Copyright © 1978 American Telephone and Telegraph Company
THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 57, No. 4, April 1978
Printed in U.S.A.

Loop Plant Electronics:

The Loop Switching System

By N. G. AVANEAS and J. M. BROWN

(Manuscript received October 26, 1977)

A new system for achieving more efficient use of cable pairs, the Loop Switching System (LSS), has been developed which uses a microcomputer to control the call processing, traffic measurement and display, system maintenance, and manual testing. The LSS, which works with any central office, switches 96 subscriber lines onto 32 voice frequency trunk pairs by means of a graded multiple space division switching network at the remote terminal (RT) and expands the trunks back into the individual line appearances at the central office terminal (COT) located within a central office. An additional 96 lines and 32 trunks can be added to the LSS, either at the same RT or a second RT on a different cable route, using the same COT common control equipment. Control of the RT is via two standard voice-frequency pairs used for a full-duplex data link. This four-wire data link, operating at 1250 bits per second, is used to transmit concentrator connection orders from the COT to the RT, service request information from the RT to the COT, and other information pertaining to LSS maintenance and alarms. This paper describes the system features, operational characteristics, and circuit designs used in the LSS system.

I. THE HISTORY OF LINE CONCENTRATORS

The concept of using subscriber line concentrators to reduce the cost of subscribers loops has been considered for many years. As early as 1908, development engineers proposed the use of remote line concentrators.[1] Line concentrator design effort[2–8] by the Bell System and other companies throughout the world has continued ever since on both electromechanical and, more recently, all electronic versions. Designs for use with specific central offices avoid the expansion stage of switching in the central office terminal needed by universal line concentrators which work with any central office. They, therefore, can achieve lower costs in a more limited market area. However, past field experience has been with concentration of the universal type.

Early universal line concentrators suffered from the technical difficulties of maintaining complex switching equipment remote from the central office. The harsh outside plant environment also created a number of electrical and physical reliability problems. The traffic capacity was inadequate to handle the wide variations in traffic generated by small groups of subscribers, resulting in an excessive number of blocked calls. Consequently, the use of line concentrators by the telephone companies fell into disfavor.

A new breed of electronic concentrators has solved these basic problems and began to reverse these attitudes. Introduced in the early 1970's was the Subscriber Loop Multiplex (*SLM*™) system,[9] designed by Bell Laboratories and manufactured by Western Electric. The *SLM* system concentrates 80 subscriber lines on 24 T1 carrier derived channels. To date, 190 *SLM* systems have been installed.

The *SLM* system demonstrates that electronic concentrator systems for use in the outside plant are reliable and can be maintained by the telephone companies. Trouble report rate studies of customers served by the *SLM* system show that the service is comparable to that of customers served by standard voice frequency loops.

One of the most significant results of the *SLM* field experience is that there have been no traffic problems. The *SLM* system is conservatively designed to handle more than twice the customer traffic level compared to previous concentrators.

The experience gained from the *SLM* development formed the basis for the development of the *SLC*™-40 carrier system[10] and the Loop Switching System (LSS), the latter being the subject of this paper. Both the *SLC*-40 system and the LSS system provide service more economically than the *SLM* system. However, the *SLM* system played an important role in establishing the practicality of both digital transmission and modern electronically controlled line concentration in the loop plant.

II. THE LSS SYSTEM

This section describes the features of the LSS system and the reasons for certain design decisions. Figures 1 and 2 illustrate the LSS configuration for one-RT and for two-RT operation.

2.1 LSS applications

The LSS system provides feeder cable relief in both permanent and temporary applications. Generally, permanent applications will be to serve growth in suburban and rural areas with clusters of a hundred or

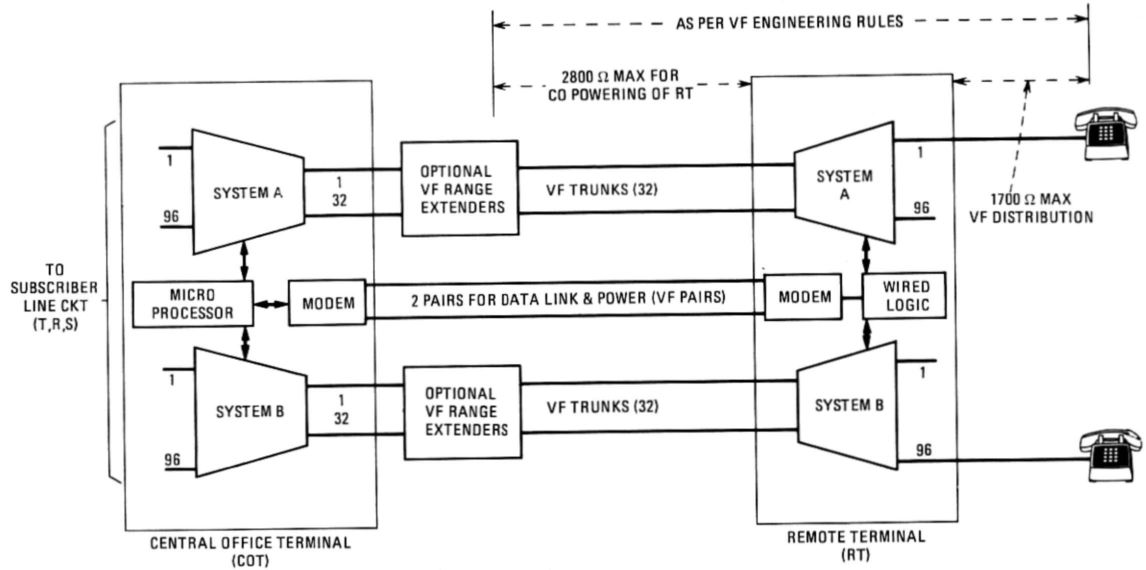


Fig. 1—Typical LSS system layout, one RT.

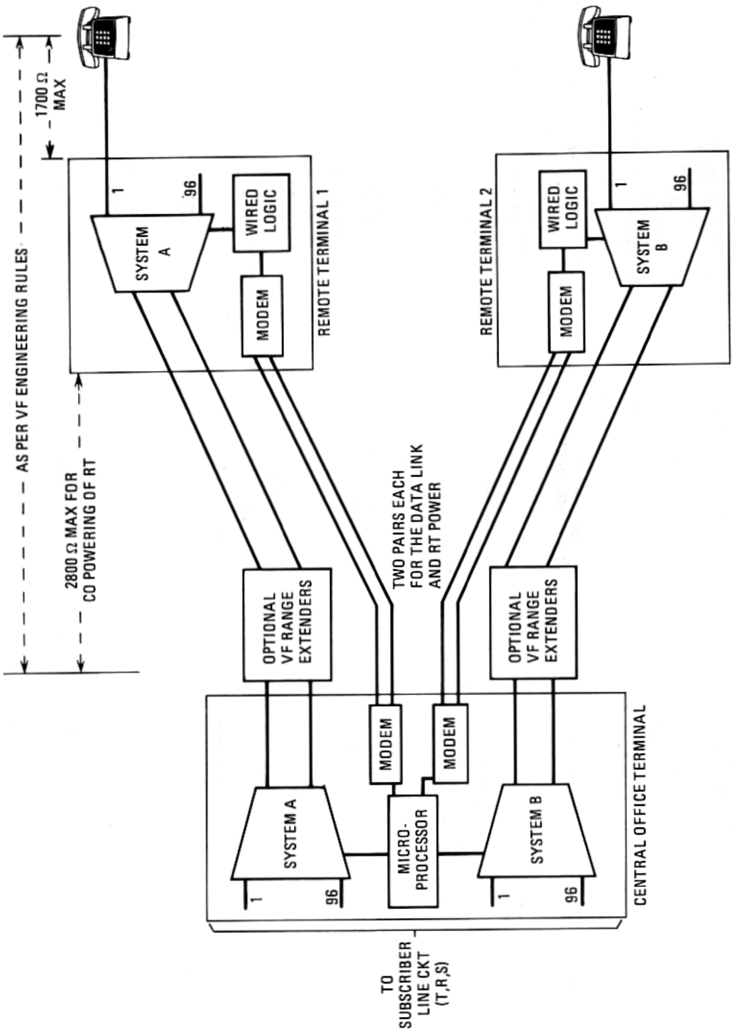


Fig. 2—Typical LSS system layout, two RTs.

more customers. Mobile home parks, rural subdivisions, and resort areas typically have that characteristic. Temporary application to defer cable and/or structure will be found in suburban and rural areas. Another application will be for wire center deferral, particularly in conjunction with subscriber carrier for the trunks.

2.2 Central office interface

The LSS system is designed as a universal line concentrator to interface with step-by-step (SXS), No. 5 Crossbar (#5XB), and ESS central offices. Sleeve lead control chosen for the LSS system has the strong advantage of compatibility with automatic line insulation testing (ALIT) and repair service bureau testing of subscriber lines with the local test desk or the Line Status Verifier (LSV). Systems with ringing detectors and loop current detectors cannot be tested without ringing phones.

Interfacing with SXS and #5XB central offices is accomplished by terminating tip, ring, and sleeve on the LSS central office terminal (COT) for each subscriber line. Interfacing with ESS offices also requires ESS signal distributor applique circuits to provide sleeve leads and ESS remote master scanner applique circuits for transmitting trunk busy information from LSS to ESS. To associate these ESS circuits with specific subscriber lines, ten words per line are required in the line translator program store of No. 1 ESS and a lesser number of words in No. 2 ESS and No. 3 ESS.

2.3 Facility requirements

In its simplest application, LSS uses ordinary voice frequency cable pairs for trunks and the distribution plant beyond the RT. This avoids any plant conditioning, achieves the lowest cost, and is compatible with existing and future repair service bureau functions. The distribution pairs and the station set together can have a resistance of 2000 ohms limited only by service request detection by the RT.

The LSS system adds into the subscriber loop only relay contacts and 40Ω of resistance to protect the contacts from surges. Ringing signals and battery are supplied by the central office and not by the LSS system. Therefore, the total subscriber loop length from the COT to the customer station is limited by the standard signaling and transmission requirements for subscriber loops from the serving office. Range extension devices[11] such as the 5A REG or the 2A REG can be used on the trunks of the concentrator to obtain additional range in a manner similar to nonconcentrated loops.

Carrier systems such as the *SLC*-40 system also may be used to provide the concentrator trunks for situations requiring still greater pair gains, i.e., when feeder cables are too small to provide the necessary trunk pairs in multiple LSS installations. However, the economics of this combination will be somewhat less attractive than the LSS system alone.

2.4 System powering arrangements

A basic design goal was to power the RT from the COT for a distance of up to 2800Ω of loop resistance (80 kft of 22-gauge cable). This distance was chosen to be consistent with voice frequency engineering rules for loops with range extenders with gain (REGs). Using +135 and −135 Vdc from the central office, the highest dc voltages permitted, a simplex powering arrangement using two pairs of wires can deliver about 13 watts to the remote terminal. A new dc-to-dc converter was designed that is 80 percent efficient and derives a useful low voltage power of ten watts for the circuits in the remote terminal. This limitation of ten watts of power requires a latching switching network and CMOS and low-power TTL logic circuits in the common control.

The simplex power for the RT is generated in the COT from a current limited (95 mA) ±135 Vdc 30-watt converter operating from the −48 Vdc central office battery. Alternatively, this simplex power may be obtained from the ±130 Vdc common systems central office battery supply in conjunction with a 95-mA series regulator. For this latter case, the RT powering range is 1800Ω of loop resistance (900Ω of simplex resistance) instead of 2800Ω because of the lower available voltage and the voltage drop in the auxiliary series regulator.

When the RT is too far from the COT to be supplied from the central office or if the trunks and data link are carrier derived, the RT may be powered from a locally available −48 Vdc common systems supply in a small hut or building or from commercial 117 Vac 60-Hz power brought into the cabinet. If commercial power is used, batteries are required to maintain equipment operation for approximately 10 hours after a commercial power failure.

The COT of the LSS is powered from a low voltage converter which delivers about 100 watts to the COT at ±5 Vdc and −24 Vdc from the −48 Vdc central office battery.

2.5 Data link

The same two pairs used to power the remote terminal are also used for a full duplex data link. Modems similar to those used in 202 type data sets convert the low level logic signals to 1250 bits per second frequency shift keying (FSK) analog signals for transmission over the data link. This bit rate allows the use of standard voice grade cable pairs with no special conditioning for the maximum distances envisioned.

2.6 Maintenance

A major design objective was a trouble rate (troubles per 100 stations per month), service availability (downtime), and maintenance costs for customer lines served by the LSS system similar to that of equivalent cable service.[12] To achieve this goal, the LSS is provided with important maintenance features including continuous monitoring of system performance, alarm displays at the COT which indicate system status and any defective plug-in units, and automatic troubleshooting procedures which aid in maintaining and restoring service. Some of the routine maintenance functions performed automatically by LSS include the following:

(*i*) Each time a trunk is assigned to a line, the trunk assignment is verified, and the trunk and switching network are tested for leakage paths worse than 50 kΩ and for continuity. Failure of the test initiates a new trunk assignment and causes a minor alarm.

(*ii*) Data transmission between the COT and RT is continuously checked for accuracy.

(*iii*) Once a day, all relays are operated and released to insure that they are working satisfactorily.

(*iv*) On a routine basis, much of the per-line and common control circuitry is tested for proper performance.

If any of these tests fail, an appropriate alarm is brought in.

The following troubleshooting procedures are implemented automatically when the routine maintenance tests show a failure:

(*i*) Should the LSS be unable to process a call, the system transfers automatically from the main data link pairs to an alternate set of pairs consisting of LSS trunk pairs 31 and 32. If it is not possible to communicate with the RT via either the main or alternate data link pairs, all of the critical common control plug-in units in the COT are tested automatically, and the appropriate plug-in and central office alarms are raised.

(*ii*) When COT power is restored after a failure or a critical plug-in unit is replaced, the LSS automatically reinitializes itself by disconnecting all idle lines and reconnecting all active lines (sleeve grounded).

(*iii*) When a line unit is plugged in at the COT all lines on that unit are disconnected in order to ensure that the switching network is in an initial state.

The following manual tests can be performed at the LSS central office terminal:

(*i*) When any of the common control units in the COT are replaced, the automatic troubleshooting procedures can be initiated manually to verify that the new units are functioning.

(*ii*) The leakage and continuity tests for trunks and the switching network can be initiated manually on a desired line for all the trunks accessed by that line.

(*iii*) Any trunk can be removed from service by operating a trunk make-busy switch.

(*iv*) The number of busy trunks can be read out on a numeric display.

(*v*) The trunk connected to a specific working line can be read out.

(*vi*) All indicator lights can be tested.

Remote interrogation of the alarm indications can be made over the DDD network by the use of an optional COT maintenance unit. The types of alarms are COT, RT1, and RT2 major and minor. The alarm status is conveyed by means of a series of six sequential tones either modulated or unmodulated depending on the alarm state.

At the remote terminal, a leakage and continuity test can be initiated manually for the switching network and the idle lines and trunks associated with a selected line unit.

2.7 Traffic capacity, monitoring, and administration

The LSS is designed to provide a traffic handling capability similar to that of the *SLM* system. Specifically, for 6 ccs per line and 25 percent intracalling, the probability of blocking is 0.5 percent when the LSS is fully loaded. Both rural and suburban residential traffic measurements indicate that this level of traffic and intracalling is reached only on the four busiest hours of the year.[13]

The traffic characteristics of the LSS are designed far more conservatively than the 10-trunk, 50-line 1A concentrator. For example, in order to achieve the same traffic performance as the LSS, the 1A would have to be limited to about 22 lines instead of 50.

The LSS traffic monitoring capability is similar to that of the *SLM* system. The peak hourly traffic and the total number of calls blocked since the storage registers were last reset is displayed on a test and display unit at the COT. By means of the optional traffic unit, an office traffic usage recorder register can be connected to the LSS for remote monitoring of LSS traffic. However, frequent traffic measurements are really only justified during the initial loading procedures.

Traffic administration procedures are similar to those already approved for *SLM*. In brief, the LSS can be loaded with 70 main stations initially. Additional loading is based on the weekly peak traffic for four weeks. It is expected that in over 90 percent of the applications of LSS, the traffic administration procedures will permit fully loading each LSS system with 96 lines on 32 trunks.

After these initial procedures, blocked calls are monitored automatically. A minor alarm comes on if the number and frequency of blocked calls exceeds service objectives.

The same high level of traffic performance could have been engineered using intra-switching and fewer trunks. Studies showed that at 25 percent intracalling this approach would have cost more per net pair gained for the type of switching network used in the LSS, would have degraded badly were the intracalling rate lower than predicted, would not allow LSS lines to utilize central office custom calling features and would have required local rather than central office powering of the RT. Therefore, intracalling is not provided by LSS in spite of a certain emotional appeal.

2.8 The switching network

2.8.1 Configurations

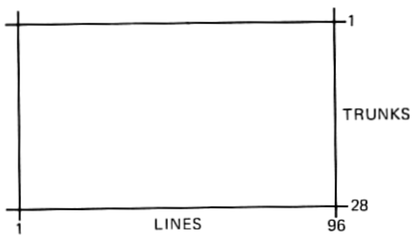
There are three basic types of switching networks which are candidates for use in line concentrators: one-stage, two-stage, and graded multiple.[14] These networks are shown in Figs. 3, 4, and 5.

For the traffic levels described in Section 2.7, computer simulation shows that the two-stage design shown in Fig. 4 is just as efficient as a one-stage switch. Twenty-eight trunks are required for each, yet the two-stage network requires only three-eighths as many crosspoints as the one-stage switch.

For the graded multiple network of Fig. 5, four lines have access to seven trunks; the trunks are multipled to other groups of four lines in a manner maximizing the traffic capacity. But because of the limited access of the lines to the trunks, it is less efficient than a one- or two-stage network. Hence, 32 trunks must be used instead of 28 for the same traffic capacity again as determined by computer simulation.

However, the graded multiple shown in Fig. 5 has ⅔ of the number of crosspoints compared to the two-stage network of Fig. 4, and ¼ of the crosspoints of the one-stage network. The lower cost of the graded multiple network, due to the lesser number of crosspoints and simpler control, offsets the traffic inefficiency, equivalent to four trunk pairs. Hence, the fully loaded price per pair gained of a graded multiple concentrator is about the same as a concentrator with a two-stage network.

The graded multiple network has an advantage for low growth applications because of a lower getting started cost. The reason is that the



CROSSPOINTS = 96 X 28 = 2688

Fig. 3—One-stage network.

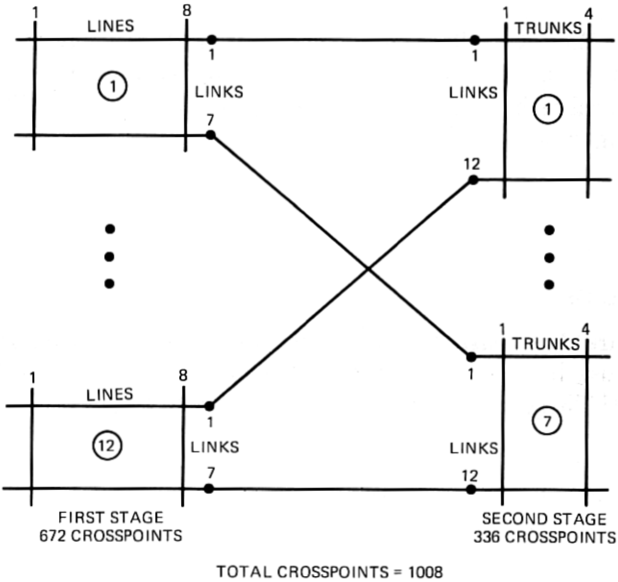


Fig. 4—Two-stage network.

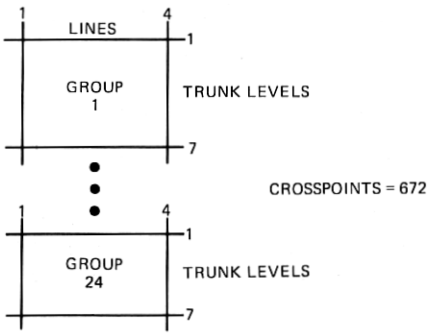


Fig. 5—Graded multiple.

entire second stage of the two-stage network plus the control circuitry must be installed initially. Only the first stage of the two-stage network but all of the graded multiple network may be added as a function of line growth. Also, the graded multiple can be organized into modules for easy maintenance, with all the crosspoints for eight lines on a single plug-in unit. Hence, the LSS uses the graded multiple network of Fig. 5.

The seven trunks out of a total of 32 trunks accessed by each line group are called level 1, level 2, . . . , level 7. Assignment priority is sequential in level, with level 1 having the highest priority and level 7 the lowest. A trunk wired to a given level in one line group is multipled to only the same level of other groups. Six trunks are used for level 1 and level 2, with each trunk multipled between four line groups. Four trunks each are used for levels 3 through 7 with each of these trunks multipled between six line groups. The lowest priority level is almost never assigned except when traffic overload is imminent. In order to equalize trunk usage, every 24 hours the priority sequence alternates between levels 1, 2, 3, 4, 5, 6, 7 and levels 1, 2, 7, 6, 5, 4, 3.

Trunks are tested for leakage and continuity prior to connection to avoid assigning a defective trunk (see Section 2.6). If a trunk should test good but is defective for reasons other than leakage or continuity, e.g., noise, a service problem may develop during light traffic conditions. To avoid this "killer trunk" problem, assignment priorities alternate between level 1 and level 2 after every call. This arrangement prevents always assigning a defective level 1 trunk to the same line making successive originations.

2.8.2 Crosspoints

Switching crosspoints may be broadly classed as either the semiconductor type or the electromechanical type. For use in a line concentrator subject to a rather harsh environment, e.g., lightning surges, power line crosses, ringing voltage, and dc currents, only the electromechanical type of crosspoints can meet the environmental requirements without the use of special per line circuitry.

Both sealed and nonsealed types of electromechanical crosspoints are available. The sealed types offer protection from dirt and humidity but the ones available today from Western Electric are somewhat less rugged compared to the nonsealed types; the sealed contacts should not be used to switch dc in the transmission path and have one-tenth the surge current capability.

An example of sealed crosspoints is the remreed switch used in ESS systems. The remreed switches consist of a matrix of magnetically latching reed type make contacts sealed in a glass envelope. These sealed contacts contain some water vapor to help prevent the hard gold contacts from sticking at high temperatures. But the water vapor presents a finite probability of contact freezing at the low temperatures to which a concentrator RT may be subjected. Hence, remreed switches in the form available today were eliminated from further consideration for LSS.

The nonsealed category of crosspoints includes wire spring and flat spring relays, crossbar switches, and stepping switches. Of these, the Western Electric miniature magnetically latching wire spring relay was clearly the best and was chosen as the switching crosspoint for LSS. This relay is about one cubic inch and contains six transfer contacts. The latching feature is consistent with the low power requirement for a batteryless, simplex-powered RT. These relays can handle 30 A surge currents; hence, they are far more rugged than any of the sealed reed relays.

Extensive testing[15] has been performed on these relays at room temperature in the presence of dust, moisture, and various gases such as sulfur dioxide and hydrogen sulfide. Other tests were performed at high humidity over a −40°C to +70°C temperature range. These tests clearly establish that adequate protection from such an environment is obtained when the relays are mounted on a printed wiring board attached to a die cast aluminum frame with an aluminum cover. Gasketing around the connectors insures that particles greater than 20 microns are filtered out.

2.8.3 The LSS switching network

As shown in Fig. 6, three of these multicontact relays (K1, K2, K3) wired in a tree configuration provide each line with access to one of seven trunks. The eighth port of this tree network is connected to a per-line service request detector at the RT and a ring trip and overflow circuit at the COT. Overflow is applied to a line in the COT when all of the seven accessible trunks are busy. A fourth relay (K4), a nonlatching miniature flat spring relay, serves as a network isolating relay. This relay isolates the line from the switching network during the switching of the three per-line relays in order to avoid objectionable transients on the line and on working trunks. Contacts on the K4 relays at the RT and COT also are used to check the quality of the assigned trunk and the switching network just prior to connecting the line. This preconnection trunk testing ensures that a defective trunk is not assigned to a subscriber.

In order to confirm that the desired line relays have been operated (or released) and that a line is connected to the desired trunk, an additional contact on each of the relays K1, K2, and K3 provides a voltage on one of three corresponding confirmation buses if the relay is latched while relay K4 is operated. The confirmation buses are multipled to all line networks. The concentrator common control interrogates these confirmation buses and initiates corrective action if the actual trunk connection differs from the intended connection.

As shown in Fig. 7, one end of each of the three network relay coils for each line is connected to three common drive buses. The other end of each of these relay coils is connected to three common return buses through make contacts on the K4. A specific line relay network is connected to the six common buses by simply operating the desired line isolating relay (K4).

Reliable operation of the switching network is obtained by carefully controlling the latching and releasing currents for the latching relays. One set of three current regulators supply the latching current of −140 mA ±15 percent for 16 ms for the K1, K2 and K3 relays. Another set of three current regulators supply the releasing current of +35 mA ±15% for 52 ms. The appropriate combinations of latch and release current

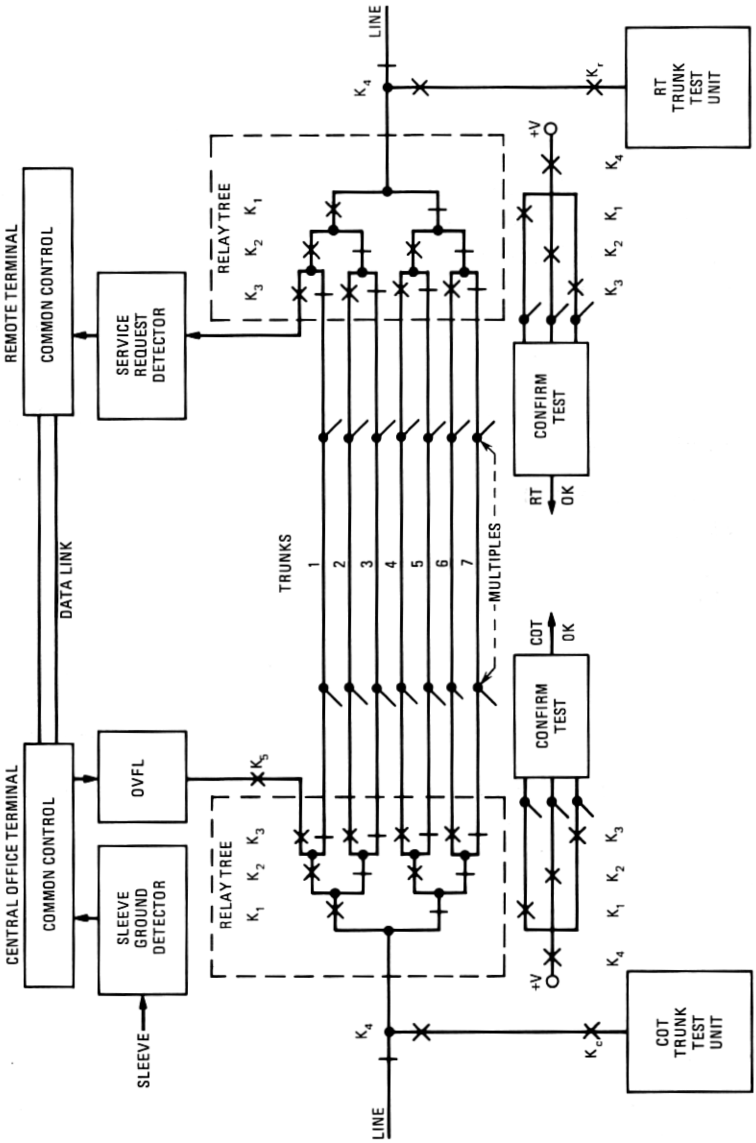


Fig. 6—The LSS switching network.

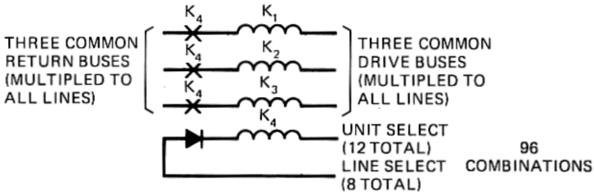


Fig. 7—Switching network control for one line.

are supplied to the three relays depending upon the desired trunk connection contained in a 3-bit trunk code supplied by the processor. Sensing circuits within this "network controller" monitor relay drive current. Incorrect current indications result in a major alarm and a network controller failure indication on an alarm unit.

The K4 relay is also operated by means of a current regulated to -32 mA ± 10 percent. The maximum operate time is less than 32 ms. The relay releases in less than 52 ms after the drive current is removed since it is nonlatching. The appropriate K4 relay (one out of 192) is connected to this drive signal by means of a decoding network in the network controller which receives an 8-bit line number from the processor.

III. SYSTEM OPERATION

3.1 Call processing

A stored program controller at the COT implements the call processing algorithm and communicates with a relatively simple wired logic processor at the RT via the data link. The basic function of the common control circuitry is to connect a trunk in accordance with the results of an RT scan of the service request detectors and a COT scan of the sleeve lead status. A trunk is disconnected only when a sleeve lead is ungrounded.

Three types of orders are transmitted by the processor to the RT: a scan order, a network order, and an activate order. Scanning is performed at all times except when interrupted during the connection and disconnection of a trunk. The response of the RT to each of these orders is discussed in turn.

When the RT receives a scan order, the RT transmits the number of the line requesting service and, for redundancy, its binary complement. If differences occur between the line number and its complement, the COT rejects the scan result and initiates another scan order.

When a network order is received by the RT, it is stored in a register and also is returned to the COT for comparison with the original transmission. If there are no errors, the COT transmits an activate order to the RT which triggers the RT into implementing the network order, e.g., connecting a trunk to a line.

After the trunk is connected to a line, the RT returns the confirmation answer to the COT. This confirmation answer, which indicates the actual line number and trunk level connected to the line, is compared with the original network order for consistency. Corrective action is initiated if differences exist.

If two RTs are connected with one COT via two separate data links, the COT scans first one RT and then the other for call originations. If an origination is discovered in one RT, the necessary network order is transmitted to that RT only. Scanning then resumes with the other RT.

Data transmission between the COT and RT is asynchronous, i.e., information is not transmitted in predetermined and regular time slots. Instead, orders and answers to orders are recognized by special preambles. These orders and answers are shown in Fig. 8.

The timing associated with the LSS call processing algorithm is shown in Fig. 9. For a terminating call, a trunk is connected within about 300 ms after the sleeve lead is grounded. For an originating call, a trunk is connected within about 400 ms after a station set goes off-hook. Originating call times include 100 ms for the service request detector; this delay is caused by a filter used to reject 60 Hz longitudinal signals.

3.2 COT processor

The LSS is controlled by PROCON, a microprocessor manufactured by Western Electric. The LSS uses the 8-bit data, 24-bit instruction PROCON with a 500-kHz clock. Every instruction is fetched and executed in one clock period (2 μs).

To control LSS, 5700 words of ROM (instructions) and 512 words of RAM (data) are required. Approximately 2000 words of program instruction are used for basic call processing and 3,700 words are used for automatic trouble locating, manual testing, alarming, and traffic measurements.

As shown in Fig. 10, the separate 8-bit data input and output buses of PROCON are combined into an 8-bit I/O data bus by means of hardware external to PROCON. Data is transferred between PROCON and the peripheral units by means of this I/O bus.

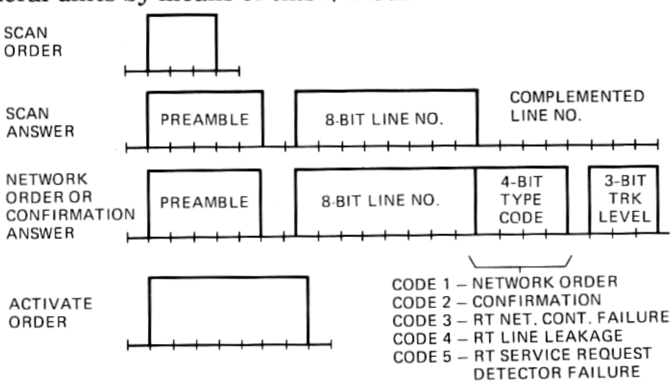
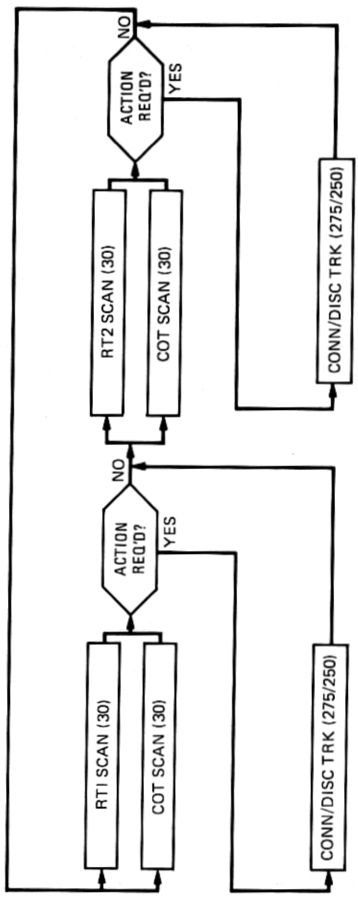


Fig. 8—Data organization for orders and answers.



NOTE: ALL NUMBERS IN MILLISECONDS (MS)

CONNECTION TIME* 275 – 335
DISCONNECT TIME 250 – 280

*FOR CALLS ORIGINATING AT THE RT, ADD APPROXIMATELY 100MS FOR THE TIME DELAY OF THE SERVICE REQUEST DETECTOR. IF TRUNKS ARE DERIVED FROM SLC-40 OR USE THE 5A RANGE EXTENDER, ADD THE TIME DELAY CONTRIBUTED BY THESE UNITS.

Fig. 9—Call processing times.

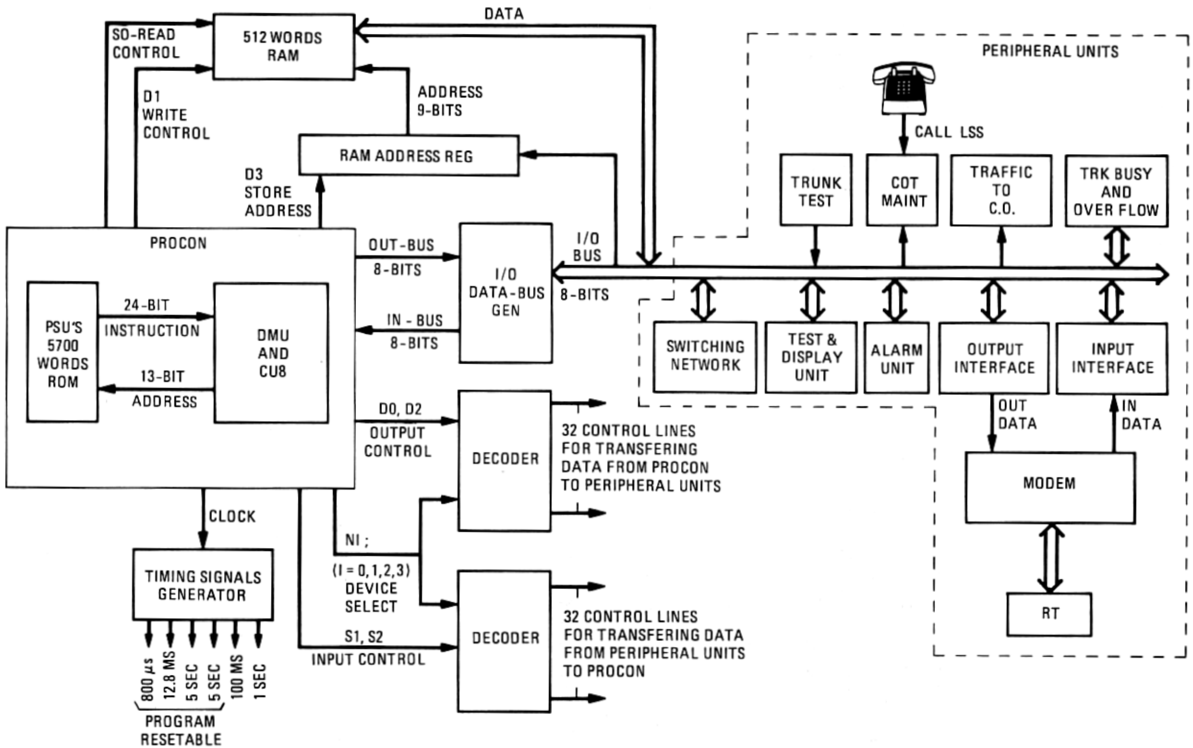


Fig. 10—Block diagram showing communication paths between PROCON, COT units, and the RT.

Thirty-two output control signals are used to transfer data selectively via the I/O bus from PROCON to various other peripheral units. The PROCON destination signals D0 and D2 and four device selection signals N0, N1, N2, N3 are used to generate these 32 control lines by means of a decoder external to PROCON.

A different set of 32 input control signals are used to transfer data selectively from the peripheral units to PROCON via the I/O bus. These control signals are generated from the PROCON source signals S1 and S2 and the same four device selection signals used for the output control.

The 512 word RAM is divided into an upper and lower half, corresponding to the ninth bit of the 9-bit RAM address. As long as successive RAM addresses are confined to either the upper or lower half of the RAM, the RAM can be addressed with 8 bits (one PROCON instruction) plus the ninth bit previously stored. But if the RAM address changes from one-half of the RAM to the other, two instructions are required to generate the 9-bit RAM address. After the RAM address is stored in the RAM address register, the RAM is then accessed in one instruction which enables either the S0 read control signal or the D1 write control signal.

A timing signal generator external to PROCON generates all of the timing signals necessary for the operation of LSS. This generator is driven by the PROCON clock and is controlled by the PROCON stored program.

3.3 RT wired logic processor

A wired logic processor at the RT is under the direct control of the COT microprocessor via the interconnecting data link. CMOS logic was chosen to minimize power drain. A stored program processor at the RT was not possible because of power drain with available technology.

When the processor recognizes the identifying preamble for the network order, the 16-bit network order, which follows immediately, is read into a 16-bit shift register and also is returned to the COT for verification. Upon receipt of an activate order from the COT indicating that the network message in the shift register is indeed correct, the line number and trunk level are transmitted in parallel from the shift register to the network controller for execution and also to the scanner. After execution, the processor receives the 3-bit confirmation code from the corresponding per-line switching network circuitry and inserts it into the trunk code position in the shift register. The line number is read back into the register from the scanner. The type code is changed and the contents of the register is serially transmitted to the COT.

After the execution of the network order, but just before the K4 line relay is released, i.e., after the K1, K2, K3 switching network relays have operated or released as required, the processor interrogates the status of the service request detector for that line via the scanner. If the network order is the type which assigns a trunk and hence disconnects the service request detector from the line, the service request detector output should show an on-hook condition (test state 1). If, on the other hand, the network order is the type which disconnects a trunk from the line and hence reconnects the service request detector to the line, the service request detector output should show an off-hook condition before the K4 relay is released (test state 2), and an on-hook condition after the K4 relay is released (test state 3). This off-hook condition is caused by the resistance provided by the RT trunk test circuit connected to tip and ring of the line via the K4 line relay. If any of the above three tested states of the service request detector are inconsistent, the processor indicates this fact by altering the normal 4-bit "type code" portion of the 16-bit confirmation message returned to the COT. The COT will raise the appropriate alarm if test state 1 or 2 is in error or will enter the line number in the leakage memory if test state 3 is in error. This leakage memory is discussed in greater detail in Section 3.10.

The tests of the service request detector described above also serve to test the network controller decoder and the scanner multiplexer. When a network controller, a scanner, or a line unit fails, at first it may not be readily apparent which unit has failed and only an RT line unit failure minor alarm is raised. Eventually, the COT microprocessor will be able to deduce the specific failure by correlating subsequent trouble conditions, and the major alarm for a failed network controller or scanner, or both, will be added to the minor alarm for the line unit failure.

When the RT processor receives a scan order from the COT, the processor enables the RT scanner. The scanner sequentially interrogates the service request detectors for originating calls or specific RT alarms represented as a nonused line number and transmits to the processor the line code of the first line found which requires service. The processor inserts the 8-bit line code and its complement into the shift register in parallel and serially transmits this line code to the COT.

When the COT microprocessor is not transmitting network or scan orders to the RT, auxiliary COT hardware continuously transmits the activate order to the RT, thereby preventing a locally powered RT from switching to the alternate data link pairs.

3.4 Scanning at the RT

The RT scanner contains an 8-bit counter which generates the line numbers in sequence. Three bits of each line number are used to interrogate one of eight service request detectors mounted on one line unit or various alarms and other maintenance functions contained in the maintenance unit. Five bits are used to choose the output from one of 24 line units or from the maintenance unit. The line number generator is enabled by the RT processor when a scan order is received from the COT, and is disabled when a service request is encountered. The contents of the line number generator is transferred to the RT processor for transmission to the COT. Scanning resumes at the next line number in the sequence when another scan order is received from the COT. If no service requests are detected in the length of time it takes to generate all line numbers, the line number generator is disabled and the processor transmits to the COT the no-request-for-service code of 255. If the scanner fails to scan, the line code 254 is transmitted instead, causing a major alarm in the COT.

3.5 Scanning at the COT

Generation of line numbers for scanning the sleeve lead status at the COT is accomplished within the microprocessor itself. By means of external multiplexing hardware similar to that used at the RT, the 8-bit line number generated by the microprocessor is used to interrogate the status of one of up to 192 sleeve ground detectors. Analogous to the RT, each COT line unit contains eight sleeve lead detectors and a one-of-eight selector with the outputs of these selected by a common multiplexer.

The scanning of all 192 sleeve leads at the COT is completed in the 30 ms period required to send a scan order to an RT and receive back the scan answer. It is necessary to scan for terminating calls this rapidly in order to provide the proper control interface with ALIT in SXS and #5XB offices. When a terminating call is detected, a control signal is passed to the ALIT system which causes it to reduce the rate of line tests. The slower testing rate provides time for the LSS system to connect a trunk and permit a valid ALIT test to be completed through to the subscriber's station set. Every new sleeve ground is interpreted as a possible ALIT test. Since ALIT tests are usually performed late at night when the traffic is light, the few subscriber calls on LSS lines should have little adverse affect on ALIT testing speeds.

3.6 Data modems

Data modems similar in design to those used in 202 type data sets are used at both the COT and the RT. The modems are designed for up to 24 dB of loss in the data link. This amount of loss permits the use of up to 3600 ohms of loaded 19, 22, 24, or 26 gauge pairs, or a mixture thereof. Additionally, the facility may also consist of low-loss channels derived from a digital voice-grade carrier system such as the *SLC*-40 system.

Circuitry is provided within the COT modem to permit automatic looping of the FSK analog output of the modulator to the input of the demodulator. This loop-back is used during automatic troubleshooting procedures to test modem operation.

3.7 Data link switching

In the event of a data link failure, a means is provided for automatically interchanging the data link pairs with two of the level five trunks of the concentrator. The level five trunks are, on the average, the least used trunks and the probability of interrupting a customer on a level five trunk is minimal.

Interchanging the data link pairs at the COT is under the control of the microprocessor. This same function is performed at the RT by the data link switching circuit. If the RT is powered over the data link pairs, the data link senses on which pairs the power is present and connects those pairs to the data modem. If the RT is locally powered, the data link switch hunts between the data link pairs at a 2.5-second rate when a hunt signal is received from the processor. The processor generates this hunt signal when a scan order or an activate order is not received at least every 400 ms. In order to prevent false hunting when the COT microprocessor has failed, or when the microprocessor has entered the troubleshooting phase, activate orders are continuously generated by COT hardware and transmitted to the RT.

3.8 Blocked calls

When all of the seven trunks accessed by a line are busy, the K5 relay (see Fig. 6) is operated and connects a ring trip and overflow circuit at the COT. If a terminating call arrives during the time when all trunks are busy, the LSS circuitry trips and ringing and supplies the overflow or fast busy signal in both SXS and #5XB offices. In ESS offices, a blocked call is never completed through to the LSS system. This ring trip and overflow function is performed by ESS. The fact that all of the LSS trunks are busy is obtained from another contact on the K5 relay via an ESS remote master scanner applique circuit. One such applique circuit is required for each group of four lines which share the same seven trunks.

If an originating call is blocked by the LSS system, dial tone is delayed until a trunk becomes available.

3.9 Testing the trunks and the switching network

The trunk test units at the COT and the RT are used for testing the trunk and the switching network for longitudinal leakage, metallic leakage, dc continuity, and ac transmission just prior to cutting through a line. The K4 line relay (see Fig. 6) is operated at the COT and the RT to isolate the line from the switching network and prevent clicks on working trunks when the K1, K2, and K3 relays are operated or released. After 70 ms, the Kc relay at the COT operates and the COT trunk test unit is connected through to the switching network and the trunk. The Kr relay at the RT is not operated until after the leakage measurements are completed at the COT. The trunk is an open circuit at the RT during the leakage measurements.

The longitudinal leakage test is made by connecting tip and ring at the COT to a −24 Vdc supply for 40 ms to condition the trunk. After the conditioning period, the leakage current flowing is integrated for exactly $1/60$ second to cancel out the effects of power line induction. At the end of the integration period, a flip-flop is set to a "1" state (test failure) if the integration result exceeds a threshold equivalent to 50 kΩ of leakage.

The longitudinal leakage measuring circuit is designed to function with up to 50 mA of induced 60 Hz longitudinal current flowing into a 100Ω impedance to ground. The measuring circuit can also tolerate a power-line frequency error of up to 0.5 percent.

The next test to be performed is the metallic leakage measurement. A floating −24 Vdc source is connected between tip and ring for 30 ms. At the end of this 30 ms period, a second flip-flop is set to a "1" (test failure) if the current flowing exceeds a threshold equivalent to a metallic leakage of 50 kΩ. The metallic current due to power line induction is not expected to exceed 0.1 mA ac.

The last two trunk tests, i.e., the ac loss test and the dc continuity test, are both made at the same time. A 2100-Hz tone is connected to tip and ring at the COT. A dc voltage of 24 V is also connected to tip and ring.

After the Kr relay at the RT operates, the RT trunk test unit is connected to the trunk. The input circuitry for this unit completes the path for the dc continuity test. The COT dc continuity circuit indicates a pass condition only if the dc resistance of the loop is less than 50 kΩ. The circuitry, and hence the threshold, is the same used for the metallic leakage test and the test result is the logical complement.

The 2100 Hz tone transmitted from the COT is detected by the RT trunk test unit and causes a 660 Hz oscillator at the RT to turn on for about 40 ms. The 660 Hz tone transmitted from the RT is detected at the COT. The ac transmission test passes if the transmission loss at 2100 Hz and 660 Hz does not exceed 20 dB.

The results of the four trunk tests are combined logically to produce a pass or fail indication.

3.10 Service disconnection and the "leakage" memory

If service is discontinued for an LSS line, the tip, ring, and sleeve jumpers for this line are removed at the MDF and the line placed on intercept. It is not necessary to remove the corresponding jumpers at the RT cross-connecting terminal.

If a low resistance condition should occur on an LSS line beyond the RT which has been disconnected at the MDF, a trunk will be assigned to this line in the normal manner. Since the sleeve lead is not connected, the trunk will be disconnected within five to ten seconds. When the trunk is disconnected, the service request detector is reconnected to the line at the RT and will show an off-hook condition, contrary to the normal case. The fact that the sleeve was not grounded and that the service request detector still shows an off-hook condition causes the line number to be put into the "leakage" memory. Sixteen such memory locations are provided for system A and sixteen for system B. Any line appearing in the leakage memory will be semipermanently assigned a trunk. This procedure prevents a trunk from being repetitively connected and disconnected to an off-hook line for which the sleeve is not grounded, and marks this trunk as available when necessary during high traffic conditions. Once a day this leakage memory will be cleared automatically.

If a working line develops a trouble beyond the RT which is recognized as an off-hook by LSS, causing a trunk to be assigned, but is not recognized as an off-hook by the central office, the situation is identical to that described above for an off-hook nonworking line. The line number will be put into the leakage memory and a trunk will be semipermanently assigned. Eventually, this condition will be identified by the central office during routine leakage testing.

3.11 Permanent signals

For SXS and #5XB offices, a line with a permanent signal will be assigned a trunk in the normal manner and will remain connected to this trunk for the duration of the condition. To LSS, the permanent signal condition appears like a normal call because the sleeve is grounded by the central office. A sufficiently large number of permanent signals will cause excessive blocking during high traffic conditions. For ESS offices, a permanent signal line will enter a "high-and-wet" condition after about two minutes. During the high-and-wet condition, the sleeve lead is not grounded. Consequently, in ESS offices a permanent signal line is treated as a leaky line by LSS. The line number is placed in the leakage memory, and a trunk is semipermanently assigned, thereby avoiding repetitive connection to the ESS recorded announcement trunk. Trunks connected to lines in the leakage memory can be used for other lines during high traffic conditions.

IV. EQUIPMENT DESCRIPTION

As shown in Fig. 11, the COT of the LSS requires a maximum of 61 inches of vertical space on a 23-inch wide miscellaneous bay and consists of up to four assemblies which are interconnected by connectorized cables. The 17-inch common control assembly consists of a fuse and alarm panel, two power units, PROCON, and an 8-inch shelf for 13 common control plug-in units.

The common control assembly for RT2 consists of a 4-inch high shelf which accommodates a power unit and a modem and is required whenever a second RT is provided.

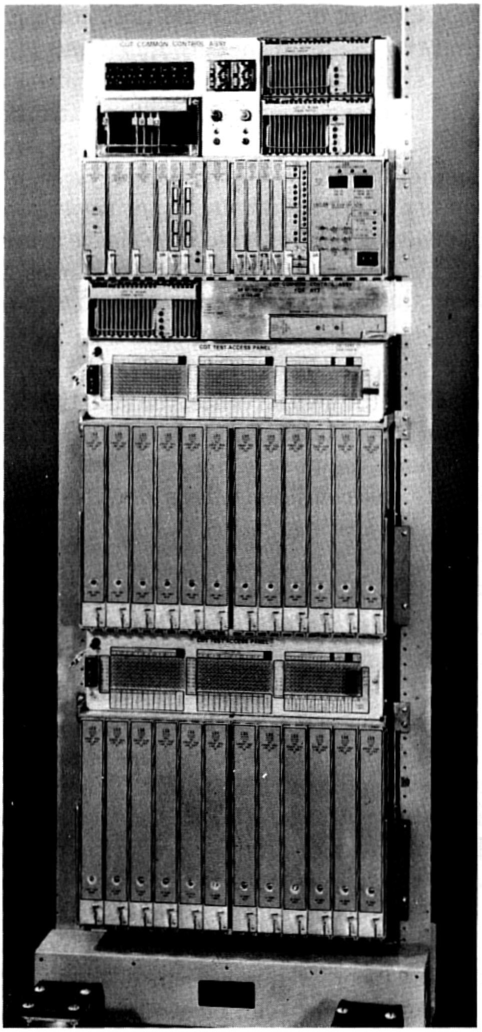


Fig. 11—COT of the LSS.

The 20-inch line unit assembly consists of a 14-inch high tray, which accommodates up to twelve 8-line line units and a 6-inch high field of terminals which provide test access to the lines, trunks, and other pairs. All external distributing frame connections for these wires are connectorized.

A second line unit assembly is used for the second set of 96 lines.

As shown in Fig. 12, the RT of the LSS is mounted in a cabinet 48 inches high, 29 inches wide, and 13 inches deep and consists of up to four assemblies which are interconnected by connectorized cables. These assemblies can also be mounted on a 23-inch wide miscellaneous bay.

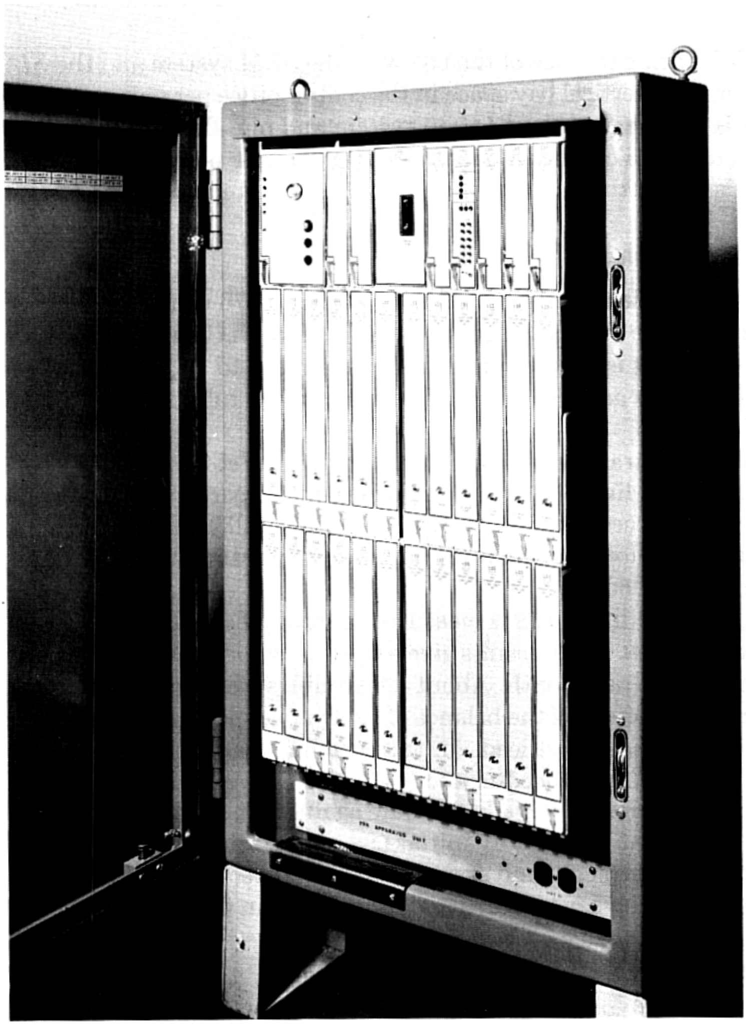


Fig. 12—RT of the LSS.

The common control assembly consists of an 8-inch high shelf for eight common control plug-in units.

The line unit assembly consists of a 14-inch-high shelf which accommodates up to twelve 8-line line units. It is equipped with gas tube protectors for the trunks, lines, data link and order wire pairs.

A second line unit assembly is added for a second set of 96 lines.

A 3-inch panel contains a thermostatically controlled heater and a duplex power outlet and is required only when it is necessary to control the humidity level within the cabinet.

A connectorized stub cable is used to interconnect the lines, trunks, data link pairs, and the order wire pair with a cross-connecting terminal or a distributing frame.

Comparing the size of the LSS with the *SLM* system and the *SLC*-40 system, the vertical bay space in the central office per pair gained for the LSS is half that of the *SLC*-40 system and one-third that of the *SLM* system. For a cabinet mounted RT, the volume per pair gained for the LSS is one-fifth that of both the *SLC*-40 system and the *SLM* system.

V. FIELD TRIAL

The LSS field trial began during August 1976 near San Diego, California, in the Pacific Telephone and Telegraph Company. The two-RT arrangement is used to provide service for up to 192 customers served by both SXS and No. 1 ESS. The system was fully loaded in January 1977.

The peak traffic carried by the LSS between February and May of 1977 is 4.7 ccs per line. The traffic level is about 20 percent below the design criteria of 6 ccs per line. Only one blocked call occurred during these entire four months, which is completely consistent with theory for this peak traffic load.

The reliability of LSS is measured in terms of service to the customers served by LSS. Early results give a trouble report rate of 4.2 reports per 100 stations per month. About 2.8 troubles were caused by non-LSS-related problems. Of the balance of 1.4 troubles, incorrect administration of central office sleeve leads for ESS customers served by LSS contributed 0.7 trouble. Test procedures for verifying sleeve lead connections have since evolved which should mitigate against such errors. The remaining 0.7 trouble was caused by initial LSS programming errors which have since been corrected and system outages caused by intermittent solder connections on several early models of plug-in units.

VI. SUMMARY

The Loop Switching System described in this paper utilizes a microcomputer which permits a wide variety of operational and maintenance features to be included in the system which would not have been possible if a hard wired logic approach had been used. By storing the history of system performance, a more accurate and thorough diagnosis of system trouble is possible and a more flexible call processing algorithm can be implemented. In addition, the turnaround time on correcting system bugs and adding features is greatly reduced when such changes can be implemented by software modifications.

The LSS system is currently in production. The first LSS systems were shipped by Western Electric to Pennsylvania and South Dakota in mid-1977.

VII. ACKNOWLEDGMENTS

The LSS system is the result of the joint efforts of and consultations with persons too numerous to mention by name from over 20 different departments within Bell Laboratories, Western Electric, and AT&T.

REFERENCES

1. E. F. Clark, "Automatic Switching System," U.S. Patent 1,125,965, applied for January 20, 1908, issued January 26, 1915.
2. A. E. Joel, "Experimental Remote Controlled Line Concentrator," B.S.T.J., *35,* No. 2 (March 1956), pp. 249–293.
3. W. A. Malthaner and J. P. Runyon, "Controller for a Remote Line Concentrator in a Time-Separation Switching Experiment," B.S.T.J., *39,* No. 1 (January 1960), pp. 59–86.
4. C. E. Brooks, J. L. Henry, G. E. Markthaler, and W. C. Sand, "Distributed Line Concentrator with Unique Intra Concentrator Completion Circuits," *IEEE Trans. Commun., 67,* pp. 435–441.
5. R. G. Fisher, "Universal Line Concentrator," U. S. Patent 3,099,718, applied for May 1960, issued July 1963.
6. R. G. Fisher, "Universal Line Concentrator," U. S. Patent 3,250,859, applied for December 1962, issued May 1966.
7. W. Whitney, "New Line Concentrator No. 1A," Trans. AIEE, *81,* Part 1, 1962, pp. 83–90.
8. M. E. Krom, "1A Line Concentrator," Bell Laboratories Record, *40,* No. 8 (September 1962), pp. 297–302.
9. I. M. McNair, "Subscriber Loop Multiplexer—A High Pair Gain System for Upgrading and Growth in Rural Areas," IEEE Trans. Commun. Tech. *COM-19,* No. 4 (August 1971), pp. 523–527.
10. M. T. Manfred, G. A. Nelson, and C. H. Sharpless, "Digital Loop Carrier," B.S.T.J., this issue.
11. G. T. Hawley and K. E. Stiefel, "VF Electronics for Loop Applications," B.S.T.J., this issue.
12. D. H. Morgen, "Loop Electronics Maintenance and Administration," B.S.T.J., this issue.
13. R. V. Laue and R. K. Even, "Traffic Considerations for Line Concentrators," Nat. Telecommun. Conf., December 1977.
14. M. N. Youssef, "Grading Traffic Properities and Design Rules," Nat. Telecommun. Conf., December 1974, pp. 580–588.
15. T. E. Graedel, J. P. Franey, and R. E. Schwab, "Environmental Testing with Giant Aerosols: Exposure of Miniature Relays," Elec. Contacts/1976—Proc. of the Ann. Holm Seminar on Elec. Contacts, September 1976, pp. 47–55.