
- The protective switch 8TR 636
- Operation and maintenance of the air conditioning and power plant.

Documentation

As each link is completed, AT&T will deliver a complete set of documentation in Spanish to TelMex. This documentation will include "as built" drawings for the cable route, factory data, installation inspection and test data, system description, maintenance instructions, and fault location procedures. By the time this entire project is completed, AT&T will have submitted more than 65,000 system drawings to TelMex.

Customer Support

As construction proceeds, AT&T's experience in operating and maintaining optical fiber networks is being shared with TelMex personnel at both the executive and technical levels. About 40 executives have participated in seminars customized for TelMex. These seminars, which describe AT&T 's transition to a digital network, were conducted in the U. S., The Netherlands, and Spain, and were structured as round-table discussions covering topics such as network architecture and technology (switching, transport, signaling, synchronization, etc.). The seminars also dealt with planning, implementation, and operation of each technology sector, and traffic management trends.

AT&T is encouraging ongoing dialogues with TelMex executives to reinforce the flow of information at all levels. About 120 TelMex technical personnel will complete hands-on training covering the application and maintenance of the network from each respective AT&T business unit for the specific products being deployed. AT&T Network Cable Systems has customized a restoration plan based on AT&T's own restoration experiences in the United States. To give TelMex the most advanced and field-proven procedures for quickly restoring service should a service outage occur, AT&T will present a complete package of hardware and procedures, along with hands-on training, to maintenance, engineering, and management employees in each of the six TelMex districts.

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