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# The LT-1 Connector Family of Transmultiplexers

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The LT-1 family of transmultiplexers was designed to provide a flexible and economical means of interconnecting the widely deployed long-haul analog transmission plant with the emerging network of digital switches and facilities. The LT-1 connector eliminates redundant interfaces and uses custom integrated circuits. The most significant improvement is in the analog signaling circuits—the function of an entire circuit pack is reduced to circuitry occupying less than 2 square inches. Reuse of circuits designed for other systems under development helped to introduce this technology rapidly. The original design, targeted for the *4ESS*™ market, was enhanced with three additional designs, which expanded the signaling capability to include special services, added a digital echo canceler for satellite applications, and provided compatibility with international signaling.

## I. INTRODUCTION

In 1976 the first digital toll switching office *4ESS*† switch was placed into service in the Bell System and plans were finalized to develop the LT-1 connector. It was clear that in the decade ahead, most of the vast network of analog toll trunks would need a digital signal format at the switching system interface. This was the primary motivation for developing the LT-1 connector—to economically terminate analog trunks on a time division, digital switching machine. This equipment is referred to generically as a transmultiplexer.

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## II. LONG-HAUL TOLL NETWORK

Plans for deploying the LT-1 connector were closely linked to the *4ESS* cutover program. At the outset it was clear that even with expedited development and manufacture, initial shipment would not be possible before the year 1979; *4ESS* installation schedules indicated that actual service on the equipment could be achieved in 1980. In the 5 years (1979 through 1984), plans called for retiring about 120 electromechanical 4A toll switches, and replacing them with about 90 digital *4ESS* switches. Figure 1 illustrates an estimate of analog trunk needs in the LT-1 connector availability time frame. This estimate indicated a program to deploy 900 frames of LT-1 connectors providing 432,000 analog trunk terminations each year. By 1985 all but 14 percent of these analog trunks will be switched by digital *4ESS* machines; over 83 percent of the analog trunks will be terminated with transmultiplexer equipment.

The intertoll transmission facilities are predominately analog and include coaxial cable, FM radio, and, most recently, single-sideband AM radio. This situation is not expected to change until the advent of long-haul optical fiber and digital radio transmission systems in the late 1980's.

Toll-connect transmission facilities also incorporate significant amounts of analog, as well as digital, equipment. The division is about equal; the current, modest analog majority is expected to change to a modest digital majority by the mid-1980's.

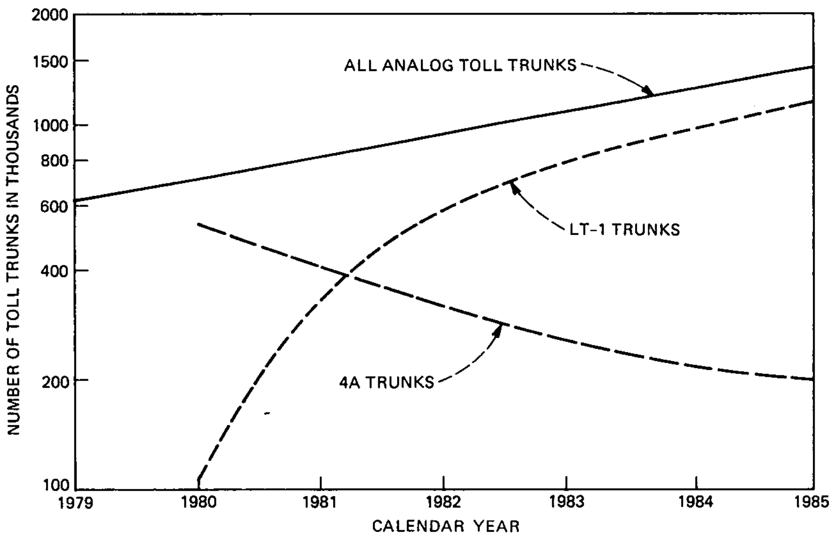


Fig. 1—Long-haul, toll network, analog trunk estimate.

## III. OTHER APPLICATIONS

Another application of the LT-1 connector is the more general interconnection of digital, T-carrier transmission facilities with analog, L-type facilities. When this potential application was surveyed, the telephone operating companies indicated fairly limited needs (estimated to be less than 10 percent of *4ESS* switch analog trunk termination applications). It was thus decided to defer the facility interconnect development (LT-1B) and concentrate on making the *4ESS* switch version available as soon as possible. Also, the need to accommodate many signaling types in the facility interconnect applications made possible a less costly version, tailored to the less stringent signaling requirements of the *4ESS* switch application.

The digital access and cross-connect system (DACS) has considerably changed the facility interconnect application. DACS "grooms" digital facilities by collecting individual special-service channels from a number of different digital systems and routing them to the special office equipment required to operate and maintain them. Similarly, the individual channels can be distributed to many different digital systems to reach the end customers. The LT-1B facility connector, in combination with DACS, will collect and distribute special-service channels, utilizing analog transmission facilities in a similar manner.

## IV. DESIGN PHILOSOPHY

Two design techniques were originally investigated. The first approach was to merge the block diagrams of the individual systems—frequency division multiplexing (FDM), single frequency signaling, and digital pulse code modulation (PCM)—into a single diagram. Immediately, it was clear that much of the interface circuitry in an integrated terminal was redundant, consisting primarily of magnetic components used to isolate the circuit packs from the outside world. Also, standard interfaces for signaling and transmission were unnecessary for this application.

Once these standard interfaces and the interface circuitry were removed, up-to-date integrated circuit techniques would be applied to the remaining circuits. The result was a compact modern design that was within the bounds of existing manufacturing technology. Figure 2 shows the block diagram.

The 12-channel analog FDM signal is buffered and distributed on a low-impedance bus to the 12 channel units. On the channel unit, the 4-kHz band of interest is selected by a crystal bandpass filter and demodulated to voice frequency (VF). Any signaling information present is detected and sent to the digital transmit unit in the form of a digital logic signal. The voice signal is then sampled at 8 kHz, and the

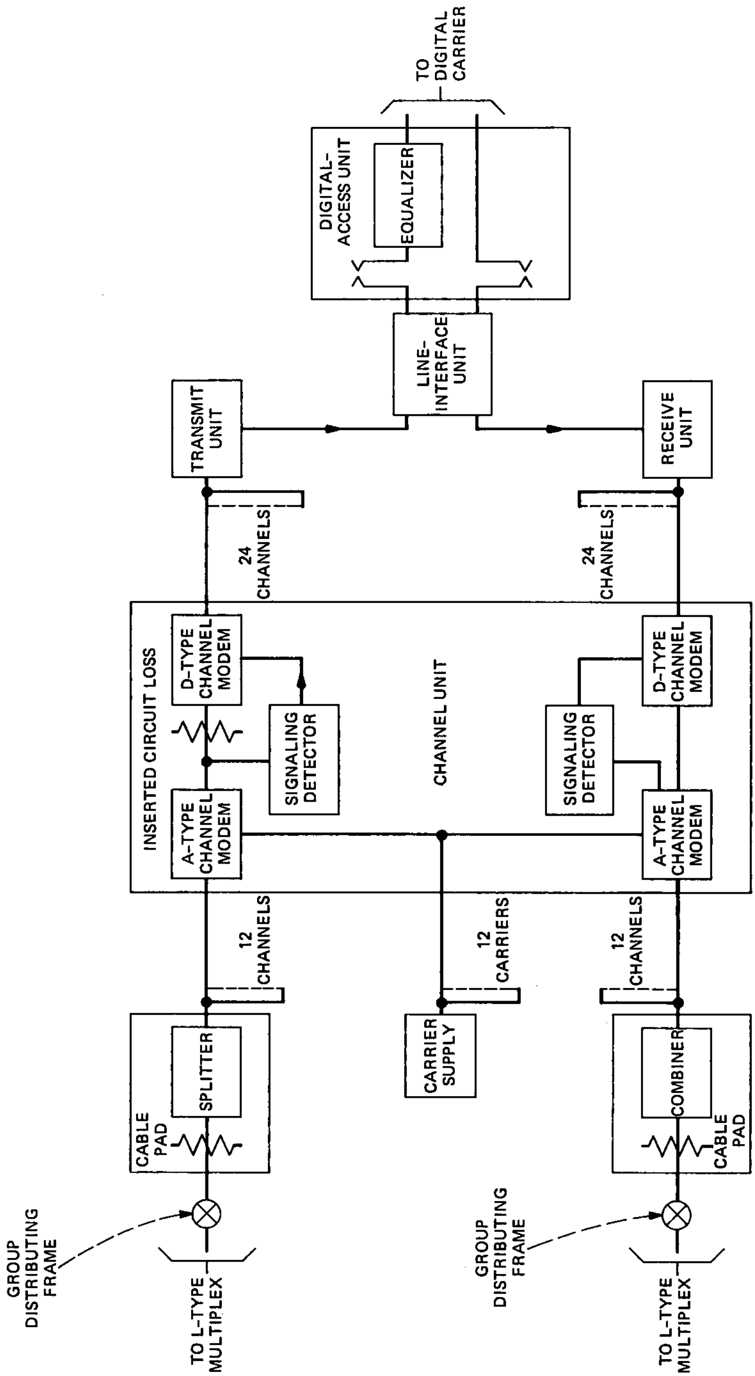


Fig. 2—LT-1 connector.

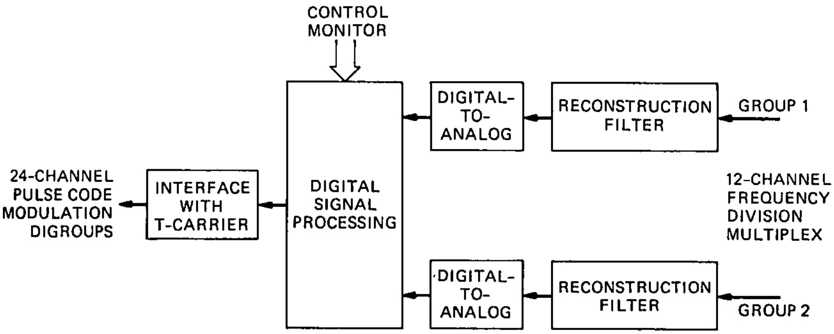


Fig. 3—All-digital transmultiplexer.

samples are time-division-multiplexed on a pulse amplitude modulation (PAM) bus with 23 other channels. These samples are encoded, along with the signaling information, into the standard 24-channel DS-1 signal. The other direction of transmission inverts this process.

Also, some of the circuits are identical to those used in two recently completed developments—D4 and N4. This reduces manufacturing needs and training requirements for the operating companies.

The second approach considered was an all-digital design. Very simply, it would convert the analog group signal into a digitized version with a high-precision, high-speed, analog-to-digital (A/D) converter and perform the demodulation, signal detection, and time division multiplexing functions entirely with digital hardware. It could time-share the circuitry over a large number of channels and thus achieve the well-known benefits of digital circuitry. Figure 3 shows a simplified block diagram of the terminal.

Selecting the approach for final development required an estimate of the cost, size, and power consumption of each design, as well as an estimate of the development time and risk. The results of the study with the per-channel parameters normalized to one are shown in Table I. To the authors' knowledge, this is the first time in which such a study has shown that an all-digital version of what is essentially an analog transmission function could be cost-competitive with a modern per-channel design. We believe this is caused by two factors. The first factor is the degree of complexity possible with very large-scale integrated (VLSI) devices; tens of thousands of switching elements can be integrated into a single device. The second reason is inherent in the transmultiplexer itself in that an A/D conversion need be performed only in one direction of transmission. The fact that the cost estimate for an all-digital transmultiplexer was comparable to the per-channel design suggests that continued development in this area is warranted, and further, it seems likely that an all-digital design soon will become

Table I—Transmultiplexer parameter comparison

| | Per Channel | Digital |
|---|---|---|
| Cost | 1.0 | 1.0 |
| Size | 1.0 | 0.5 |
| Power | 1.0 | 2.0 |

more economical than the per-channel design. However, the all-digital design was considered to have significantly greater risk and a longer design interval than the per-channel approach. The cutover of a 4*ESS* office is planned several years in advance, and the unavailability of a significant amount of terminal equipment could jeopardize the service date. This would result in a large amount of capital not being used productively. Therefore, it was decided to proceed with the per-channel transmultiplexer for final development and, at the same time, continue, on an exploratory basis, the all-digital transmultiplexer.

As we stated earlier, LT-1 initially was used to terminate analog trunks on the 4*ESS* switch. In the beginning, two types of circuit designs were made available—the common channel interoffice signaling (CCIS) channel unit, and E and M channel unit. Both channel units share identical transmission circuits. The difference between them is that the E and M channel unit has additional circuits to detect the 2600-Hz signaling tone and map it into the robbed eighth-bit signaling format used in the DS-1 signal.

## V. CHANNEL-UNIT DESCRIPTION

Figure 4 shows that the channel unit performs three separate functions: analog modulation, signal conversion, and digital sampling. On the analog side, the channel unit must interface with a broadband FDM signal that contains twelve voice channels in a basic group. These must be converted to voice frequency. Signaling information, if present, must then be extracted and the VF signal must be sampled and applied to the PAM bus to interface with the digital common circuits. These three functions are described in the following paragraphs.

## VI. ANALOG MODULATOR

A single custom integrated circuit performed the analog modulation functions. This circuit had been thoroughly characterized previously when it was used in LMX-3 and N4. In this circuit the signal voltage is converted into a current and applied to a pair of emitter-coupled pairs. These are switched on and off under the control of the carrier. The switching effectively multiplies the signal by plus and minus one and performs the modulation process. Because of the balanced nature

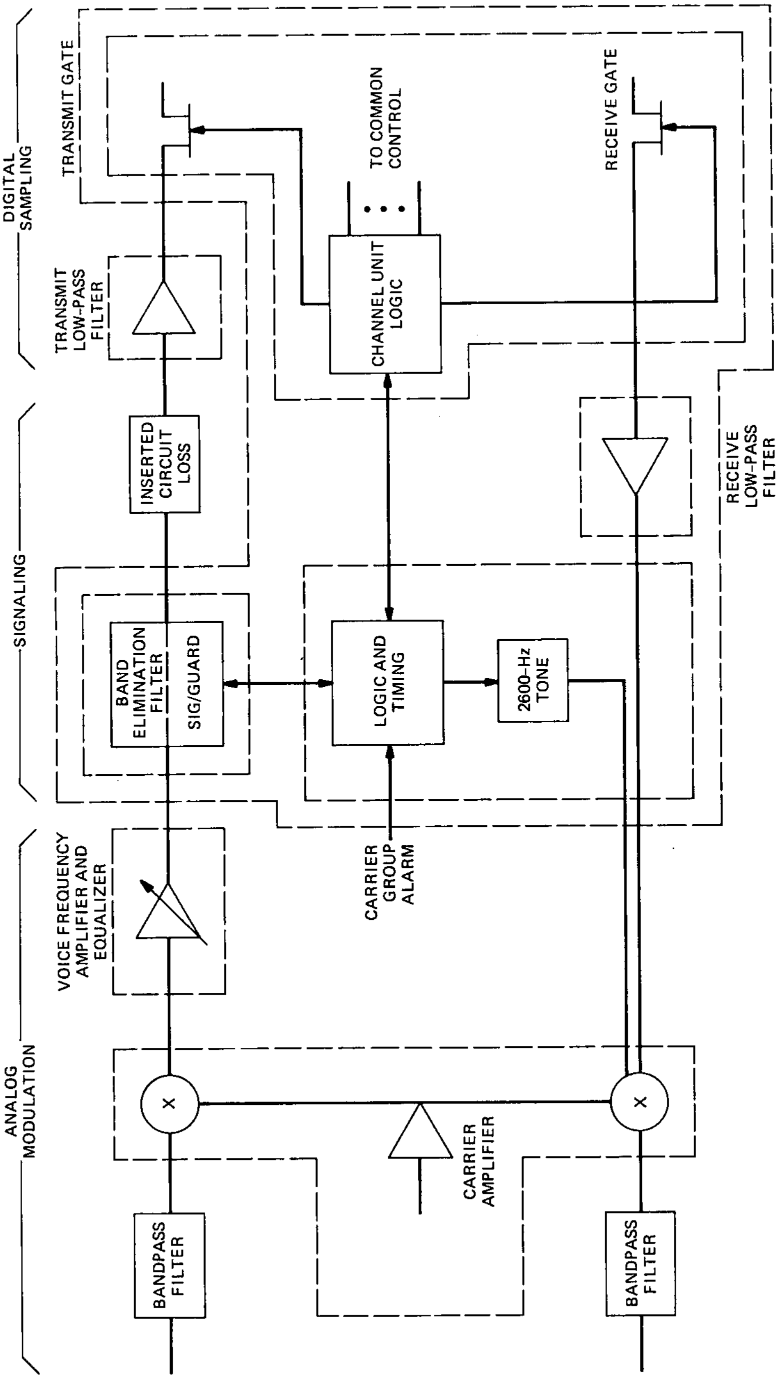


Fig. 4—LT-1 channel unit.

of the circuit, the VF signal and the 2600-Hz signal are effectively summed at the same time. The double-sideband output of the modulation process is filtered with a discrete crystal filter, which selects the lower sideband.

The reverse of this process occurs in the opposite direction. The broadband analog signal is applied to a crystal filter, which selects one channel, and the modulator circuit converts it to VF. Equalization to compensate for low frequency rolloff is provided, as well as a variable gain adjustment to compensate for amplitude misalignment in the analog facility.

## VII. DIGITAL SAMPLER

The next step in the process is to convert the VF signal into PAM samples. This is accomplished with a standard D4 high-pass active filter and junction field-effect transistor (JFET) sampler. The sampler timing is controlled by a channel counter that interleaves the samples from 23 other channel units to create the complete PAM bus signal.

In the reverse direction, a second JFET gates in the appropriate sample from the receive PAM bus, also under the control of the channel counter. This sample is then filtered in a low-pass filter to reconstruct it into a continuous waveform and applied to the modulator. These circuits were designed to be compatible with the common circuits used in D4 so that the latter could be used interchangeably in an office that has both LT-1 and D4.

## VIII. SIGNALING

Figure 5 shows a block diagram of the functions in the signaling receiver. The requirement is to distinguish between the presence of the true 2600-Hz signaling tone and talker energy, which may have frequency components around 2600 Hz. To accomplish this, the signal is processed by two active filters. Since one has a transmission peak at 2600 Hz (SIG) and one has a null (GUARD), the relative amount of energy from the two filters determines if the input is a pure 2600-Hz signal or if it contains significant energy at other frequencies. Because the circuit has short time constants so it can respond to pulse inputs in a few milliseconds, the output of the comparator, EN, must be further processed by pulse-correcting circuits before being transmitted to the digital circuitry.

During certain high noise conditions, such as those that occur during radio fades, the amount of energy detected by the guard amplifier can simulate talker conditions. If no other action was taken, it would appear that a trunk seizure had occurred. Since this would happen on all trunks simultaneously, the switching machine could become over-

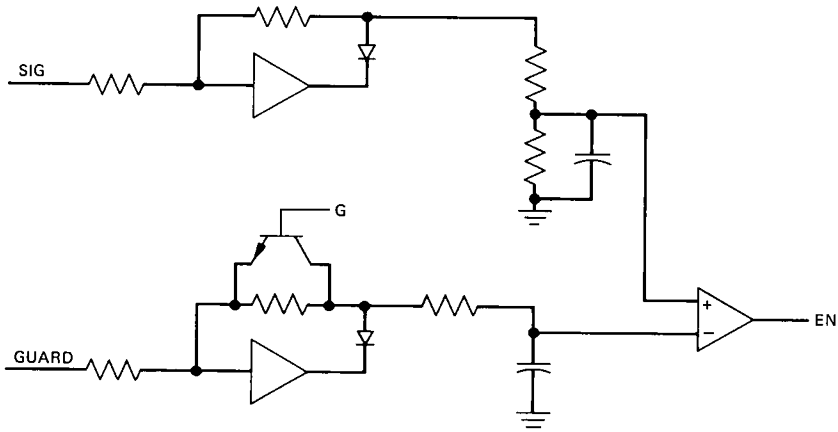


Fig. 5—Signal receiver.

loaded. To prevent this, the gain of the guard amplifier is reduced after 185 ms of being in the idle state.

Figure 6 shows a simplified block diagram of the signal transmitter. When the 2600-Hz signal is first transmitted, it is applied at a −8 dBm0 level, the high level. Because the continuous application of that much power in every channel exceeds the power level that the analog facility was designed to carry, the power is reduced to −20 dBm0 after 400 ms. In Fig. 6, the buffers convert the unregulated transistor-transistor logic (TTL) signals 2600H (high) and 2600HL (high-low) into controlled amplitude square waves. Generating none, one, or two of these signals and summing them produces tone off, low tone, or high tone. This output is added to the VF signal and modulated to the group band.

The balance of the signaling circuitry, which consists of seven timers, is shown in Fig. 7. The timers perform pulse correction in both directions, M lead correct and E lead correct; control the amplitude of the tone (HI-LO); enable an active filter to remove the received tone (BAND ELIMINATION FILTER TIMER); control the gain of the guard amplifier (G TIMER); and disable the transmission path during signaling activity (CUT A, CUT B). These seven timers are all implemented on two custom digital integrated circuits.

Because the LT-1 architecture does not require standard interface points for VF and signaling, the entire signaling function can be accomplished with these three chips mounted on a hybrid integrated circuit, along with an active filter and a few discrete components. Before LT-1 was developed, signaling required an entire printed wiring board. Further, since the timers are all digital, no problems exist with aging or component drift.

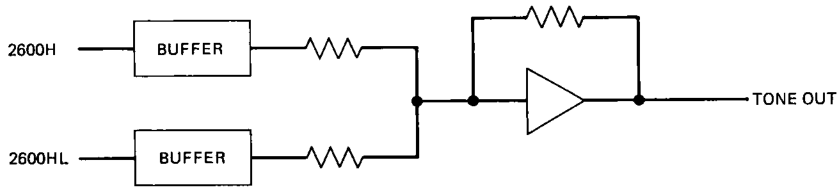


Fig. 6—Signal transmitter.

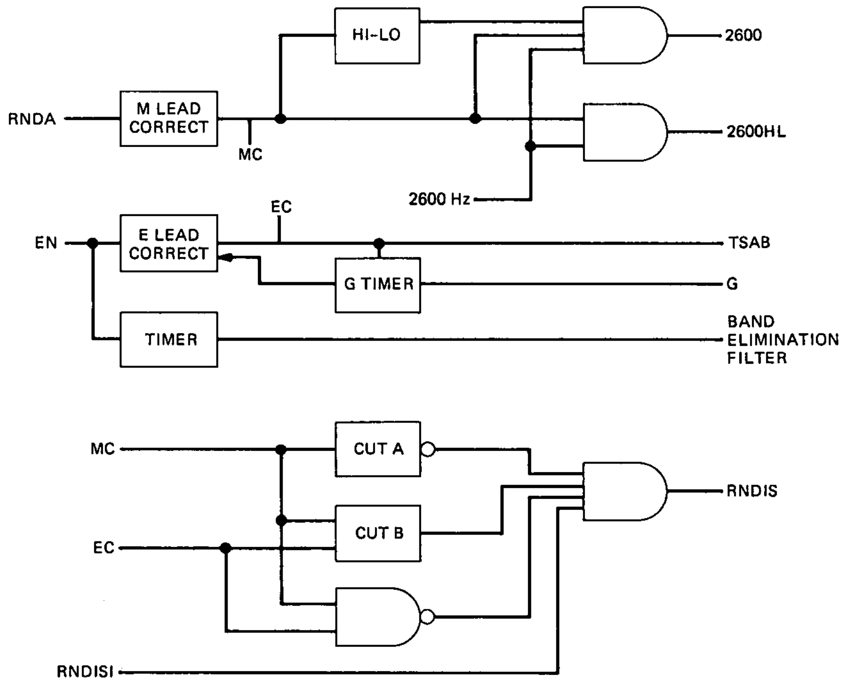


Fig. 7—Signaling control.

These two types of channel units are sufficient for all 4*ESS* switch trunks since only E and M, or CCIS signaling is used in that machine.

After the CCIS and E and M channel units were introduced, a different CCIS channel unit equipped with an echo canceler was developed. Echo canceling is implemented by a VLSI chip[1] that can generate an approximation of the echo introduced at the 2- to 4-wire points in the transmission path. The echo canceler was first used in LT-1 on satellite circuits. As is well known, the subjective annoyance of echo increases with delay. The round-trip delay through a geostationary satellite is approximately 600 ms. Long-distance connections whose echo performance would have been satisfactory on terrestrial circuits became unsatisfactory on a satellite. Further, echo suppressors, traditionally used on long terrestrial circuits, are unsatisfactory on domestic satellite circuits. The echo canceler has been shown to provide a grade of service on a satellite that is equivalent to terrestrial circuits.

LT-1 is a natural point in the transmission path to place an echo canceler because it is located at the termination of an analog trunk on the switching machine. Further, since the VLSI echo canceler was implemented as a digital device, the canceler will interface with the digital signals already present in LT-1. Figure 8 shows the initial LT-1 transmission path. The receive unit converts the PCM to PAM and distributes it to the channel unit. Similarly, the transmit unit converts the PAM samples from the channel unit to PCM. Figure 9 shows how the echo-canceler unit operates. In the digital transmitting direction, the same PAM-to-PCM conversion occurs, but the PCM is sent back to the channel unit for echo canceling. In the receiving direction, the digital-to-analog (D/A) converter is not used. Rather, the received PCM is sent directly to the echo canceler as a digital signal. Having access to both directions of transmission allows the canceler to make an approximation to the echo path and thereby cancel the echo. The output of the canceler is a digital signal, which must be converted to VF by a per-channel decoder. The analog portion of the terminal is unchanged.

## IX. COMMON UNITS

The line interface, transmit, and receive units are unchanged D4 units. The alarm control units (there are two versions) use the D4 alarm control unit layout but with features not needed for LT-1 deleted to reduce their cost. The version used depends upon whether LT-1 is located in the same office as the *4ESS* switch or in another office with connection to the *4ESS* switch provided by a T1 line.

The D4 line build-out circuit was incorporated into the LT-1 digital access units, of which there are two versions. These units provided the access points for testing and aligning the digital access time-slot selector (DATS). One of the versions provides a looping point, so that the *4ESS* switch could be looped back on itself prior to LT-1 being put into service. Which digital access unit is selected depends upon whether the *4ESS* switch is to be looped at the LT-1 or at a DSX-1 cross-connect frame located in the circuit between the LT-1 and the *4ESS* switch.

The combine-and-split unit provides low-impedance summing and driving points for the 12 channel filters. Finally, a power unit provides ±12V and +5V power to all plug-ins in a double digroup. With the development of the echo canceler, an echo-canceler timing unit has

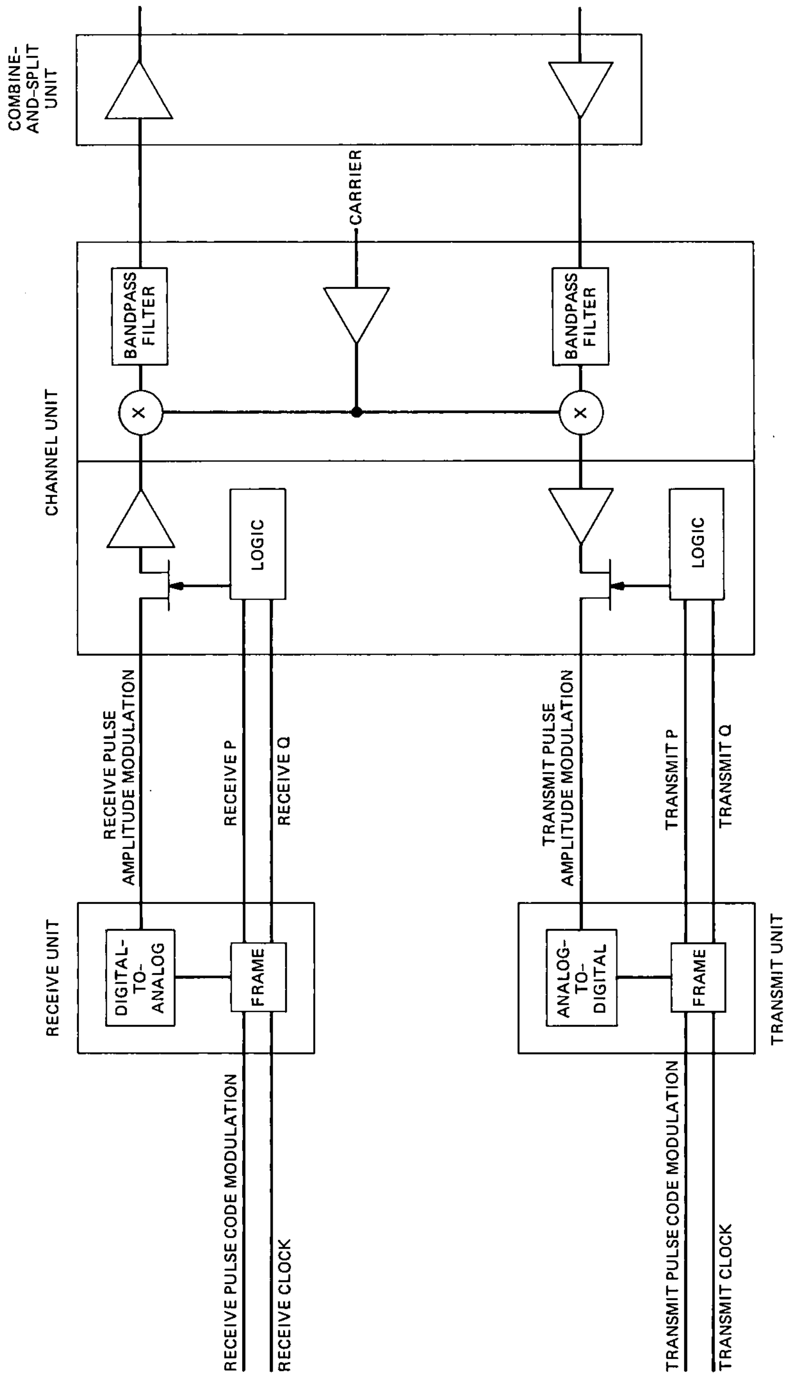


Fig. 8—Existing LT-1 connector.

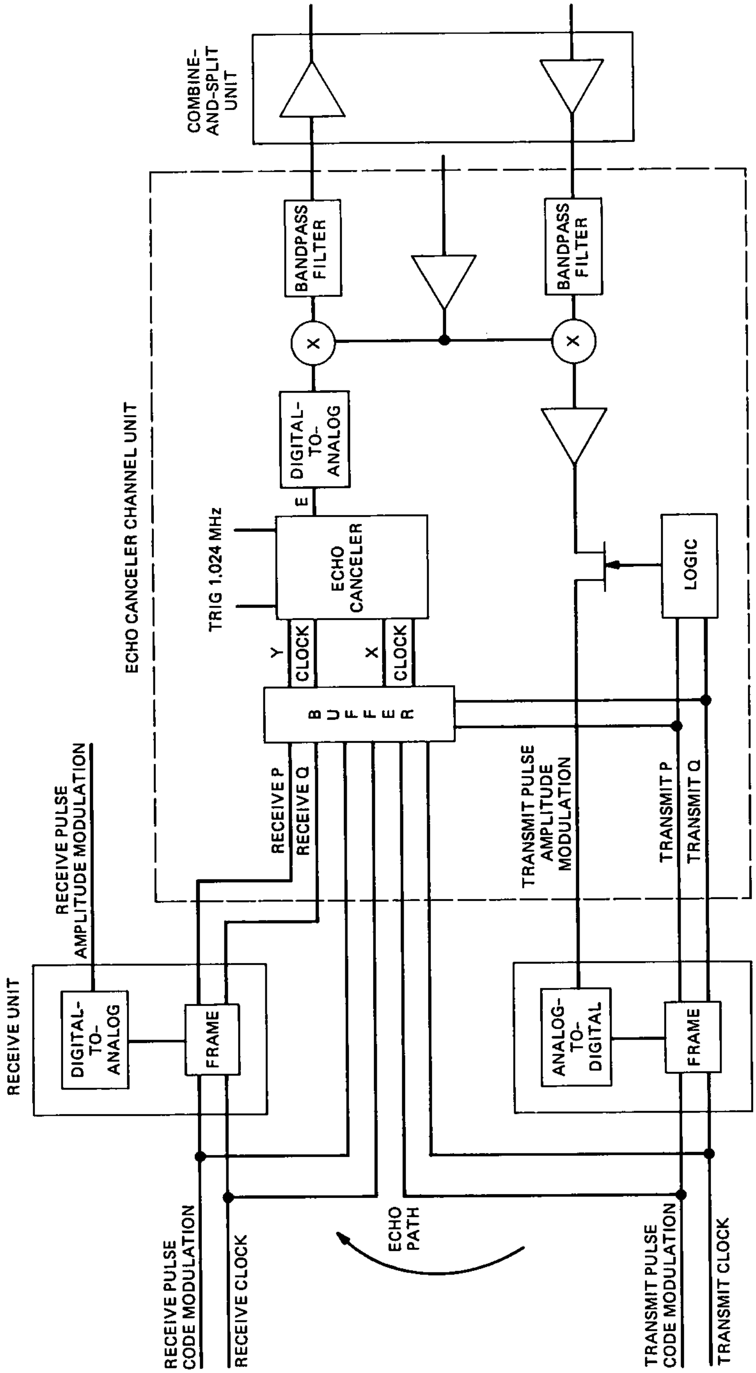


Fig. 9—LT-1 connector with echo canceler.

been added. Also, a new power unit, with additional +5V power capability needed to drive the echo cancelers, has been designed. It is interchangeable with the original unit.

These various units, together with the equipment shelves, are the major components of the LT-1 double bay frame.

## X. MAINTENANCE CONSIDERATIONS

An integral part of the design for the 4*ESS* switch was a plan for installing and maintaining the LT-1. Existing equipments used the switched maintenance access system (SMAS) to enable VF testing to be done on various trunks from a remote test position. Since LT-1 has no VF access, a new testing method was needed. DATS filled this need.[2] The DATS is essentially a portable D4 channel bank under microprocessor control. It can address any two of the 24 channels (one for use as an order wire, the other for test) and measure the VF power or frequency or the state of the signaling bits. It can generate a set of tones at three frequencies and four levels from information stored in a read-only memory (ROM). In addition, it can interface with any VF equipment and digitally encode external test signals or convert the digital signal on any channel into the equivalent VF signal so that it can be measured by using standard test equipment. This capability gives the DATS several advantages. First, since it is measuring and generating digital information, there is no error in the measurements caused by circuit misalignment beyond the measurement point. Second, since the DATS is microprocessor-controlled, macro programs that very quickly do repetitive tasks characteristic of trunk lineup procedures can be, and indeed have been, written.

## XI. FACILITY CONNECTOR

After the LT-1 design for 4*ESS* switch applications was completed, the more general problem of a facility connector, to be designated LT-1B, was investigated. Here the purpose was to connect two 12-channel group signals to a 24-channel digital signal independent of trunk type or orientation. The differences in requirements were primarily related to signaling. The types of signaling units currently in production were studied to find any commonality in the way they represent trunk conditions in the analog and digital signaling domains. The results indicated that a great deal of commonality exists, while the differences between the various units are typically in the interface circuitry, e.g., two wire or four wire, rather than in the mapping of 2600 Hz into the A and B signaling bits. It follows that for LT-1B, a single design could handle all of the 2-state signaling. The 3-state design is more complex. Here a 20-Hz modulation is placed on the 2600-Hz tone to indicate the third state. A channel unit must be able to detect or generate the modulation, depending upon the orientation of the analog and digital sides of the transmultiplexer relative to the switching office. Finally, a fourth type of channel unit without a signaling circuit was developed for CCIS applications.

With 4 signaling types and 12 channel filters, it was obvious that the signaling circuits should be placed on a small module that could be plugged into the main channel unit. This would give complete flexibility to the operating company planners and simplify sparing.

In addition to the enhanced signaling capability, LT-1B provides features not required in LT-1.

1. The channel counting sequence in each digroup can be made compatible with D1D, D2, or D3/D4 channel banks in the field.
2. The transmitting clock can be locked to either incoming digroup or it can run free.
3. The digital side can operate in mode 2 (DS-1C) or mode 3 (two DS-1s).
4. An optional 2-way carrier failure alarm (CFA) with trunk processing can be provided.

This last feature is necessary to allow arbitrary routing of the analog groups. Consider the arrangement shown in Fig. 10. A short-haul, 24-channel digital DS-1 signal from Lawrence, MA is converted, by an LT-1B in Boston, into two long-haul analog groups that terminate in different cities, Cleveland and Chicago. If a failure occurs on the digital digroup, the normal red and yellow alarms will be propagated and trunk processing will occur at the Lawrence, MA end. The LT-1B will remove the outgoing CFA pilot, and the channel banks in Cleveland and Chicago will be processed. However, if a failure occurs on one of the analog trunk groups, it cannot be propagated to the digital banks without all 24 trunks being taken out of service. Therefore, supervisory trunk processing is performed by the LT-1B only on the 12 trunks affected by the failure. This allows service to continue on the other group.

To accommodate the various kinds of signaling, three trunk processing options may be selected on a per-channel basis:

1. On-hook for 2.5s followed by off-hook
2. On-hook
3. Off-hook.

The purpose of these three options is to terminate billing when a failure occurs on any calls in progress and to prevent false ringing or other similar problems on special-service lines.

A particularly important application for LT-1B is its use, in conjunction with DACS, to groom analog facilities. The DACS, which was introduced in 1981, performs a time-slot interchange function, similar

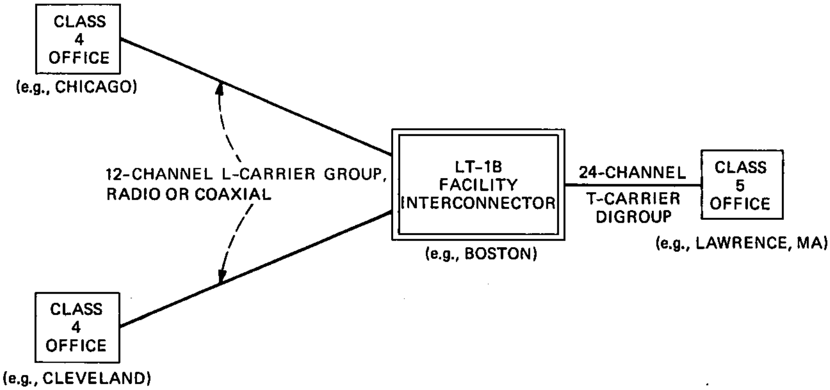


Fig. 10—LT-1 facility connector end-office trunking.

to that of the *4ESS* switch. Its role in the network is to separate switched message and special services on T1 lines. The combination of LT-1B and DACS will allow the same type of network flexibility in the analog plant.

## XII. THE LT-1E CONNECTOR

Another variation in the basic LT-1 design is compatible with International Telegraph and Telephone Consultative Committee (CCITT) transmission and signaling on the analog side and the standard North American DS-1 on the digital side.

The LT-1E connector is the CCITT version of LT-1. It required new carrier supply units, a new channel unit, and a new combine and split unit. The channel unit was a combination of CCITT analog modem and D4 circuits. The analog circuit used 2-step modulation requiring both 12-channel carriers in the 192- and 236-kHz band and a 128-kHz premodulation carrier. The advantage was that only one code of channel filter was required, and hence, the same code of channel unit could be used for all 12 channels. In addition, the channel unit used out-of-band signaling at 3825 Hz. This signal tone could be transmitted at either a high level of −5 dBm0 or a low level of −20 dBm0, and it could be used as "tone on" or "tone off" in the idle (on-hook) state.

The new combine-and-split unit provided CCITT levels at the group distributing frame (GDF). It could insert a pilot frequency of either 84.08 or 104.08 kHz into the analog path and included regulating circuits for the receive pilot.

The carrier supply used the LT-1 shelf but was made up of 12 carrier generators whose frequencies were equally spaced between 192 and 236 kHz, a premodulation generator, a pilot generator, a signal generator, and a power unit. The last four items were duplicated for reliability.

## XIII. LT-1 EQUIPMENT DESIGN

### 13.1 Introduction

The similarities between the LT-1 carrier supply needs and the needs of N4 have been pointed out earlier. Secondly, a number of digital D4 common circuits could be used directly in LT-1. Finally, there was also a similarity in systems' architecture. In its simplest form, LT-1 converted and combined two sets of 12 separate analog signals to form a (digital) DS-1 signal. In D4, 24 separate analog signals were combined to form a DS-1 signal. Additionally, it would be of economic benefit if components, piece parts, or entire units from N4 or D4 that were developed ahead of LT-1 could be used in LT-1.

The plan was to use a reduced N4 carrier supply, the D4 channel bank shelves, and many of the D4 common units, with the LT-1 channel units and certain of the common units being new.

### 13.2 Equipment considerations

LT-1 operates in conjunction with the digital interface frame (DIF) to terminate analog signals on the *4ESS* switch. Five DS-1 signals (120 channels) from the LT-1 are combined in the DIF to form a DS-120 signal, which is the input to a *4ESS* switch. To maintain compatibility with the *4ESS* switch, LT-1 was made up in multiples of 120 channels.

The decision to use N4 and D4 equipment shelves meant using an unequal flange bay with a nominal width of 2 ft 2 in. Further, since LT-1 was to be installed in a *4ESS* switch, the bay height (7 ft) was set by the new equipment building standards (NEBS), to which both the DIF and the *4ESS* switch conformed. An objective of 480 channels for LT-1 in two 7-ft bays was established. This was accomplished by a special channel unit design described below.

### 13.3 Channel units

The basic D4 shelf assembly consists of four shelves, each with 12 channel units. The shelves are die-cast type with 60 equally spaced slots on both sides for the printed wiring boards. Each channel unit requires four slots, with the remaining ones left over for the common units. This arrangement, if used for LT-1, would result in empty shelf space since not all the D4 common units are needed. To alleviate this problem, the channel units were rearranged so that 48 channel units would fill two shelves (that is, 2-1/2 slots per channel), with the third one for the common units. This was done by turning every second channel unit assembly over so that within a pair of assemblies the boards were on the outside and the components extended towards the middle. The components on each board were also rearranged so that the high and low components mesh properly without touching. Each double-channel unit thus occupies five slots.

### *13.4 The LT-1 double digroup*

Since LT-1 requires only three of the four shelves, the D4 shelf assembly was reworked. New castings slotted on one side only were designed to be used either as the top or the bottom and were attached by side panels to create a 13-1/2 in. high, 3-shelf module. The center shelf accepts the D4 common units, and the top and the bottom shelves contain the LT-1 channel units. Each shelf assembly is thus a 48-channel, self-contained module; a 480-channel system would require two 7-ft bays.

A fully equipped system (480 channels) with E and M channel units requires 35 different codes, or circuit packs. Of these, six are double channel units, ten are new to LT-1, and the remainder are taken directly or with slight modifications from N4 or D4.

### *13.5 Carrier supply shelves*

Since the LT-1 and N4 were progressing in parallel, the N4 supply shelf was redesigned to meet both LT-1 and N4 carrier supply requirements. The new castings are slotted on one side only so that they can be used as the top or the bottom of a shelf. These castings were screwed to the side plates and to a connector panel (backplane), with provision for 24 carrier units.

### *13.6 Carrier supply units*

The 24 carrier supply units, including those for the carrier failure alarm, were made from 20 codes. Twelve carrier generators provide separate carrier frequencies, of which six were used unchanged from N4, while the other six were modified to remove a transmitted carrier circuit not needed in LT-1. The twelve received their reference frequency from a 4-kHz generator driven from the office primary frequency supply. This unit also provided 4 kHz to the 100.08-kHz carrier failure alarm generator. The 2600-Hz signaling frequency was generated by a free-running oscillator. These three units were duplicated for reliability. Finally, there was an alarm unit and duplicate power units.

### *13.7 Channel units*

A double channel unit consists of two printed wiring boards with components between them. The terminal (pin out) arrangement was kept the same on both boards so that all channel units had the same functions on the same terminals. This simplified bus wiring on the connector panel backplane for all common functions. Similarly, components that would be adjusted by craft personnel were kept in the same relative position on faceplates. Except for layout, the only difference among 12 channel units of the same general type, within a group, was the frequency of their filters.

The same pair of printed wiring board layouts was used for both E and M and CCIS double-channel units, with the E and M signaling circuits left off the CCIS units. However, a switch was provided on the E and M unit so that it could be converted directly to CCIS.

Later, when the echo-canceler circuits were incorporated into the channel units using a single, 2-1/2 position unit, the high components were placed at the top of the board and the low components at the bottom. This was reversed on the adjacent board, and by using notched faceplates that conformed to the component arrangement, one unit of an opposing pair slid past the other as it was moved in and out of a shelf.

### 13.8 LT-1 double bay frame

The LT-1 connector is housed in a double bay frame made from two standard 7-ft unequal flange bays set side by side. The base is 4 ft 4 in. wide and 12 in. deep.

Prior to assembly, the individual equipment shelves are wired. The transmit and receive leads from the digroups are then connected to the connectors on the bays.

### 13.9 Cabling

The transmission path for LT-1 is connected to the GDF on the analog side, and to either the DIF, the digroup terminal (DT), or the digital cross-connect frame (DSX-1) on the digital side.

The analog connections are made using twisted shielded pairs (761A type), with the shields grounded at the GDF and floating at the LT-1. There are two pairs—one transmit and one receive—for each group. They are terminated on the combine-and-split unit connector at the back of the double digroup.

The digital connections are made using 600B (type) cables. The cables for the DIF and DT connections are fully connectorized, while the DSX-1 cable is connectorized at the LT-1 end and wire wrapped at the DSX-1. The aluminum cable sheaths are grounded at the LT-1 bay, and there are separate cables for the transmit and receive paths.

### 13.10 The LT-1B connector

The LT-1B is packaged in three versions. The first is a 7-ft unequal flanged bay, which, from the top, contained a fuse and alarm panel

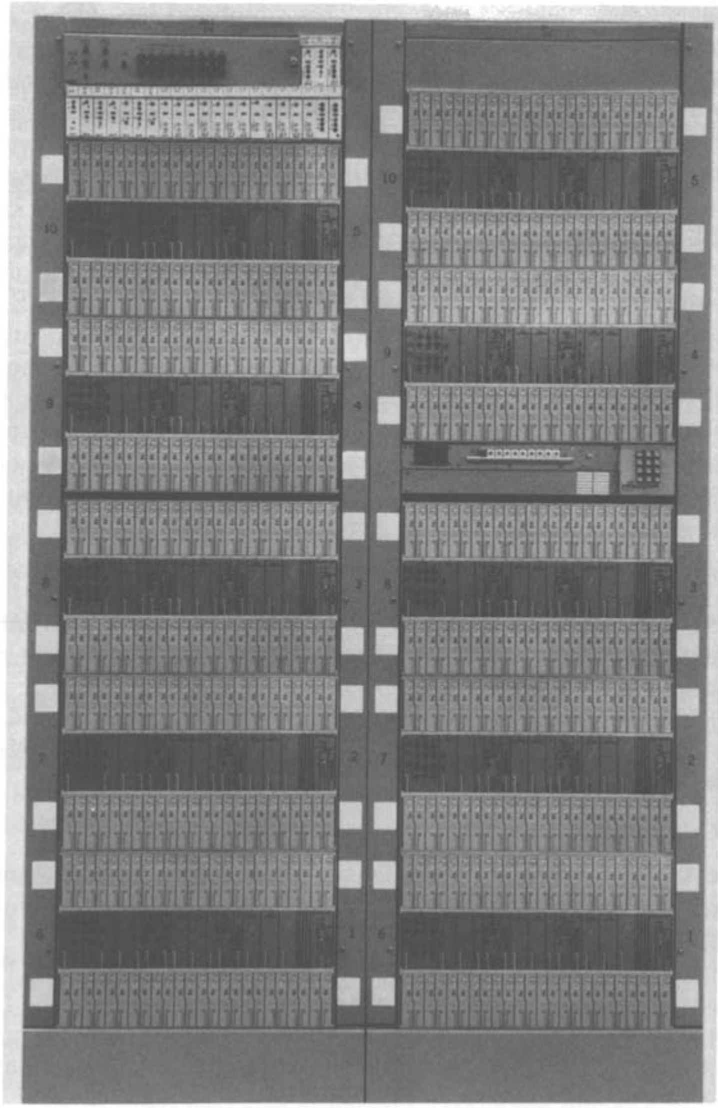

Fig. 11—LT-1B connector primary and secondary bays.

designed for LT-1B, the LT-1 carrier supply, and five modified double digroups. The double digroups have two more connectors on the common shelf connector panel so that they can be used for LT-1 and LT-1B with and without T1C operation. New channel units and a synchronizer/desynchronizer (SYNDES) unit (a D4 circuit) were added. This was the primary bay of a pair and contained 240 channels.

The second bay holds an additional 240 channels. It contains five double digroups and an optional 660 communications panel located between the third and fourth digroups from the bottom. This bay receives its power and carriers from the primary bay and was alarmed through the bay. The LT-1B primary and secondary bays are shown in Fig. 11.

The third bay is 11 ft 6 in. high and self-contained, with a total of eight double digroups (384 channels). Its layout is similar to the 7-ft primary bay except that between the third and fourth double digroups there is a communications panel, and above the fuse and alarm panel there are three more double digroups.

The channel units are similar in concept to the LT-1 echo cancelers but include four removable circuit modules (daughter boards) containing the signaling circuits. They are completely interchangeable and can be mounted on any of the 12 channel units.

## XIV. SUMMARY

This article has described the LT-1 connector design. The original design, intended for *4ESS* applications, would accommodate E and M and CCIS signaling only. It took maximum advantage of the common technology of D4 and N4, as well as custom integrated circuits. Additional features and signaling capabilities were added to the design for facility interconnect applications. An echo-canceler plug-in was added to improve the grade of service on satellite circuits. Finally, technology developed for international markets was incorporated into the design to interface with an export version of the *4ESS* switch.

The LT-1 design has been very flexible in meeting the needs of AT&T Communications and the Bell Operating Companies. It economically converts between analog and digital transmission, a critical function as AT&T Communications and the Bell Operating Companies move toward an all-digital network.

## REFERENCES


1. D. L. Duttweiler, "A Twelve Channel Digital Echo Canceler," IEEE Trans. Commun., *COM-26*, No. 5 (May 1978), pp. 647–53.
2. R. T. Bobilin and Yau-Chau Ching, "DATS—A New Approach to VF Testing on Digital Carriers," NTC Conference Record, *2* (December 1978), pp. 21.6.1–4.


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