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L5 SYSTEM:

Centralized Transmission Surveillance

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A centralized and automated transmission surveillance system has been developed for the L5 Coaxial-Carrier Transmission System as a means for attaining desired transmission reliability. Additional benefits are extensive and include accurate data-processing capabilities plus substantial cost and time economies. The system consists of two basic measuring and control facilities: (i) a transmission surveillance center, located at a designated main station, originates all control operations and accumulates and processes all measured data through use of a small computer, and (ii) transmission surveillance auxiliaries, located at all other main stations, perform measurement functions as directed and return the resulting raw data to the controlling transmission surveillance center. Digitally operated test equipment makes desired measurements under local or remote programmed control, and the E2 Status Reporting and Control System provides interstation transmission of commands and data through time-sharing of a four-wire data transmission link.

I. INTRODUCTION

Verification of the transmission integrity of a complex, broadband network such as the L5 Coaxial-Carrier Transmission System requires many measurements at different locations and considerable processing of the measured data. To minimize the manpower and time requirements for these maintenance operations while providing a high degree of system reliability, a centralized, automated transmission surveillance system has been developed and forms an integral part of the L5 network.

The transmission surveillance system (TSS) takes advantage of a technology evolving from the availability of inexpensive, flexible, small central processors (minicomputers) and programmable test sets. A surveillance network, consisting of a computer-controlled center located at a strategic L5 main station and a set of remotely controllable auxiliaries located at other stations and having digitally operated test sets with automatic access to key test points, provides the following advantages on a large segment of an L5 route:

(*i*) Transmission performance overview that is not possible with local individual station maintenance.
(*ii*) Early warning of slowly developing troubles.
(*iii*) Rapid localization of trouble by automatic techniques.
(*iv*) Efficient use of manpower through computer control of routine tasks.
(*v*) Accurate, flexible records as a result of computer processing and teletypewriter printout.

A four-wire data-transmission system transmits all remote control commands and retrieves remotely measured data in digital form. This data transfer capability is realized by utilizing a new feature included in the E2 Status Reporting and Control System.

The L5 system also has a built-in fault-location capability for remotely identifying a defective repeater in a coaxial line. It consists of an oscillator unit associated with each repeater and a logic unit located in the manhole. Commands from an adjacent main station activate an oscillator unit, and signals injected at the repeater input and output ports are monitored at the receiving end of the line to verify proper repeater operation.

Some additional automated features described in more detail in the following sections include local and remote pilot measurements, line transmission measurements (out of service), computer analysis of measured results, and a system for built-in diagnosis of troubles in the surveillance system itself.

II. OVERALL STRUCTURE

2.1 *Functional divisions*

The transmission surveillance system (TSS) for the L5 carrier system provides computer-controlled transmission-measuring capability utilizing technology evolving in the field of digitally controlled transmission-measuring equipment. A typical TSS, shown in simplified block schematic form in Fig. 1, serves a segment of several hundred route miles in an L5 system. The main functional units are as follows:

(*i*) One transmission surveillance center (TSC), the focal point of each surveillance system, originates all automatic operations.

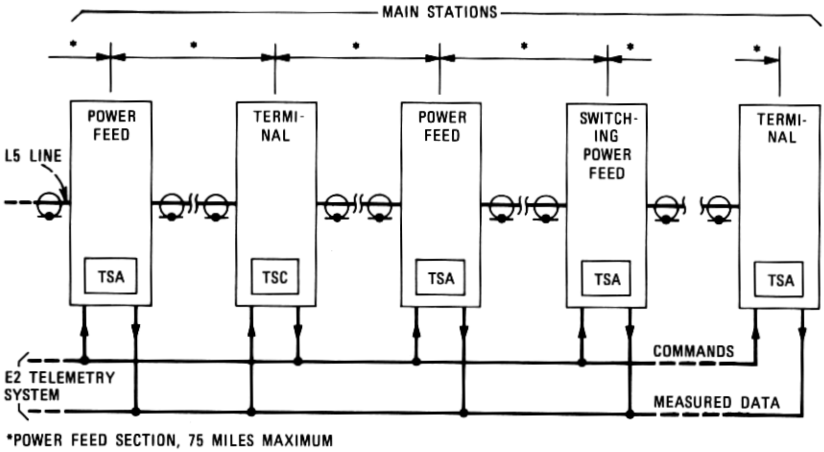

Fig. 1—L5 transmission surveillance system.

(*ii*) Several transmission surveillance auxiliaries (TSA's), preferably not over 10 to 12 per system, are controlled remotely by the TSC and are located at all main stations other than the TSC site.

(*iii*) A modular, coaxial, switched access network is associated with each TSC and TSA.

(*iv*) A fault-location facility provides test oscillators at each repeater, remote-control circuits, and power for operating the oscillators.

(*v*) A data-transfer facility is used for transmission of remote-control commands and measured data, and is provided by the E2 Status Reporting and Control System on a time-shared basis with other services such as alarm surveillance.

2.2 *Transmission surveillance center*

The TSC is generally located at a well-manned terminal main station having significance in the overall maintenance and operation of the L5 system area covered by the TSS. The TSC functions as a nerve center for originating and processing automatic measurements on L5 line and jumbogroup multiplex (JMX) equipment. Upon diagnosing a trouble condition, TSC personnel may request maintenance action at other distant main stations, which may normally be unmanned or partially

Fig. 2—L5 initial route.

manned. The TSC for the initial L5 carrier installation (Fig. 2) is at the Xenia, Ohio, station, which is on the main backbone route and has three sidelegs and JMX equipment. In this installation, the TSC monitors 13 other stations and 815 miles of repeatered line. Placing the TSC at a station with the largest number of sidelegs and JMX signal-processing equipment maximizes the "local-category" control and measurements. This hastens surveillance operations by minimizing the amount of data-link time sharing required for remote control through the E2 Status Reporting and Control System.

2.3 Transmission surveillance auxiliary

The TSA does essentially the same transmission measurements and local control functions as the TSC, but does not originate automatic commands or process results other than sending raw data back to the TSC. A TSA appears at all station types, which are described in Ref. 1 and listed below:

(*i*) Power-feed main.
(*ii*) Switching power-feed main.
(*iii*) Terminal/terminal main.

2.4 Transmission measuring system

Recently developed 90-type digitally controlled test equipment[2] associated with the TSC and each TSA measures transmission at the various stations in a transmission surveillance system. The equipment consists of a signal generator providing an adjustable sine-wave output in the amplitude range of −99.9 to 0 dBm and frequency range of 10 kHz to 100 MHz. The selective detector measures the amplitudes of received signals in the range of −119 to 0 dBm and 10 kHz to 100 MHz. Most transmission measurements are made automatically under computer control in the surveillance system. A digital control unit (DCU) associated with the 90-type equipment operates the signal generator and selective detector in this mode. Four 16-bit binary words set the output signal amplitude and frequency of a signal generator. Five 16-bit words set the frequency, sensitivity, bandwidth (250 or 2500 Hz), and noise-distortion mode of a selective detector. An analog-to-digital converter in the DCU transforms the analog measurements of a selective detector to digital form suitable for input to the computer or to a data-transmission facility such as the E2 Status Reporting and Control System.

2.5 Command- and data-signal transmission

During automatic surveillance operation, an E2 Status Reporting and Control System associated with the L5 system transmits remote-control commands from a TSC to the various TSA's and raw measured data from the TSA's to the computer in the TSC. The E2 system, as arranged for L5 use, provides interstation communication under the following categories or modes:

(*i*) Alarm polling.
(*ii*) Status reporting.
(*iii*) Remote switching.
(*iv*) Data transfer or remote callup.

Alarm polling, the principal E2 function, continues automatically until interrupted by a request for one of the other functions. Data transfer required for TSS operation is interleaved on a time-shared basis with the other E2 operations. If not inhibited periodically, the remote callup processing of most TSS programs would interrupt the alarm-polling cycle longer than the permissible alarm-updating period. Therefore, the E2 system suspends callup operation every 30 seconds and polls all remote stations for alarms. Callup resumes after a complete alarm-polling cycle, which takes two to four seconds, depending on where the sequence starts.

The E2 system consists of the following units:

(*i*) A central station, which initiates, supervises, and controls most of the E2 system operations.

(*ii*) Remote stations, which may be widely separated.

(*iii*) Remote call-up units (RCU's) (one provided as an integral part of each remote station having general-purpose data-transfer capability).

(*iv*) A four-wire data link for interconnecting the remote stations and central stations.

The manual-type E2 central station provided for the initial L5 installation is located at Williamstown, Ky. (Fig. 2). It accommodates one data link, which may interconnect a maximum of 16 remote stations. At least one remote station is provided at each of the 14 L5 stations for alarm reporting and TSS control purposes.

During alarm polling, the central station automatically interrogates each remote station in succession and registers the station location and category of an alarm should one occur. When an E2-central operator desires detailed status information about a station, he manually initiates the status reporting operations. The frequency and duration of the alarm-polling interruptions for this purpose depend on the number of statuses assigned to each alarm indication and the amount of information needed. Remote switching is used in TSS operations to control the switching of remote line sections for out-of-service measurements.[3] Each remote switch command interrupts the polling cycle for approximately 0.3 second.

During any of the first three E2 system operating modes, the central station and the addressed remote station communicate only with each other. The RCU provides the remote-to-remote communications or data transfer capability needed by a TSC for sending commands to a distant TSA and retrieving remotely measured data. The E2 central station supervises the callup operation, which involves communication among remote stations and between the remote and central stations. The RCU accepts and delivers commands and data in bit-parallel, word-serial form, with each word containing 16 information-bearing bits. As used with the L5 carrier, the E2 system transmits bits serially through the data link at a rate of 600 bits per second.

III. TRANSMISSION SURVEILLANCE CENTER DESCRIPTION

Figure 3 shows the functional arrangement of the principal parts in a TSC. A desk-type console (Fig. 4) contains all the items except two. The standard teletypewriter console is located at the left. The switched access equipment is mounted in the surveillance distribution bay, which is at the left rear in this particular installation.

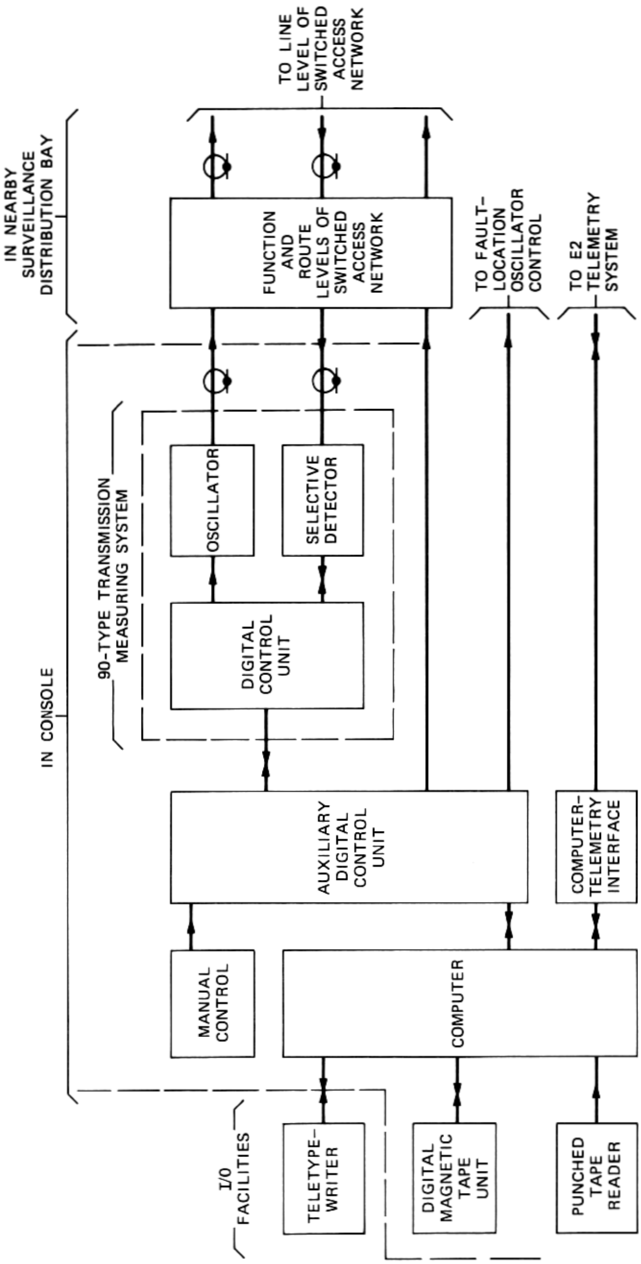

Fig. 3—Transmission surveillance center.

Fig. 4—Transmission surveillance center at Xenia, Ohio, station.

3.1 Computer

The small general-purpose digital computer (minicomputer) in the TSC serves as the central processor in a TSS. The extensive computational and control capabilities in it provide much flexibility for scheduling and sequencing measurements, processing data, and presenting results. Among the salient features of the computer are core memory for 8192 16-bit binary words, a comprehensive program-interrupt system, interface circuits for peripheral equipment, and an internal power supply.

3.2 Teletypewriter

The TSC operator uses the teletypewriter for entering commands and program parameters. The teletypewriter also prints measured results or processed information derived from measured results as directed by the programs.

3.3 Tape reader

The punched-tape reader provides direct computer loading of program material from punched tape. Depending on the type and operational phase of a program, it may be used when initializing the system, when adding information on magnetic tape, when running special programs, or during diagnostic procedures.

3.4 Peripheral storage

Small magnetic tape cassettes, having a maximum storage of 180,000 computer words each, are used in the digital magnetic-tape unit for convenient storage of programs and data. An operator loads tape contents into the computer by typing a command at the teletypewriter.

3.5 Measurement procedure

The digitally programmable transmission-measuring system makes measurements at the TSC location when directed by the computer. The switched access network described in Section V automatically connects the oscillator and/or selective detector to the desired measuring points. Binary-coded instructions pass through the auxiliary digital control unit (AUX DCU) and are held in memory in the DCU to control test set parameters such as frequency, output power, sensitivity, and bandwidth. An analog-to-digital converter in the DCU encodes the measurements into digital form suitable for input to the computer.

Logic in the AUX DCU transfers and steers control commands from the computer or manual control circuit to test equipment, fault location, or switched access control circuits. Flip-flop memory holds the fault location or switched access commands until the command selection is changed or released.

3.6 Computer backup

Front-panel pushbutton keys and associated programmed logic in the manual control provide manual backup of local switched-access and fault-location oscillator control. Numeric readouts display the selections made with these keys. Other keys permit generation of any 16-bit binary word for testing or limited operation of the transmission measuring system. Presently, manual control is possible only on the local-office operated equipment. Subsequently, remote manual control capability will be provided for operating fault-location control logic at adjacent stations and one beyond the adjacent stations.

3.7 Computer-E2 system interfacing

The computer-telemetry interface circuit and a software program driver adapt one 16-bit computer input/output (I/O) channel to the control format of the E2 Status Reporting and Control System. The time multiplexing in the interface circuit and software programming enable the computer channel to receive 16-bit information-bearing words from the E2 system and, in addition, to monitor six E2 system control leads. The interface circuit transfers outgoing 16-bit words from the computer without modification, but does stretch the outgoing strobe pulse (device command) to the duration required by the E2 system.

IV. TRANSMISSION SURVEILLANCE AUXILIARY DESCRIPTION

The TSA has all the functional units of a TSC except the computer and associated I/O peripherals (Fig. 5). A bay framework mounts all equipment except the transmission-measuring system, which is assembled in a rolling console and plugged into the bay. The console may be disconnected temporarily from the TSA and used for general-purpose measurements anywhere in the office during visits by maintenance personnel. The TSA bay also contains portions of the switched access network.

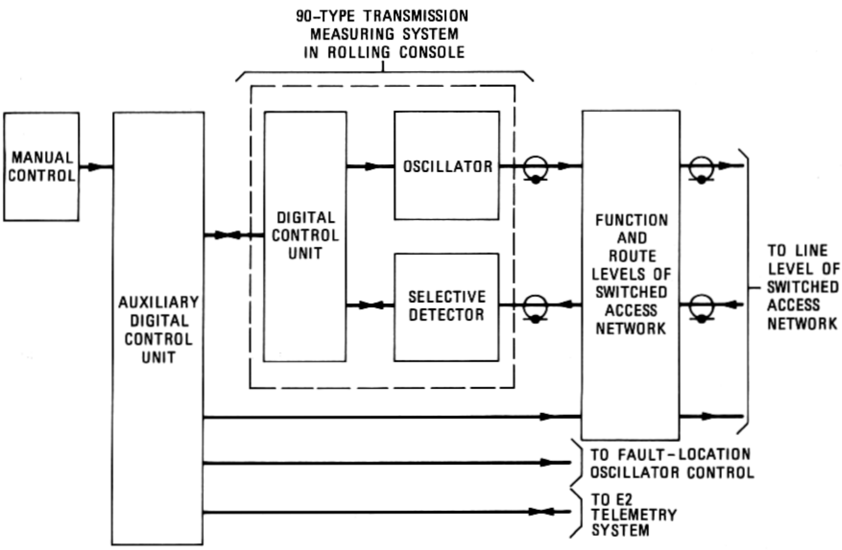

Fig. 5—Transmission surveillance auxiliary.

The TSA operates the local switched access network, fault-location oscillators, and transmission-measuring equipment similarly to the TSC. However, all automatic commands originate at the computer in the TSC and are delivered to the TSA through the E2 data link. When directed by an operational program, the TSA sends raw measured data in digital form through the E2 data link back to the computer in the TSC. The local switched access network and locally powered fault-location oscillators may be operated manually by means of the TSA manual control, which is the same as that in the TSC.

V. SWITCHED ACCESS NETWORK

5.1 Purposes

Signal paths between the measuring equipment and desired L5 system test points are established under computer or local-manual control through a three-level, dual array of multiport, coaxial, ferreed-type switches (Fig. 6). The transmitting array conveys outgoing signals from the oscillator in a TSA or TSC, and the receiving array con-

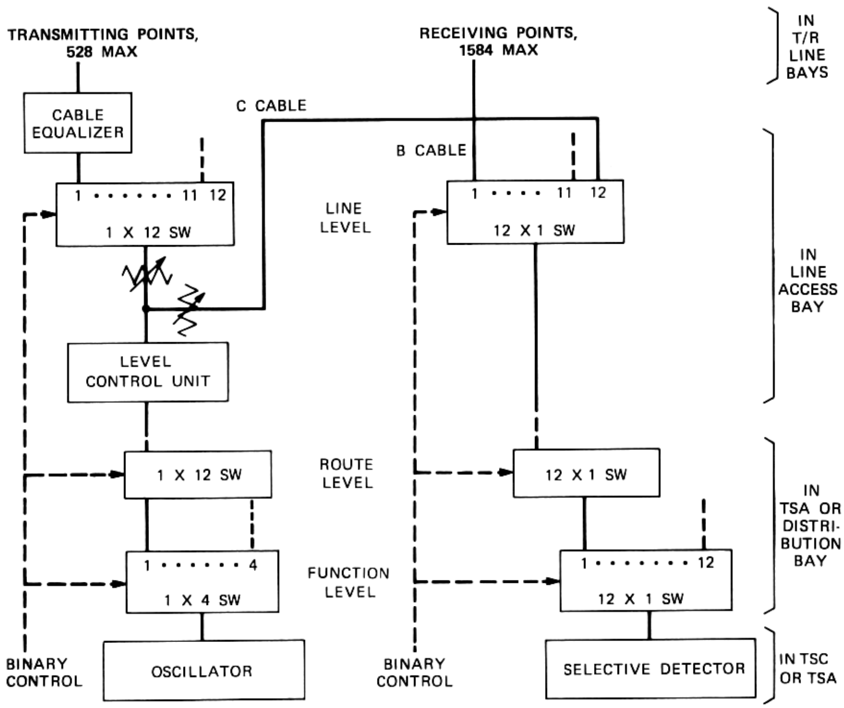

Fig. 6—Switched access network.

veys the signals from certain designated measuring points to the selective detector. Interconnection with the L5 line-protection switching system safeguards working channels from strong test tones.[2] A switched-access-network transmitting path is not completed to an L5 line unless the line is out of service.

5.2 Capacity and growth flexibility

The circuit and equipment groupings of three-level switching (function, route, and line) offer much flexibility and accessing capacity and permit modular growth. The basic arrangement of Fig. 6 yields a maximum of 528 transmitting line-level ports and 1584 receiving line-level ports, not including those used for network calibration. Only 110 transmitting ports and 330 receiving ports are used for switched access to L5 line facilities in a maximally equipped TSC location (10 routes). Most of the remaining capacity will be used for accessing jumbogroup multiplex equipment if the station has much of it.[4]

5.3 Switching-level definitions and equipment placements

A port on the function switch determines the class of an accessed measuring point, such as a particular place in the L5 lines or the JMX equipment. For example, port 1 of the receiving function switch always gets signals from a test point designated receiving line test (RCVG LINE TST), regardless of the selected route or line. A port on the route switch determines the cable entrance, and a port on the line switch determines the coaxial line.

The route- and function-level switches, with an associated power enabler and decoder circuit for controlling all switches, are mounted in the TSA bay at TSA locations and at a TSC in the nearby distribution bay. A line access bay associated with each L5 transmission bay (transmit-receive) lineup contains the line-level switches, which make connections to the L5 line test points. A transmit-receive bay lineup is associated with each cable entrance, which is designated as a route for TSS administration and control purposes. A station without sidelegs and located along a through backbone system has two of these routes defined above, which result from the two cable entrances. Each sideleg contributes one route to a station, since it has one cable entrance.

5.4 Access network control

The switched access network is controlled either automatically or manually by registering specific binary-coded commands in the AUX DCU memory, which outputs this information as continuous dc signals.

The power enabler and decoder circuit decodes and converts these dc signals to decimal arrangements with current capacity and voltage necessary to energize the switch windings. Switch-selection control progresses through the levels as follows:

(*i*) A signal from the AUX DCU enables the function switch.
(*ii*) Operating a function-switch crosspoint enables the route switch connected to that crosspoint.
(*iii*) Operating a route-switch crosspoint enables the line switch connected to that crosspoint.

Interlock logic prevents simultaneous closure of more than one crosspoint at the same switching level to assure adequate crosstalk isolation in the access network.

5.5 Optimizing transmission performance of the switched access network

Several circuit features and operating procedures combine to minimize the contribution of the switched access network to measuring errors. For receiving measurements, the losses are effectively calibrated out in the paths from the test access points in the transmission bays to the selective detector input. The implementation is as follows:

(*i*) All B cables are made equal length between the 12 × 1 line-level switch and the associated receiving measuring points in the transmission bays (Fig. 6).
(*ii*) The loss-frequency slope from the level-control output through the C cable to the 12 × 1 line-level switch input is made equal to that of the B cables.
(*iii*) As part of the measuring program, a reference value is obtained at each frequency by sending a signal from the oscillator, through the level-control unit to the 12 × 1 line-level switch, and then down through the route and function switches to the selective detector.
(*iv*) The computer programming takes the reference into account in determining the absolute amplitude of the received signal.
(*v*) The attenuation in the signal-splitting arrangement at the level-control output brings the calibration-signal amplitudes near those of frequently measured signals to minimize or eliminate attenuator ranging in the selective detector.

For transmitted test signals, the circuit paths from the level-control unit to the transmitting point, where signals are applied to the line, are equalized to a nominal 50-dB flat loss. The accumulation of small errors in the switched access network, together with the inherent accuracy of the transmission-measuring equipment, should yield an overall measuring accuracy of better than 0.2 dB for received signals. Straightaway measurements should have slightly less accuracy because of switching and measuring equipment involvement at two locations.

VI. FAULT LOCATION

6.1 Procedure

Location of failed or degraded repeaters along an L5 coaxial line is based on measurement of tones transmitted through the line from a four-oscillator fault-location unit associated with each repeater (Fig. 7a). During fault location, dc power and control commands are sent through interstitial wires in the cable from the nearest TSC or TSA to the manhole locations to energize one oscillator group at a time. Two simultaneously closed coaxial switches in an energized oscillator unit connect the four different test frequencies to the input and output of the repeater, as shown in Fig. 7a. The separations between the two low frequencies and between the two high frequencies permit measurement of each individual tone with a selective detector in a distant TSC or TSA.

Before the oscillators are installed in a repeater manhole, the outputs are adjusted so that signals leave the location as follows:

(*i*) The two low-frequency signals have nominally equal amplitudes if the low-frequency gain of the repeater is normal.

(*ii*) The two high-frequency signals have nominally equal amplitudes, but not the same as the two low frequencies, if the high-frequency gain of the repeater is normal.

Therefore, the signals received from a basic repeater indicate a gain abnormality if the low-frequency pair or the high-frequency pair differs in amplitude. Signals from a regulating repeater require different interpretation because the gain varies with seasonal temperature changes. Equal amplitudes should be expected in the received signal pairs only when the cable temperature is at the seasonal mean.[5]

6.2 Fault-location-oscillator control and powering

A rectifier power supply and control unit associated with each route, or cable entrance, at a TSC or TSA station directly control one fault-location unit at a time through interstitial wires in the coaxial cable (Fig. 8). In straightaway runs, direct control extends halfway to the adjacent station, which in turn controls the far half of the power

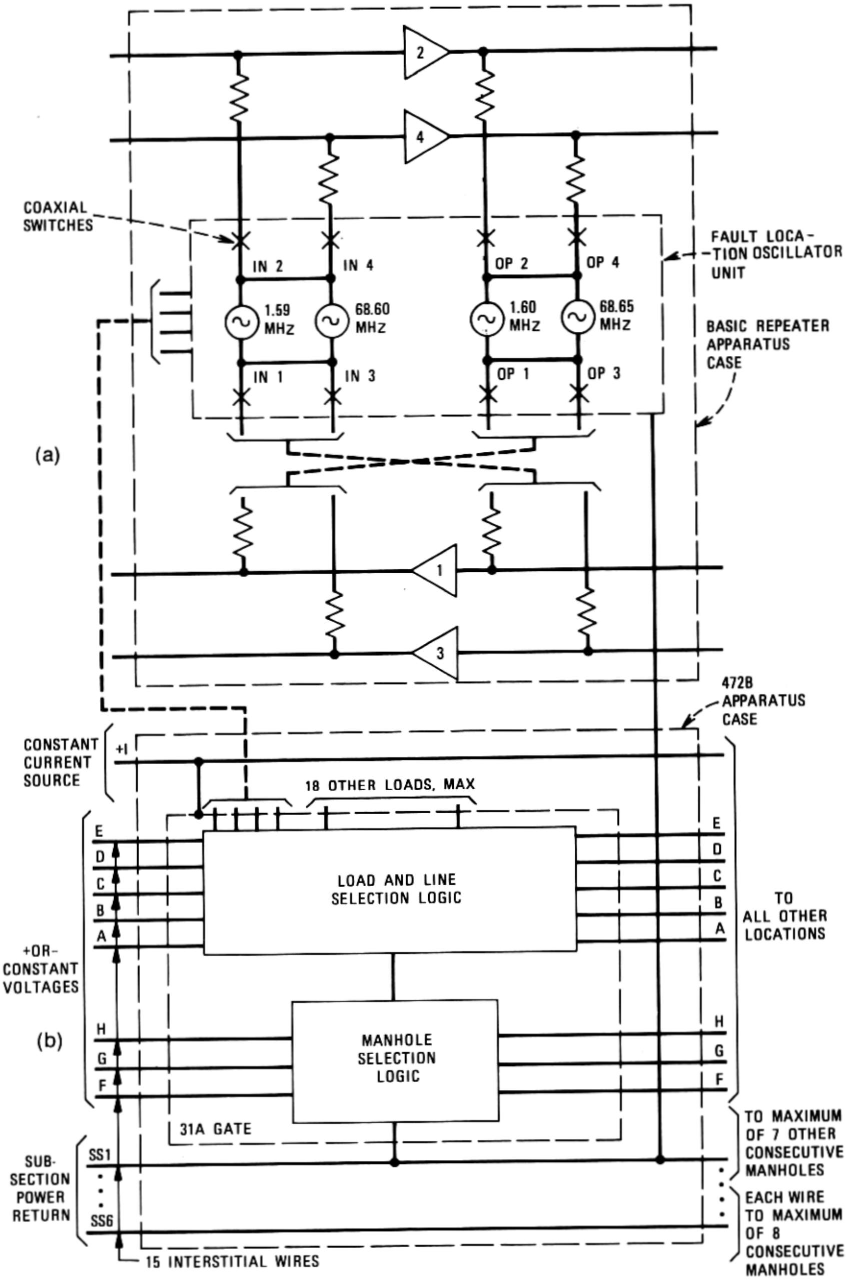

Fig. 7—Fault-location oscillator. (a) Manhole signal arrangement. (b) Manhole control arrangement.

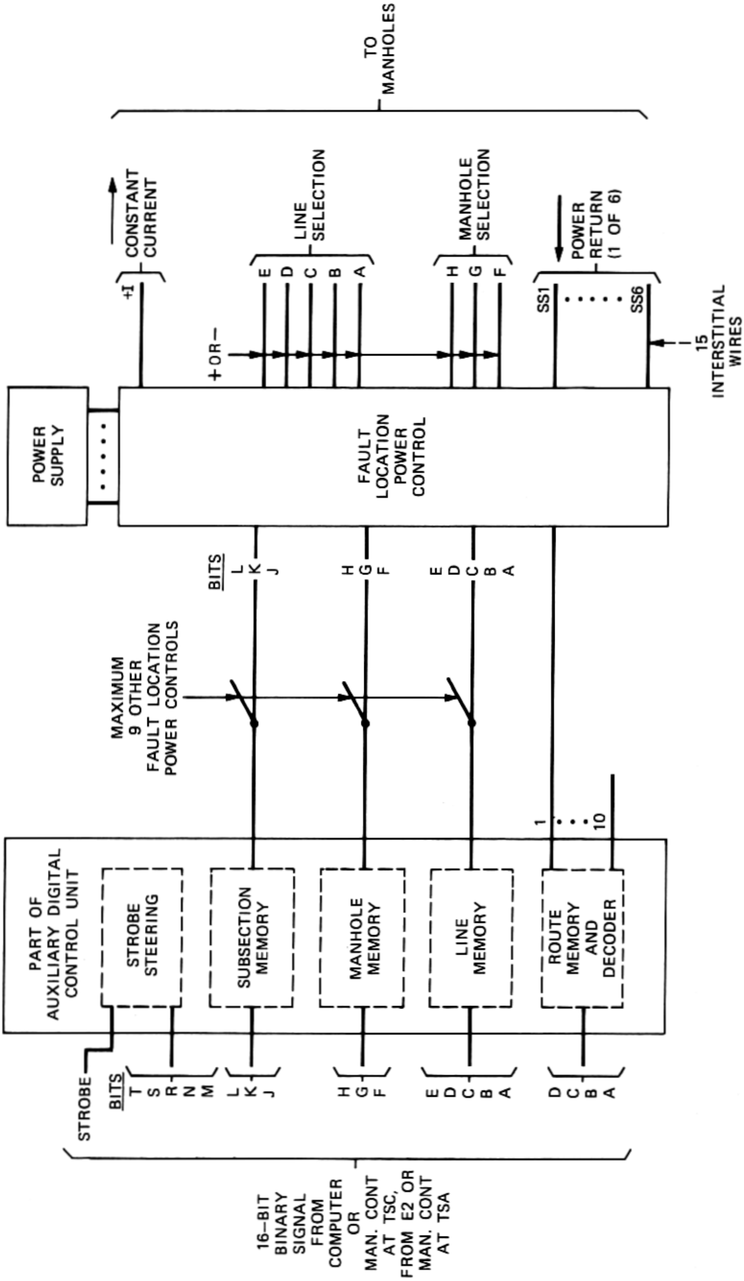

Fig. 8—Station fault-location control.

section. The 48-location capability (maximum) of the fault-location power arrangement permits one-end control in a significant fraction of the sidelegs and end links. Voltage drop in the interstitial wires and the permissible sending-end voltage limit the powering and control distance.

Fault-location-oscillator control typifies the various TSS control operations and is described in some detail as an example. Turning on a fault-location-oscillator unit involves the following sequence at a station (Fig. 8):

(*i*) Upon receiving an appropriate two-word sequence from the computer or manual control at a TSC location, or from the E2 system or manual control at a TSA location, the AUX DCU registers the selection (route, line, subsection, and manhole).

(*ii*) The AUX DCU sends continuous dc voltages through office wiring to operate a fault-location-oscillator power-control circuit.

(*iii*) The operated power-control circuit makes connections to an associated power supply, applies constant current to one interstitial wire ($+I$), applies binary-coded combinations of plus and minus voltages to eight interstitial wires (A to H), and establishes a connection to one of six subsection wires (SS1 to SS6) that provides a return path for the oscillator-load and control-signal currents.

With one possible exception, each subsection wire serves a group of eight consecutive locations. The last or highest numbered wire serves the most distant group, which may have fewer than eight locations. Most TSS control words use the four most significant bits (N, R, S, and T) of the 16 for strobe steering or addressing. Fault-location-oscillator turn-on also uses a fifth bit (M) for this purpose. The first fault-location control word conveys the route selection via bits A to D; and the second word conveys the selections of line via bits A to E, manhole via F to H, and subsection via J to L. A binary-to-decimal decoder provides a dc signal on one of 10 outputs to enable the power-control circuit associated with the desired route.

6.3 Fault-location power-control circuit

Transistor logic in the enabled power-control circuit operates miniature relays, which apply the appropriate control voltages to outgoing wires A to H and complete connections from the power supply to the $+I$ constant current lead and the desired subsection lead, SS1 to SS6.

The constant-voltage control signals applied to leads A to H are referenced to the subsection leads at the sending end. Positive voltage signifies a logical 1 and negative voltage a logical 0.

6.4 Manhole control logic

At each controlled location, a combinational logic circuit (31A gate) bridged across the interstitial control wires decodes the binary-coded combinations of positive and negative voltages on these leads and performs desired switching (Fig. 7b). The circuit consists of a tree of many simple transistor gates and transistor switches. A mechanical rotary switch assigns one of eight binary codes appearing on wires F, G, and H to each manhole in the subsection. The load- and line-selection logic part of the 31A gate responds to voltages on the A to E leads and selects a desired oscillator load. Coaxial windings in series with the oscillator loads enable directing the outputs to a desired line. Of the 32 binary combinations available with the five A to E bits, 22 only are used for oscillator turn-on and switching, corresponding to the maximum number of coaxials in a cable. Inhibit logic in the power-control circuit at the station prevents sending out an unused code, which could operate the 31A gate ambiguously.

The low current drains in the 31A gate decoding circuits permit individual control of fault-location oscillators at many different locations over a few wires of relatively small diameter. The turned-off locations draw almost negligible current. Since the coded control information is applied continuously while a load is turned on, the interstitial wires need not be loaded or delay equalized as for pulse signals. Use of memoryless logic contributes to reliability by minimizing the possibility of a sustained lockup at a remote point during a malfunction of the control system.

VII. POWER AND FUSING

Commercial 117-volt, 60-cycle power energizes the entire TSS. Should this source fail, an "essential" supply such as a local engine- or turbine-driven alternator carries the load after a few seconds of interruption. Since the TSS is off-line equipment not in the service transmission paths, the five-second or longer start-up time permitted in an "essential" category supply is tolerable.

Solid-state rectifier supplies provide the nominal 5- and 25-volt dc needed to operate the office logic and control circuits in the TSS. Fuses in the distribution paths to the various circuits provide overcurrent protection and convenient power-disconnect capability for maintenance. A blown fuse operates an alarm relay, which activates the local office alarms and furnishes an indication to the E2 Status Reporting and Control System for transmission to the E2 central.

VIII. FUNCTIONAL ARRANGEMENTS

The TSC equipment is assembled in a desk-type console having a writing area and a turret-type structure with three vertical panel regions just beyond the writing area (Fig. 4). Frequently used units have front-panel access. The left turret has the computer, the center turret the manual control panel, and the right turret the transmission-measuring system. The punched-tape reader is accessible in the left front, behind a hinged door under the writing area. The teletypewriter console is conveniently located to the left of the TSC operator position. Infrequently accessed units such as logic circuits and power supplies are mounted in the rear of the console behind hinged doors. Slides on the logic unit shelves facilitate access for maintenance.

A surveillance distribution bay located near the TSC console contains the function- and route-level coaxial switches for the switched access network, the associated control circuitry, and terminal blocks for connecting numerous station control wires to the TSC and line access bays.

The TSA bay contains essentially all the equipment of both the TSC console and the surveillance distribution bay except the computer, the punched-tape reader, and the transmission-measuring system. Personnel normally stand while operating TSA equipment locally. The same type of transmission-measuring system as that in a TSC is provided in a rolling console.

One line-access bay is associated with each route or cable entrance. It is located in the associated lineup of L5 transmit-receive bays and contains principally fault-location power and control equipment, the line-level switches and level-control unit of the switched access network, and the 31A gate for controlling fault-location oscillators in the station.

Except for the 31A gate, which uses discrete solid-state components, the various logic control circuits throughout the TSS contain mostly commercial integrated circuits assembled on plug-in printed wiring boards. Most mounting frameworks and panels are fabricated sheet aluminum.

IX. SOFTWARE CONSIDERATIONS

Software has been developed to exploit the computational and control facilities of the TSS computer (Section 3.1). Features are provided to minimize operator interaction and to process and present results in an easy-to-use format. Discussion of the software has been divided into the following categories.

(*i*) Operating system.
(*ii*) Application programs.
(*iii*) Data-base generation and administration.
(*iv*) Diagnostic system.

Computer programming is done in two languages, Assembly and FORTRAN. Assembly language is used primarily to write software drivers (routines to control peripheral devices), where the pseudo-machine-language code is needed to set up and complete input/output operations. The higher-level FORTRAN language is used for applications programs (complete routines for each surveillance activity), where advantage is taken of its speed and flexibility in program development.

A teletypewriter is used to enter system commands and program parameters. The teletypewriter is vendor-modified to allow bit-parallel transfer of information and independent control of the input, print, and punch functions.

The fault-location subsystem, switched access network, and test set are controlled directly by the computer at TSC locations. The computer remotely controls identical equipment at TSA locations via the E2 telemetry facilities.

To relieve the TSC operator of much punched-tape handling, a cassette-type digital magnetic tape unit is also interfaced with the computer; and programs for surveillance system operations are stored on magnetic tape. The magnetic tape unit can read or write on a data track or an address track and access tape files quickly. Tape positioning addresses are prerecorded on the address track of each cassette in proportion to the number of spindle revolutions. To access a file, the tape unit counts spindle revolutions as the file approaches at high speed and then reads the address track only during the last few revolutions to verify that the desired tape position has been reached.

A 64-word program, used to load other programs into the computer via the high-speed punched-tape reader, resides in a protected area of computer memory. This program is used, for example, to load the TSS bootstrap program, which, in turn, loads the operating system from magnetic tape.

The next few sections describe in more detail some programs provided with the TSC. Typical TSS software is given in Table I. Not discussed here are other programs, such as the editor, compiler, relo-

Table I — Typical TSS software

Operating System	Data Base

Basic Binary Loader
TSS Bootstrap
Directive Processor
Input/Output Control
Drivers for:
  Teletypewriter
  Paper Tape Reader
  Magnetic Tape Unit
  Test Set
  Fault Location Oscillator
  Switched Access Network
  E2 Telemetry
Formatters for:
  Teletypewriter
  Magnetic Tape Unit
Arithmetic Routines
 	
Applications
 	
Pilot Measurement
Fault Location
Line Measurement
JMX Measurement
Surveillance Library
General Purpose Measurements
	Generators for:
	  Pilot Measurement
	  Fault Location
	  Line Measurement
	  JMX Measurement
	  TSS Diagnostic
	
	Diagnostic
	
	TSS Diagnostic
	Teletypewriter
	Paper Tape Reader
	Magnetic Tape Unit
	E2 Telemetry
	Digital Control Unit
	AUX DCU
	Computer Diagnostic for:
	  Computer Instructions
	  Computer Memory
	  Hardware Functions

catable loader, and magnetic-tape storage programs, used to prepare and manufacture those programs that are a part of the TSC.

9.1 Operating system

The TSS operating system processes a small set of operator directives (Table II); and, to economize magnetic-tape space and reading time, it contains a set of subroutines expected to be used by all applications programs.

Table II — Operator directives

Command	Function
LOAD (NO.)	To recall and start an applications program stored on magnetic tape.
BEGIN	To restart the program currently in computer core.
RUN	To continue a program after a programmed pause for manual operations, or To retry certain input/output operations resulting in error messages.
REWIND	To rewind the magnetic tape cassette to clear leader.

Applications programs are stored on magnetic tape and can be recalled by file number into the computer for execution upon an operator-initiated LOAD (file number) command. At the termination of a program or after a programmed pause, the operator may request another program to be loaded and automatically started. He may restart the program currently in the computer core with the BEGIN command; or, in the case of a programmed pause for manual operations, he may cause the current program to continue with the RUN command. Also, using the RUN command, he may request retries on certain input/output operations that result in error messages. All commands for these operations are given by the operator at the teletypewriter.

Vendor-supplied, interrupt-compatible software drivers for the teletypewriter and magnetic tape and an input/output control program for policing requests to these devices are required to perform the operator directives. Software drivers have been developed by Bell Laboratories to control the E2 telemetry system, the fault-location subsystem, the switched access network, and the programmable test sets.

Vendor-supplied library routines such as a formatter for teletypewriter operations and arithmetic subroutines are included in the operating system because of frequent use by applications programs. Also included are Bell Laboratories developed FORTRAN-callable routines for teletypewriter plotting of measurement results and for controlling magnetic-tape operations. The last-mentioned routine permits reference measurement files and data-base files to be stored on magnetic tape and/or recalled under program control.

All the above routines are stored on magnetic tape as file number 2, which is automatically recalled by loading a short paper tape referred to as the TSS bootstrap. The teletypewriter prints the message *WHAT? when the computer is ready to accept an operator directive. At that time, the operator can request, for example, that a specific application program be loaded from magnetic tape and executed. File number 1 is reserved for a tape address directory, which contains the tape position of up to 67 other files for application programs, reference-measurement files, and data-base files.

9.2 Application programs

Use of a programmable computer permits quick and easy implementation of various maintenance activities. In general, an applications program is a complete sequence of computer instructions designed to monitor and evaluate a particular function of the L5 transmission equipment. For this purpose, the surveillance software includes the list of programs described in the succeeding sections.

9.2.1 *Surveillance library*

The surveillance library serves as a memory jog for the operator. It prints a list of program names and numbers and optionally will print detailed instructions regarding a specific program.

9.2.2 *Automated fault location*

After starting the automated fault-location program, the operator enters the set of cable routes (one or more power-feed sections), manholes, and the lines containing the repeaters to be interrogated. The computer recalls a data base from magnetic tape and checks for the presence of requested repeaters.

For each section of coaxial line requested, the computer initiates the following: (*i*) calibration of office trunks and coaxial switches in the line-access network between the RCVG LINE TST point (Figs. 6 and 9) and the receiver, (*ii*) access of the test point, (*iii*) turn-on of the oscillators for one repeater at a time, and (*iv*) measurement of the received set of tones. Repeater gain deviations, as derived from tone measurements, are compared with allowed limits and are printed only for out-of-limit repeaters unless the operator specifies, when starting the program, that all measured and derived data be printed. As each section of line is completed, the program releases the switched access network and the fault-location oscillators.

Figure 10 is a sample printout depicting a repeater in trouble. The teletypewriter bell and special characters in the printout provide audible and visual indications of anomalies and out-of-limit conditions. The operator may optionally obtain a teletypewriter plot of the received tone amplitudes as a function of distance along the cable.

9.2.3 *Pilot measurement*

In a composite message signal, pilot tones may be monitored by the pilot measurement program. The operator may select from the set of line, jumbogroup, mastergroup, and supergroup pilots. Pilots can automatically be measured at both ends of all JMX sections or optionally on a set of lines between two stations. The computer recalls a data base from magnetic tape and checks for allowable combinations of transmitting and receiving stations.

For each section requested, calibration of office trunks and switches is performed at both stations. At the transmitting end of a section, pilots are accessed and measured via the TRMTG LINE TST point (Fig. 9)

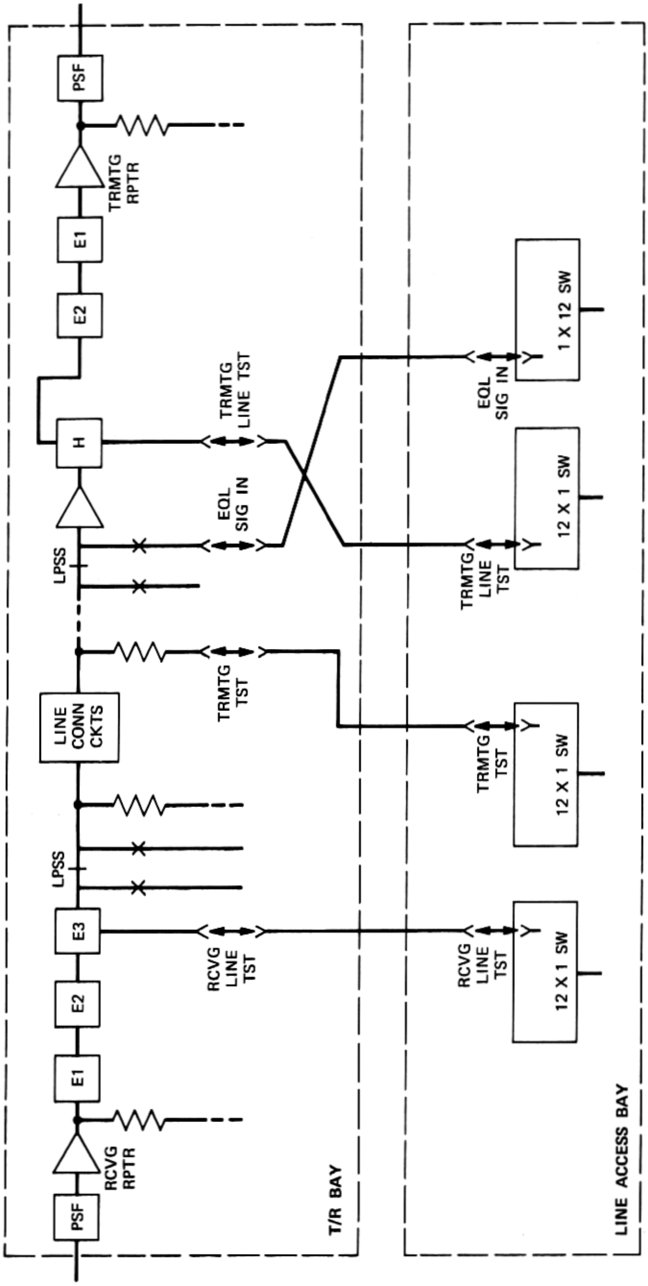

Fig. 9—Switched access network test points.

FAULT LOCATION

HEADING: DATE, TIME--? 11/28/73 10:15
ROUTE--? 0935
MANHOLES: FIRST, LAST--? 140 250
LINES: FIRST, LAST--? 501

ROUTE 935 LINE 501
11/28/73 10:15

MAN HOLE	1590. INPUT	1600. OUTPUT	LOW DIFF	OUT OF LIMITS	HIGH DIFF	68600. INPUT	68650. OUTPUT
140	-53.12	-53.12	.00		-.62	-53.39	-52.77
150	-53.58	-53.35	-.23		-.27	-53.93	-53.66
160	-53.43	-53.39	-.04		-.05	-54.10	-54.05
170	-53.37	-53.45	.08		-.31	-53.97	-53.66
180	-53.38	-53.72	.34		.38	-53.90	-54.28
190	-53.73	-53.78	.05		-.18	-55.02	-54.84
200	-53.27	-54.04	.77	***	4.23	-49.89	-54.12
210	-53.58	-53.67	.09		.00	-50.19	-50.19
220	-53.74	-53.74	.00		.39	-50.06	-50.45
230	-53.92	-53.96	.04		.50	-50.09	-50.59
240	-53.96	-53.92	-.04		.27	-50.51	-50.78
250	-54.03	-54.24	.21		-.07	-50.68	-50.61

*WHAT?

Fig. 10—Sample printout for automated fault-location program.

and, at the receiving end, via the RCVG LINE TST point. The difference in pilot amplitudes between the two stations is a measure of the gain characteristics of the line. Out-of-limit conditions or, optionally, all pilot amplitudes and differences are printed as a function of frequency. This printout can serve as an early indication of the need to re-equalize a line.

9.2.4 Line measurement

The line measurement program is used to determine the gain-frequency characteristic of a coaxial line with better accuracy and finer granularity than with pilot measurements. A sequence of tones is injected at the EQL SIG IN point in the station at the transmitting end of the desired line and measured at the RCVG LINE TST point in another station. Using the line-protection switching system, the operator must first take the line out of service and operate the message cut-off switch.

After taking the line out of service, the operator selects the transmitting and receiving stations, the line, and the set of frequencies, and decides whether or not a teletypewriter plot of the gain characteristic is required. Careful study of the printout can be used to evaluate the need for or results of equalizer adjustment. Measurements can be stored on magnetic tape for future comparison with historical data.

9.2.5 JMX measurement

Using the JMX measurement program, the operator can access the remote test switch for each jumbogroup and calibrate office trunks and coaxial switches. The program then measures carrier or jumbogroup and mastergroup pilots at 11 test points per jumbogroup. The data are compared with limits and with historical data. The historical data are updated on magnetic tape, and a printout of out-of-limit conditions is made.

9.2.6 General-purpose loss measurement

The general-purpose loss measurement program operates the transmission-measuring system in a TSC or a distant TSA under computer control to observe directly connected equipment or facilities in the selected station. Loss vs. frequency characteristics are printed and, optionally, plotted.

The operator can select the station address of the test set and all programmable functions of the test set, including the transmit amplitude and set of frequencies. Measurement averaging and reuse of calibration measurements are available.

9.3 Data-base generation and administration

Several application programs use data bases that are prepared by the data-base-generator program and stored on magnetic tape. The data bases determine the arrangement and extent of surveillance equipment to be controlled by a center location, as well as testing limits, etc. Separate data-base files are created for the automated fault location and JMX measurement programs, whereas the pilot and line measurement programs share a data-base file.

Each data-base-generator program is stored on magnetic tape and recalled by the operator using the same procedure as for other applications programs. The program simply asks questions that the operator must answer. For many questions, the operator may elect to use the preprogrammed answers. Questions are answered to define and correlate manhole designations, route numbers, coaxial lines equipped, telemetry addresses, the allowable range of measurement levels, test points available, etc. When all questions are answered, a separate database file containing this information is automatically created on magnetic tape. The operator may rerun the data-base-generator program at any time to verify or review his work by selecting a printout of the contents of the data-base file.

When new or additional equipment must be accounted for in the data-base file, area engineers provide the craft operator with completed forms for updating those files.

9.4 Diagnostic system

A separate set of programs, stored on a second magnetic tape, is dedicated to checking transmission-surveillance-related equipment for proper operation. These diagnostics are called into the computer using the TSS operating system and, if no errors are detected, control is returned to the operating system. Errors are indicated by a computer halt or message on the teletypewriter.

Separate programs are used to test the teletypewriter, high-speed punched-tape reader, digital control unit, and AUX DCU. The magnetic tape unit diagnostic is loaded from punched tape.

The computer diagnostic control program supervises the running of a large set of vendor-supplied computer diagnostics. There are diagnostics for testing all instruction types, core memory, and other computer hardware. Each computer diagnostic has an overlay associated with it to allow nonstop testing and multiple execution of each diagnostic. The control program interacts with the operator to determine the diagnostics to be run.

The TSS diagnostic program provides an indication of the health of the entire surveillance system by exercising all the hardware at the TSC and the TSA's. To narrow down possible trouble causes, each new phase of testing involves a minimum of previously untested equipment. When a problem is detected, more detailed testing is performed in the area affected. To determine what facilities are equipped in each office, the program shares a data base with the automated fault location program.

The degree to which the diagnostic system localizes troubles is established principally by the number and significance of the places where the statuses of transmission and logic signals can be determined automatically and remotely. The TSS automated diagnostic procedures generally localize a fault to a subsystem small enough for knowledgeable craft personnel to find the actual fault quickly.

X. L5 MAINTENANCE PLAN

Since the transmission surveillance system provides the potential for maintaining the L5 system on a network basis rather than as a series of independent stations, many somewhat complex and interrelated factors must be considered in the evolution of an overall maintenance plan to effectively realize this advantage. To begin with, a TSS controlled by a single TSC should be assigned to a portion of L5 route on a basis compatible with the overall administration of the system. The association of surveillance operations and alarm reporting, as provided by the E2 system, is another important consideration. A third consideration is that of defining the boundary between adjacent surveillance systems along a route. Finally, in developing an overall maintenance plan, intervals for performing routine tasks must be determined by carefully considering such factors as system size, measurement speed, need for update, and output requirements. Of course, considerable blocks of free time must be left for performing demand-type measurements to locate a trouble or to characterize performance, as a result of an external stimulus such as a line switch, E2 alarm, or a line-equalization adjustment.

10.1 Administration aspects

The rules for the layout of a transmission surveillance system are determined as much by administrative and management aspects as by any hardware constraints. Presently, the E2 data facility has a capacity of 16 remote stations, which limits a TSS to 15 TSA stations and one controlling TSC station. The resulting system bound of this number of stations, likely near 800 to 900 route miles, probably approaches the limit that can be monitored effectively by a single TSC. Other considerations include: (*i*) AT&T-Long Lines area boundaries, (*ii*) planned E2 alarm reporting and other maintenance arrangements, and (*iii*) location of strategic stations along the route.

Once a TSS arrangement has been established within a region, it is imperative that a single E2 data facility interconnect all the stations served by the TSS to provide data-transfer capability to and from the TSC. Generally, this data facility will be time-shared with normal E2 alarm polling operations.

Judicious TSC placement enhances the effectiveness of a TSS. Several factors should be considered in selecting the station. It should (*i*) be on the associated L5 route, (*ii*) be a major, manned facility, (*iii*) have significance in the area maintenance plan, and (*iv*) be a junction point with signal processing (multiplex). Examination of the TSS area and consideration of these points should lead to an appropriate TSC placement. Another highly desirable goal is to colocate the TSC and E2 central, if at all possible, since this would centralize all major maintenance operations. It is important that the TSC location be manned 24 hours a day. Although it is possible to control the TSC computer over a data set/TTY link from another office, perhaps off the route, it is not considered desirable unless craft personnel thoroughly familiar with L5 operations are available to interpret performance data.

10.2 Measurement routines

The criteria for obtaining a viable TSS layout have been given (Section 10.1), and, if availability of computer software is assumed, the role of the surveillance system in the overall maintenance scheme for the L5 system can be defined. As previously discussed, the TSS performs transmission measurements for the purposes of maintaining a high level of performance and locating troubles. These operations fall into two categories:

(*i*) Demand-type measurements.
(*ii*) Routines.

The demand measurements are unscheduled and the need is generally spontaneous, resulting from a trouble condition. The routine operations, where the words *transmission surveillance* apply, are scheduled to realize continued monitoring of performance and to spot any deteriorating conditions. Procedures and associated software for an initial L5 maintenance plan have been based on experience gained during the L5 field trial, in the early stages of the initial system turn-up, and in discussions with AT&T personnel. This plan, when implemented, will assist in maintaining a high quality of service on the L5 system. In simple terms, the plan consists of:

(*i*) Pilot measurements: Transmitted and received line and mastergroup pilots will be measured daily between all signal-processing points (terminal stations) to characterize the transmission performance of the coaxial lines.
(*ii*) Fault location runs: All line repeaters will be checked weekly, and out-of-limit conditions and regulating repeater gain changes will be printed out.
(*iii*) Jumbogroup multiplex measurements: Test points in all JMX equipment will be monitored on a weekly basis and out-of-limit conditions will be printed out.
(*iv*) Line gain/frequency measurements: Detailed measurements, on an out-of-service basis, of the frequency characteristic of a coaxial line will be made following any repair or realignment operation to verify proper performance.

(*v*) TSS diagnostics: Proper operation of the surveillance system itself will be routinely checked on a weekly basis. This includes an overall test at each station to pinpoint any problems in the access network, control circuits, or test equipment as well as diagnostic tests of the computer and associated peripherals at the TSC.

According to calculations for the 815-route-mile initial system between Lillyville, Pa., and Hillsboro, Mo., these routines should use about 50 percent of the total hours in a seven-day week when all 22 tubes are in service. The calculations have assumed that only a few pilot measurements are needed beyond those in the daily overall check between terminal stations to associate a trouble with a particular power-feed section. Methods are being investigated to reduce the measurement times before systems reach full capacity so as to free the TSC for troubleshooting operations when necessary. Furthermore, the presently provided facilities are probably just the beginning of automated transmission-measuring capability. As experience is gained with centralized and automated maintenance and more sophisticated test equipment becomes available, the role of the TSS will grow—perhaps into the areas of acceptance testing, trouble shooting of individual equipment units, and interfacing with other evolving maintenance systems.

XI. ACKNOWLEDGMENTS

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