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The 2A Line Concentrator

By U. K. STAGG

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The 2A Line Concentrator is a supplement to existing switching systems and provides concentration of line circuits up to a range of 1000 miles. It has been designed to accomplish this range extension while requiring a short (150–200 milliseconds) concentrator work time. An over-all description and a discussion of the initial application are presented.

I. INTRODUCTION

The 2A Line Concentrator is a high-speed, medium range system designed for use in the No. 5 crossbar system to provide range extension with more rapid connection of lines than is now possible. An ac signaling technique and solid-state logic circuits are combined with relay and crossbar switching circuits to provide a concentrator system with a range of about one thousand miles and a call setup time of approximately 175 milliseconds. These are improvements over the existing 1A Line Concentrator[1] (LC1A) system which is range limited to about twenty-five miles and the 1A Line Concentrator system modified for extended range with a call setup time of about 1.8 seconds.

II. OBJECTIVES

2.1 *Application*

The 2A Line Concentrator (LC2A) system was designed principally to provide concentration of lines serving TWX equipment. Although the LC2A development centered about requirements derived from its proposed application to data systems, its use is not limited to this area. Whenever concentration of lines over a distance greater than that served by the LC1A would become economically attractive, the LC2A may be applied. Several of these systems have been or are being installed at present to provide concentration of dial TWX lines.

2.2 *Development Objectives*

The initial objectives of the LC2A development were essentially as set forth below. As in most systems, some of these objectives changed during the course of the development; however, the statements are the objectives as they have been met.

2.2.1 *Number and Type of Lines Served*

Each LC2A system may serve up to 156 individual line customers. These lines are served through two remote circuits associated with one control circuit over a maximum of 32 concentrator trunks (16 trunks per remote circuit). One hundred and sixty line terminations are provided; however, two line terminations associated with each remote circuit are reserved for maintenance purposes. Each group of 78 lines (maximum) in a remote circuit has full access to any of the 16 trunks (maximum) over which it is served. Facilities are provided for operation with less than the full complement of lines or concentrator trunks, and an "all trunks busy" condition in one remote circuit does not affect the traffic handled by the other remote circuit.

2.2.2 *Customer Loop Length*

The total external loop resistance from the remote circuit to the customer's equipment cannot exceed 2795 ohms. No padding or adjustment on the individual line circuits is required.

2.2.3 *Delay Disconnect and Trunk Preselection*

The LC2A system incorporates delay disconnect, a feature which provides that all but one of the concentrator trunks serving each remote circuit shall remain cut through to the last line served, the remaining trunk becoming the preselected trunk for use on the next call. The choice of the trunk to be disconnected is changed by the trunk preselection circuit on every call, thus preventing a single bad trunk from putting the trunk group serving a remote circuit out of service. This feature is feasible primarily as the result of development of magnetically latching hold magnets for the crossbar switch.

2.2.4 *Line Preference*

To prevent a single line from holding other lines out of service and to spread seizures among all lines when simultaneous requests are made, a line preference circuit which changes preference on each call is used.

2.2.5 *Signaling*

The establishment or disconnection of a path from a line to a trunk, thence into the No. 5 crossbar network, is controlled by signals passed between the remote and control circuits. To provide for the range over which the LC2A must operate, ac signaling is used. The mode of this signaling system is frequency shift pulsing (FSP) also referred to as frequency shift keying.[2] Information is transmitted at a rate of 200 bits per second. Two narrow-band channels are used, one for each direction of signaling over a four-wire transmission path between the remote and control circuits. Both of these bands are within the audio range. Specifically, for signaling from control to remote circuit 2125 ± 100 cps is used, and from remote to control circuit 1170 ± 100 cps. Nominal adjustments of the power levels of these signals are made such that the input to the receiving end is −18 dbm.

2.2.6 *Line and Trunk Switching*

As noted in Section 2.2.1, each control circuit may have associated with it two remote circuits. At each remote circuit is a switching network consisting of four 200-point, six-wire crossbar switches. A similar network is provided at the control circuit for each remote circuit. The operation of these networks is identical at either remote or control circuit. Magnetically latching hold magnets are provided on these crossbar switches to minimize the current drain after a crosspoint is closed, since fifteen of the sixteen available trunks of each remote circuit normally remain connected to the last line served. An advantage of this feature is the ability to maintain a connection of lines to the No. 5 crossbar network in the event of a power interruption at either the remote or control circuit location. During such an interruption, calls cannot be switched; however, this feature precludes the necessity of reestablishing all connections and assures that service transmissions in progress at the time of the interruption will not be preempted by other calls when power is restored. Still another important advantage accrues from this feature — reduction in the average time to connect a customer's station equipment into the No. 5 crossbar network. Since some of the lines will be left connected to the trunks last used; any calls originating from or destined to terminate to these lines will not have to be switched by the concentrator. In the case of a service request, an off-hook signal will be passed immediately to the No. 5 crossbar office over the concentrator trunk and will cause no action in the concentrator other than that of marking the trunk busy. Similarly, a terminating call will apply ringing and mark the trunk busy with no further concentrator action. The net result of this feature is zero concentrator work time in establishing the required connection.

2.2.7 *Maintenance and Reliability*

Trouble detection and indicating facilities have been provided at both the remote and control units. When trouble occurs at either unit, indications of the nature of the trouble encountered, the line and concentrator trunk identification associated with the trouble, and indications of the call progress are recorded. At the remote circuit, a lamp panel records the call information while at the control circuit the call failure information is punched onto a standard No. 5 crossbar trouble recorder card.

Two different methods of recording call failure information are used since the remote circuits may be located in any type of central office, while the control circuit is always located in a No. 5 crossbar office equipped with a trouble recorder.

Trouble location and verification not only includes the normal techniques associated with electromechanical systems but is extended to facilitate trouble analysis of the solid-state circuits as well. Test points are provided on a group of terminal strips connected to the output of every transistor circuit with the exception of a small number of the ac signaling circuit elements.

Location and verification of a trouble is followed by clearing the cause and replacement of the printed wiring board(s) found to be defective.

Trunks connected to lines found to be in a permanent signal condition are capable of being restored to service from the control circuit end. A special maintenance call — permanent signal service denial — allows disconnection of the trunk from the troubled line and places the line in a cutoff condition, thereby preventing it from reseizing the restored or other trunks. When the permanent signal condition is cleared from the line, it may be restored to service from the control circuit.

Two line appearances are reserved for maintenance purposes. One appearance is required for making operation tests and for maintenance and transmission tests from the remote or control circuit. A second test appearance is necessary to provide loop around transmission testing facilities. Any trunk may be selected for testing, but from the control circuit only.

2.2.8 *DC Power Drain*

The remote and control circuits are combinations of relay and solid-state switching devices. The electromechanical devices, with the exception of a small number of dry reed relays, are operated from central office battery. The solid-state devices and the aforementioned reed relays (operated through conducting transistors) are supplied through a dc-to-dc converter which operates off central office battery to provide a regulated +12-volt source. The total current drain for the remote and control circuits is shown in Table I.

III. SWITCHING PLAN

3.1 *General*

The switching networks at the remote and control circuits are identical configurations of crossbar switches interconnected to provide concentration of customer's lines over concentrator trunks. This crossbar switch network is the heart of the LC2A system, and all functions of the remote and control circuits have the single over-all objective of providing proper control of this network.

3.2 *System Network*

Fig. 1 is a schematic indicating the association of a two remote circuit LC2A system with the network environment in which it is designed to operate. The control circuit is associated with a No. 5 cross-

TABLE I — CURRENT DRAIN

Circuit	State	Central Office Current Drain
Control	Idle	4.0 amps.
Control	Active*	0.9 amps.
Remote	Idle	3.3 amps.
Remote	Active*	5.8 amps.

* Figures obtained by averaging over all calls.

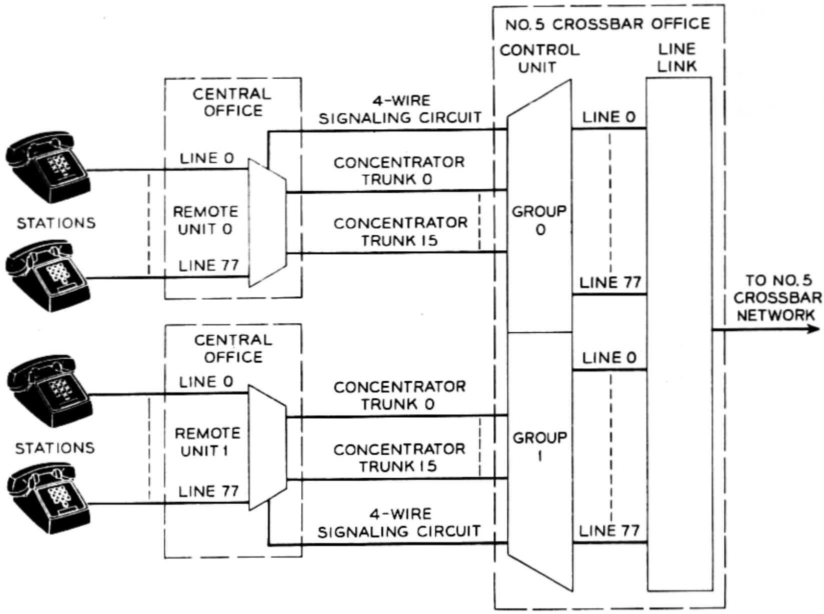

Fig. 1 — System network.

bar central office. The line appearances of the concentrator control circuit are connected to the line relays of the line link frame. Two groups of concentrator trunk circuits interconnect the control circuit with each of two remote circuits, one group of trunks serving each. A four-wire signaling circuit is extended between each remote and control circuit, providing the signaling facilities required for establishing or disconnecting paths through the crossbar switches. The trunks are switched on a two-wire basis through the concentrator crossbar networks; however, the signaling paths are not. The facilities constituting the concentrator trunks and signaling paths differ only in that the transmission trunks (trunks 0-15 of each group) need not be four-wire circuits, while the signaling paths must be to provide the required signaling capabilities. These facilities may be metallic circuits with or without E-type repeaters or carrier.

The remote circuits may be located at a variety of central office types. The choice is a matter of convenience only, since the remote circuits are associated with the central office for the purposes of obtaining central office battery and interconnecting to its alarm system. It is not in any way associated directly with the switching network of the office in which it is located. Customers' line circuits are brought directly to the remote circuit and associated with the concentrator crossbar switch line appearances. These line circuits, as indicated, may be either metallic pairs, four-wire voice-frequency repeater facilities, or carrier facilities with single-frequency signaling. Though each remote circuit is indicated to be located in different offices, there is no restriction of this nature, and where more than seventy-eight lines are to be concentrated, a second remote circuit may be used at the same location.

3.3 *Concentrator Switching Network*

To reduce the probability of the need for more than one remote circuit at a given location, and to take advantage of the greater efficiencies of larger trunk groups, a larger number of lines and a larger trunk group have been provided than in previous concentrator applications.

3.3.1 *The Network*

The networks at the remote and control circuits are comprised of four 200-point six-wire crossbar switches as shown in Fig. 2. Associated with each vertical of each switch is a customer's line circuit (remote circuit) or an appearance on the line link frame of a No. 5 crossbar office (control circuit) with the exception of verticals 78 and 79. These are the appearances reserved for test and maintenance; they are not associated with line circuits but rather terminate on other equipment within the concentrator system. The sixteen concentrator trunks are multipled to each of the four crossbar switches, corresponding levels of each switch serving the same trunk. In this fashion, all eighty line appearances have full access to all sixteen concentrator trunks. When a connection of line to trunk is being established, the corresponding select magnets of all switches are operated. Following operation of the single hold magnet associated with the line appearance, only one set of crosspoints is operated and all select magnets are released.

3.3.2 *Crossbar Switch Arrangement*

In order to terminate sixteen trunks on a crossbar switch provided with only ten horizontal levels, as indicated in Fig. 2, a scheme allowing the sharing of a level by two trunks has been used. (This is similar to the technique used on the trunk link frame of No. 5 crossbar.) By using levels 0-7 for the trunk appearances and levels 8 and 9 as "steering" levels for selecting one of the two trunks sharing the same level,

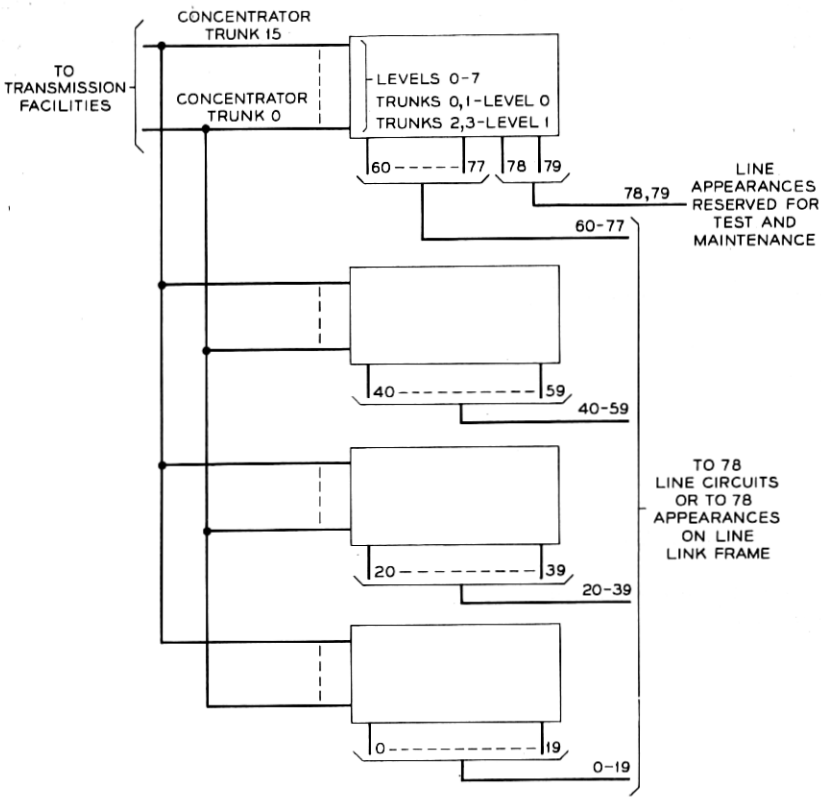

Fig. 2 — Four 200-point, six-wire crossbar switches as employed in LCZA remote or control circuit.

sixteen trunks are made available to each of the twenty line appearances of the switch. Fig. 3 illustrates the manner in which this is accomplished for one vertical unit. Only two trunks are shown, occupying level 0, the remaining trunks appearing in the same fashion on levels 1-7. (Fig. 3 shows a vertical unit for the remote circuit. A minor difference exists between this and the control circuit configuration, but it is in the disposition of the sleeve leads after switching. In general the figure is the same for the control circuit.)

3.3.3 *Trunk Select Steering*

To provide switching of two trunks per horizontal level of the crossbar switch, a minimum of four contacts per crosspoint are required — one for each tip and ring of the two trunks. In addition, a

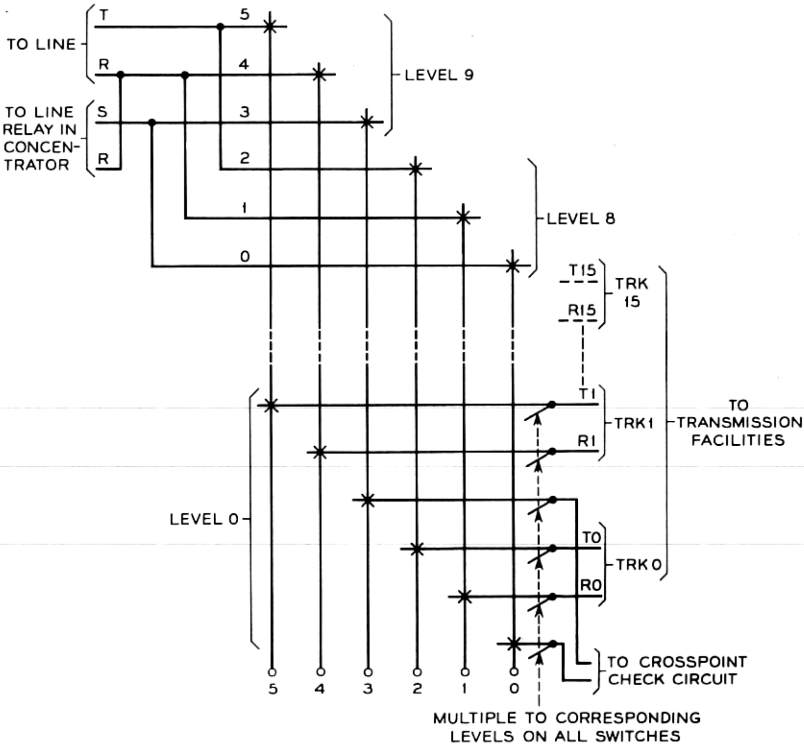

Fig. 3 — Remote unit switch vertical unit.

sleeve lead per trunk is provided for supervision and checking purposes; hence a total of six contacts are required per crosspoint. When connection of a line to a trunk is required, action within the concentrator identifies which line is to be switched to which trunk. Identification of the trunk causes operation of two select magnets on each switch — one corresponding to the level on which it appears and the other for selecting one of the two trunks sharing that same level. Fig. 3 shows two trunks, TK0 and TK1, sharing level 0. TK0 is wired to positions 0, 1, 2 and TK1 is wired to positions 3, 4, 5 of all vertical units of all switches. When the crosspoint at level 0 is operated, all six contacts are closed and both trunks are connected to the vertical unit. The operation of the select magnet for level 8 or 9 "steers" the connection of the line associated with this vertical to the proper choice trunk since only three contacts are provided at these crosspoints. For example, suppose it is desired to connect TK0 to the line. Select magnets 0 and 8 are operated, followed by the operation of the hold magnet, causing closure of six contacts at level 0 and 3 contacts at level 8. TK1 is connected to the vertical unit also, but no path exists to the line since the contacts at level 9 have not been operated. Note that levels 8 and 9 are not multipled to any other vertical unit of the same or other switches since this is the point of association of the lines with the vertical units.

IV. SIGNALING AND CONTROL

4.1 *Signaling System*

Frequency shift transmitters and receivers are used in both the control and remote circuits. Two separate frequency bands are used: the lower (f_1) to signal from the remote circuits to the control circuit and the upper (f_2) to signal from the control circuit to the remote circuits. In the f_1 band the frequencies corresponding to mark and space signals are 1270 cps and 1070 cps, respectively. Mark and space signals in the f_2 band are 2225 cps and 2025 cps, respectively.

As used in the LC2A, one of the two frequencies is present at all times with one exception. The exception is removal of both frequencies from the transmission facilities to effect the release of the concentrator. This occurs in the normal sequence and is detected by a signal-present detector circuit. If this absence occurs when the concentrator is idle, an alarm is given to indicate that the signaling circuit has failed.

When the concentrator is idle, a continuous spacing signal is transmitted from the remote to the control and the control to the remote circuit. Transmission of a message is initiated by a start pulse of mark frequency, five milliseconds in duration. This message may be started at either the remote or control circuit. Part of the receiver circuit at each end is a guard interval timer (GIT) which has the function of measuring the duration of all mark frequency signals. If the mark frequency signal is of a minimum duration of 4.06 milliseconds, the GIT recognizes the signal as a legitimate mark signal and, in the case of the start pulse, starts the clock at the receiving end. The purpose of this timer is to assure that components of the proper frequency from noise hits as produced by lightning or induced into the transmission path because of other environmental conditions do not cause false starts of the concentrator. This timer circuit is designed to respond only to a continuous signal. A series of short noise bursts with proper components will not build up to give a false start because of the fast recycle time of the timer.

4.2 *Synchronization*

The signaling scheme of the LC2A requires no special synchronization or framing pulses, even though the clocks at the remote and control circuits are independent once set into operation. In regard to the framing, no indication of message length or word length is required, since in all instances the receiving unit "knows" that the transmitted message at any time is of a certain bit length (either 11 or 16 bits), that each word is composed of five bits, and that every message is preceded by a single start pulse. The message length is determined by the point of origination (remote or control circuit) and the signaling stage of the call. All information is transmitted as binary coded two-out-of-five words.

When a start pulse is received, the output of the 4.06-millisecond GIT triggers a 3200-pps clock circuit into operation. This clock drives a four-stage binary counter, which acts as a frequency divider producing a 16-pulse string. Each pulse in this string recurs at a rate equivalent to the driving clock repetition rate (3200 pps) divided by the number of states of the binary counter (16), or at 200 pps. Three of these pulses are used to trigger the shifting, writing (sampling incoming data) and bit-counting circuits. The GIT output also sets this frequency divider to a predetermined state corresponding to the elapsed time as if the clock had started coincidently with the leading edge of the start pulse. The 4.0625-millisecond interval corresponds to 13/16 of 5 milliseconds; hence the counter is set to state 13. In this manner the receiving clock and divider circuits are set into initial synchronism with the incoming signal. Since the clock at the transmitting end is running independently of the receiving circuit clock, and since the repetition rate of these clocks is subject to a $\pm$ 1 per cent tolerance, the two clocks could be as much as 2 per cent out of synchronization. This would indicate that some form of synchronization is in order. Here advantage is again taken of the knowledge of the message structure. Since each word is composed of two mark and three space characters, a transition from space to mark must occur after the initial transition caused by the start pulse — at worst, nine bit positions later. Thereafter, at most a length of ten bit positions is the longest duration between transitions (in the case of a 3-word, 16-bit message).

By positioning the shift, sample and count pulses appropriately in the 16 available positions and by resynchronizing the frequency divider binary counter producing these 16 positions every time the GIT produces an output, no information is lost even when the two independent clocks are out of synchronization by the maximum 2 per cent allowed.

4.3 *Solid State Logic, Memory and Control*

In addition to applications in the ac signaling circuits and the clock circuits described above, solid-state devices are employed in memory elements, pulse-shaping circuits and logic gates, and as relay drivers. The memory elements are used to: (1.) indicate call progress, (2.) remember the originating circuit identity (control or one of two remote circuits), (3.) indicate to the logic control circuit the originating circuit identity, (4.) temporarily store the message when transmitting or receiving, and (5.) cause operation of relay driver gates to pass the received message to the relay circuits. The pulse-shaping circuits are monostable multivibrators used to stretch or shrink pulses obtained from the clock and frequency-divider circuit. The logic used to control the start, stop, sequencing and preference functions of the solid-state circuits is composed entirely of transistor-resistor logic (TRL) gates. These same gates are connected in re-entrant configurations to construct the binary cells and the monostable and free-running multivibrators. In addition, the same circuit used to perform logic operations is used to operate the dry reed relays in the solid-state-to-electromechanical interface. When used as a relay driver, the relay winding is substituted for the normally provided load resistor of the TRL gate. The reed relays employed were specially coded for this application, operating on 40 milliamps at 12 volts.

Throughout the solid-state part of the LC2A only one code of transistor has been used — the 16A. In the ac signaling circuit it operates as a linear amplifier and as the active element in oscillator circuits. Its application in the remainder of the solid-state circuits is in the role of a switch.

V. SYSTEM DESCRIPTION

5.1 *General*

This section described the salient features of the LC2A system and includes a discussion of the signaling method and solid state — electromechanical interface. A summary of the system characteristics is given in Section 5.5.

5.2 *Line Selection*

Simultaneous originating or terminating requests must be queued and served preferentially. The concentrator may be simultaneously summoned by more than one line at the remote circuit to connect these lines into the No. 5 crossbar network. Similarly, simultaneous termination requests from the No. 5 network to more than one line (two or more different calls) may be placed on the concentrator. Still another condition is simultaneous requests for serving a line from the remote circuit (service request call) and a request for terminating to a line (terminating call) from the control circuit. Since the LC2A can serve only one call at a time, a preference and lockout arrangement must be incorporated in the design. Where the simultaneous bids are originated at the same point (remote circuit or control circuit), an electromechanical technique suffices. What must be accomplished is recognition of the lines requesting service, determining which is to be served, remembering the identification of the served line and preventing others, waiting to be served, from interferring.

These ends have been accomplished in the LC2A by combining the classical lockout chain circuit with the circuit used to translate the operation of a line relay into a corresponding decimal number. The operate paths of ten relays used to determine the units digit of this number are chained through back contacts of these same relays. In similar fashion, the operate paths of the relays used to determine the tens digit are also chained. By providing a W-Z relay circuit, the entry point into, and preference through, each of these chains is reversed on alternate calls. Through this mechanism three things are accomplished: (1.) simultaneous requests result in one-only identification, (2.) line preference distribution tends to be smoothed by alternately preferring high-numbered and low-numbered lines, (3.) a single line in a trouble condition cannot block permanently other lines from service. Fig. 4 shows the line lockout and preference circuit for the units digit of the line number at the remote circuit.

In the event of simultaneous seizures of the remote circuit (for a service request) and the control circuit (for a terminating call) both units will initiate signaling to the other. This results from the nature of the signaling scheme (discussed in Section 4.4). By a suitable arrangement of solid-state logic and control, the LC2A system forces itself to abandon the call originating at the remote circuit and continues processing the control circuit originated terminating call. This choice was

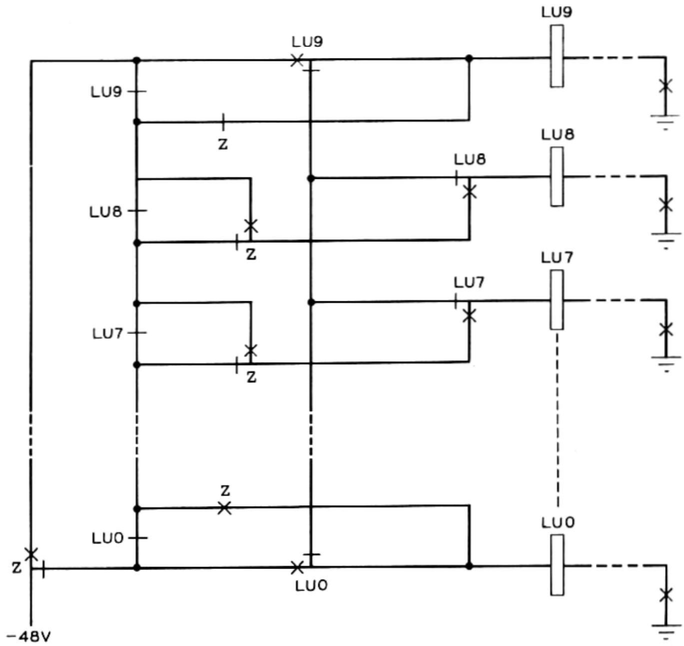

Fig. 4 — Line lockout and preference circuit.

made in order that a call which has already been through several stages of switching in the No. 5 crossbar network will not be denied completion or forced to wait for completion of a service request call which has not been switched at all.

Another possibility which must be guarded against is simultaneous seizure of the control circuit by both remote circuits. Since the control circuit is seized at the time it recognizes that a remote circuit is sending a message, the decision of which remote to serve must be rapid in order that information from the unserved circuit will not interfere with the valid information from the served circuit. In addition, the unserved remote must be so informed to prevent it from giving a false alarm. Fig. 5 shows the preference arrangement which, in the event of information arriving simultaneously at the control from both remotes, causes both flip-flops — indicating which remote circuit is to be served — to be set. However, an arrangement in the logic forces one (arbitrarily selected) flip-flop to be reset and disables the receiving circuit associated with that remote circuit. Under normal conditions the set state either flip-flop disables the receive circuit for the other remote circuit.

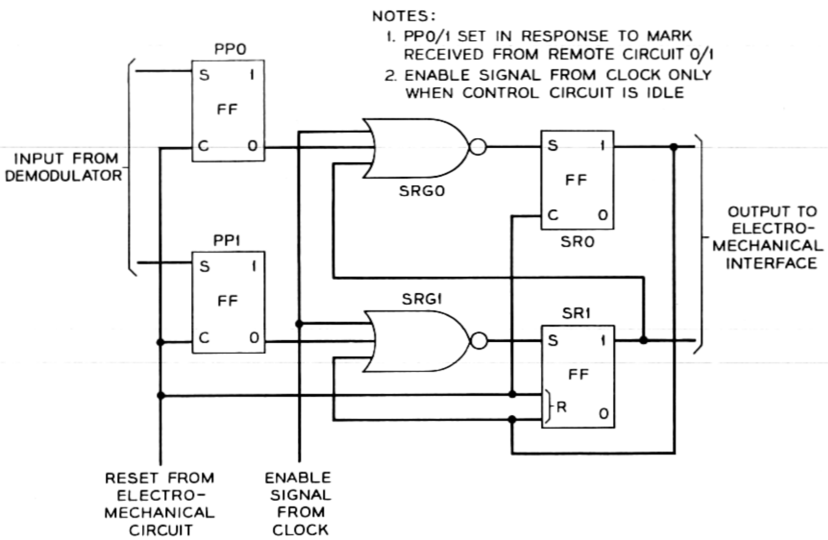

Fig. 5 — Remote circuit preference and lockout circuit at control circuit.

5.3 *Trunk Selection*

The trunk to be used on any given call is chosen immediately following the establishment of a previous call if an idle trunk is available, or if not, as soon as one becomes available. Under normal conditions this reduces the average cut through time from customer's equipment to the No. 5 crossbar office at the time connection is requested, since the identity of the trunk to be used is known or "preselected". The identity of the trunk does not have to be passed between the remote and control circuits as part of the information necessary at the time the connection is desired. In fact, before the customer's line has been identified at both ends, the select magnets associated with the preselected trunk are energized at both the remote and control circuits. Identification of the customer's line results in operation of the appropriate hold magnet, thereby closing the proper crosspoints. The identification of the trunk used on any connection is passed between the remote circuit and control circuit after the line has been identified to verify that the same trunk has been selected at both units.

As described in Section 2.2.7, a feature of this concentrator is the ability to leave all but one concentrator trunk connected to the last line served. Naturally, if all trunks are occupied with an active call, no trunks will be disconnected since all will be marked busy. However, the first circuit to become idle removes its busy indication by releasing a trunk busy (TB-) relay and is immediately selected by the concentrator control circuit as the trunk to be used on the next service call. The selection of this trunk requires storing its identification in the trunk memory of the control circuit, transmitting this identification to the remote circuit, and storing the trunk identity in the trunk memory of the remote circuit. In the normal situation, all trunks will not be occupied, and following the establishment of a call using the preselected trunk, another trunk must be selected out of the pool of idle trunks remaining connected to the last lines served. A trunk preference circuit determines which trunk is to be disconnected *if it is idle.* If the preferred trunk is not idle, the next higher-numbered trunk which is idle is disconnected and its identity stored in the trunk memory circuits. The preference circuit is advanced as the result of each trunk selection operation of the concentrator; consequently each trunk of a group serving a remote circuit is the preferred trunk for preselection once every sixteen calls involving that remote circuit. In this fashion, a trunk which is malfunctioning will not cause blocking of normal operation by preventing selection of other trunk circuits.

In addition to selection of trunks through the preference circuit, a feature has been included to allow manual selection of an idle trunk. This feature is used for maintenance calls and is accomplished by operation of a switch and key combination at the control circuit. Initiation of manual trunk selection overrides the normal trunk selection by releasing the trunk memory of the control circuit and causing transmission of the new trunk identity for storage at the remote circuit. A special code accompanies transmission of the trunk identity, causing the remote circuit to release its trunk memory before storing the new trunk identity.

5.4 *Signaling and Logic Applications*

The FSP (Frequency Shift Pulsing) signaling and the solid-state logic hardware have been provided for the primary purpose of passing the line and trunk identification necessary for establishing a transmission path between a customer associated with a remote circuit and the No. 5 crossbar network at speeds and over distances greater than attainable with the LC1A. A brief description of the different calls handled by the LC2A is presented in the following paragraphs.

5.4.1 *Service Request Call*

A call originating from a customer's equipment associated with the remote circuit is designated a service request call. A request for service is initiated by an off-hook condition, recognized at the remote circuit by operation of a line relay associated with the customer's equipment. Operation of this line relay results in translation first to a two-digit decimal number, which is stored in a temporary relay memory. The line identification is stored so that in the event of encountering trouble after operation of the crossbar switches at either or both ends but before release of the concentrator, the connection may be released and the concentrator restored to the condition existing before the call started.

After the line identification is stored, a second translation, from decimal to binary two-out-of-five, is performed and the results passed to the shift register circuit. When the information is properly stored, a start signal is passed to the control circuit which enables the clock. As the clock pulses are generated, the information stored in the shift register is passed, one bit at a time, to the FSP modulator circuit. Each output bit of the shift register is an input signal to the FSP circuit for a period of five milliseconds; hence a pulse of five milliseconds duration of the appropriate mark or space frequency is transmitted. Preceding the ten-bit message (two two-out-of-five coded words) is a one-bit start signal; hence, the total message length is eleven bits, requiring fifty-five milliseconds for transmission.

When the clock circuit has generated eleven pulse trains, causing the eleven-bit message to be completely shifted through the shift register to the FSP modulator, the solid-state control circuit disables the clock and starts timing for a response from the control circuit. During the fifty-five millisecond transmission interval, the relay control circuit has caused operation of the crossbar switch network at the remote circuit to connect the identified line to the preselected trunk.

At the control circuit, action is initiated by reception of the start pulse. This pulse enables the clock which generates a string of clock pulses identical to those generated by the remote circuit clock but in synchronism with the arriving pulses. (The clocks at the remote and control circuits are not themselves synchronized because of transmission path delay.) The first mark (the start pulse) is not stored, but subsequent marks are. As the FSP demodulator responds to the incoming signal, it produces output signals of battery or ground accordingly as mark or space frequencies are detected. This output is sampled periodically (every five milliseconds), and if a mark is being received at the time of sampling, the first cell of the shift register is set to indicate the fact. The shift register is then advanced and prepared for the next sampling operation. If a space is received and sampled, no action is taken before shifting of the register.

The receiving clock continues running until an interval of fifty-five milliseconds (corresponding to the time required for reception of the eleven-bit message) has elapsed. The solid-state control circuits then disable the clock and cause gating of all the cells of the shift register into the relay control circuits. The message is immediately checked for two-out-of-five validity, whereupon it starts action for closing the crossbar crosspoints associated with the received line identification and the preselected trunk. Simultaneously with this action, the identification of the line requesting service causes a bridge to be placed on the corresponding circuit to the No. 5 crossbar line link frame, resulting in operation of the line relay. This initiates a dial tone request before the crossbar switch has operated, thus reducing the dial tone delay by an amount equal to the operate time of the crossbar switch hold magnet. Subsequent to operation of the crossbar switch the bridge is removed, with status of the path to the No. 5 crossbar office supervised by the customer's equipment over the concentrator trunk.

As soon as the hold magnet is operated at the control circuit, the number of the trunk used in the connection at the control circuit is translated to a two-word, two-out-of-five message, passed to the shift register and transmitted to the remote circuit in a fashion similar to transmission of the line identity from the remote circuit to the control circuit in the first stage of the call. The remote circuit receives and stores this trunk number just as the control circuit received the line number. The message is checked for two-out-of-five validity, then checked against the stored number of the trunk connected at the remote circuit. If a match results, a verification signal is transmitted to the control circuit to indicate that the information was received and that it corresponded to the trunk number used by the remote circuit. Note that the transmission of the trunk number at this time is not required for establishing the connection but only to verify that both ends used the same trunk. Following this verification, both the remote circuit and control circuit release.

If at any time either unit fails to receive a valid two-out-of-five coded message, its action is to withhold its next transmission. The last unit to transmit starts timing at completion of the transmission, and if a response is not received within the proper interval, preceding action is negated by release of the concentrator and restoration of conditions existing prior to the start of the call.

A second trial feature has been incorporated in the LC2A which allows a second attempt after a timeout. No trouble indications are given unless the second trial fails. In this event a trouble record is made, indicating the nature of the failure, the numbers of the line and trunk involved, the type of call being processed, and the signaling stage of the call.

In order to inform the unserved remote circuit that it may not serve calls during the time the control circuit is occupied by the first remote circuit, the control circuit removes all signals from the transmission path to the unserved remote circuit. This remote circuit responds by removing its signals to the control circuit and disables itself. This condition obtains until the control circuit reapplies signal to the remote circuit, indicating that it is idle and is available for service. The remote circuit responds to this signal by reapplying its signals to the control circuit, at which time the system is ready to serve another call.

5.4.2 *Terminating Call*

A call destined to terminate at a customer's equipment through the LC2A from the No. 5 network is classified a terminating call. For the LC2A this call originates at the No. 5 line link frame which supplies ground over the sleeve to operate a relay in the control circuit identifying the line. This operation is followed by translation first to a decimal number then to a two-out-of-five coded equivalent. Operation of the LC2A is similar to that described above for a service request call with the signaling roles reversed. The line number is passed from the control to the remote circuit and trunk verification is transmitted from the remote to the control circuit. One major difference in signaling exists, however. Since the remote circuit can only initiate service requests, no information regarding the type of call is passed on a service request call. The control circuit, however, has the ability to originate more than one type of call; therefore, it must signal the remote circuit to inform it of the call disposition. This signaling is accomplished by transmission of a third two-out-of-five coded word representing the type of call. This information is sent with and precedes the remaining ten bits of information. On all calls originating from the control circuit sixteen, rather then eleven, bits are transmitted from the control circuit to the remote circuit. The solid-state control circuits at each unit recognize this and permit the associated clocks to run for the longer duration (eighty milliseconds) rather than cutting them off after the shorter interval used on a service request call.

5.4.3 *Other Control Circuit Originated Calls*

In addition to the terminating call, the control circuit originates the following: (1.) disconnect call, (2.) service denial call, and (3.) test calls. Each of these is signaled to the remote circuit in the same manner as a terminating call, but the type of call indication indicates a different significance for the ten-bit message which follows the type of call information. Discussion of the operations of these calls is presented rather than the signaling involved.

5.4.3.1 *Disconnect Call.* A feature of the LC2A is the practice of leaving all but one trunk connected to the last line served. The one trunk not connected serves as the trunk for the next call served. When a call is served (service request or terminating), the preselected trunk is used and another trunk, if one is available, must be disconnected from a line and placed in the idle, preselected state. The selection is accomplished by the control circuit which ascertains the identity of the trunk through the trunk preference and select relay circuit. Upon identification of this trunk, the control circuit signals the remote circuit that a disconnect call is being processed and passes the trunk identity to the remote. After the identity is checked for two-out-of-five validity and stored, a relay circuit causes operation of the line relay at the remote circuit of the line connected to the trunk. This is accomplished by grounding the sleeve of the trunk. Operation of the line relay identifies the hold magnet holding the connection, and a current pulse in a direction to overcome the magnetic field latching the vertical unit is applied. The crosspoints release, and a check is made to verify the release through back contacts of the hold magnet. Following the release, the remote circuit transmits the number of the released trunk to the control circuit, where it is verified by checking against the trunk number stored in the control circuit trunk register.

5.4.3.2 *Service Denial Call.* In order to prevent a line at the remote circuit from requesting service, a service denial feature has been incorporated. This feature is necessary to prevent lines which are in a premanent signal or other trouble condition from removing a trunk from service. Service denial is initiated at the control circuit by connecting ground to the sleeve lead at the control circuit through a key. Operation of the key initiates a service denial call and identifies the line. The type of call and line number are transmitted to the remote circuit which in turn energizes the hold magnet associated with the denial line. The hold magnet latches operated and through its back contacts opens the operate path of the line relay. No select magnets are energized; hence, no crosspoints are operated. A check is made that the hold magnet has operated and latched, and verification is returned to the control circuit. In similar fashion, the hold magnet at the control circuit is also latched, closing no crosspoints and opening the sleeve lead. Hence, terminating calls to the denied service line cannot be served.

A second key at the control circuit allows restoral of the line to service after the trouble condition has been cleared. This key causes transmission to the remote circuit of a release service denial signal and the line identification. The hold magnets are released and checked, and upon release of the concentrator the line is again able to receive or originate calls.

5.4.3.3 *Test Calls.* The LC2A has provisions for making service test calls to test the ability of the concentrator to serve regular service request or terminating calls. In addition, two lines have been reserved for making transmission test calls. Tone supplies (1000 cps, 1 milliwatt) are connected through the test line appearances and, by selection of the type of call, either transmission in one direction or loop around transmission testing may be accomplished. For loop around testing, line appearances 78 and 79 are each connected to a trunk and connected together at the remote circuit. By transmitting from one of these appearances at the control circuit and monitoring the other appearance (at the control circuit) a measurement of the trunk losses may be obtained.

5.5 *Summary of System Characteristics*

Table II summarizes the characteristics of the Line Concentrator No. 2A.

VI. EQUIPMENT FEATURES

6.1 *General*

The LC2A system incorporates some interesting equipment and apparatus applications. These result from the proposed use of the system and the combination of electromechanical and solid-state switching circuits within the same bay of equipment. Some of the choices of equipment arrangement and apparatus selection were results of laboratory testing, particularly to overcome the troubles resulting from noise generated by the electromechanical switches. Both the remote circuit and the control circuit use the same apparatus; and, in general, the equipment arrangements are similar.

TABLE II — SUMMARY OF LC2A CHARACTERISTICS

Size	
Remote:	80 lines (2 reserved for test) with full access to 16 trunks.
Control:	2 remotes (optional) 160 lines 32 trunks
Signaling	
Mode:	4-wire FSP 2/5 coded message.
Frequency:	Remote to control — 1070–1270 cps. Control to remote — 2025–2225 cps.
Range:	Transmission limited to 1000 miles.
Rate:	200 bits per second.
Concentrator Trunks	Metallic or carrier
Switching Network	
Remote:	Four 6-wire, 200-point, magnetic latching crossbar switches. Lines on verticles. HON (Hold Off Normal) contact of crossbar switch as line cutoff. 16 trunks on horizontal/level steering.
Control:	Four switches as above per remote.
Equipment and Apparatus	
Remote:	Central office mounted bulb angle frame.
Control:	Sheet metal frame.
Common to Both:	AK, general purpose, mercury, reed, 286 and B-type relays, transistors, diodes, resistors, capacitors, inductors, transformers, AMPLAS and printed wiring boards

6.2 *Frames and Equipment Arrangement*

The LC2A control circuit is designed to be used only in a No. 5 crossbar office; and, therefore, the frame is of sheet metal construction. Fig. 6 is a photograph of the laboratory model of the control circuit. The right-hand bay contains the two crossbar switch networks required to serve two remote circuits. Located between the networks are two shelves for mounting the printed wiring boards, which contain all but a few of the solid-state circuits. Also mounted in the top shelf, extreme left, is the dc-to-dc converter, which supplies the +12 volt needs of the solid-state circuits. Immediately below the second shelf are two mounting plates containing the test terminal strips for the solid-state circuits and AMPLAS component assemblies mounting diodes, resistors and capacitors associated with the printed wiring boards. The lower plate mounts the transformers and filters for the two four-wire circuits used to signal to the two remote circuits.

The left-hand bay includes the line lockout, trunk preference and

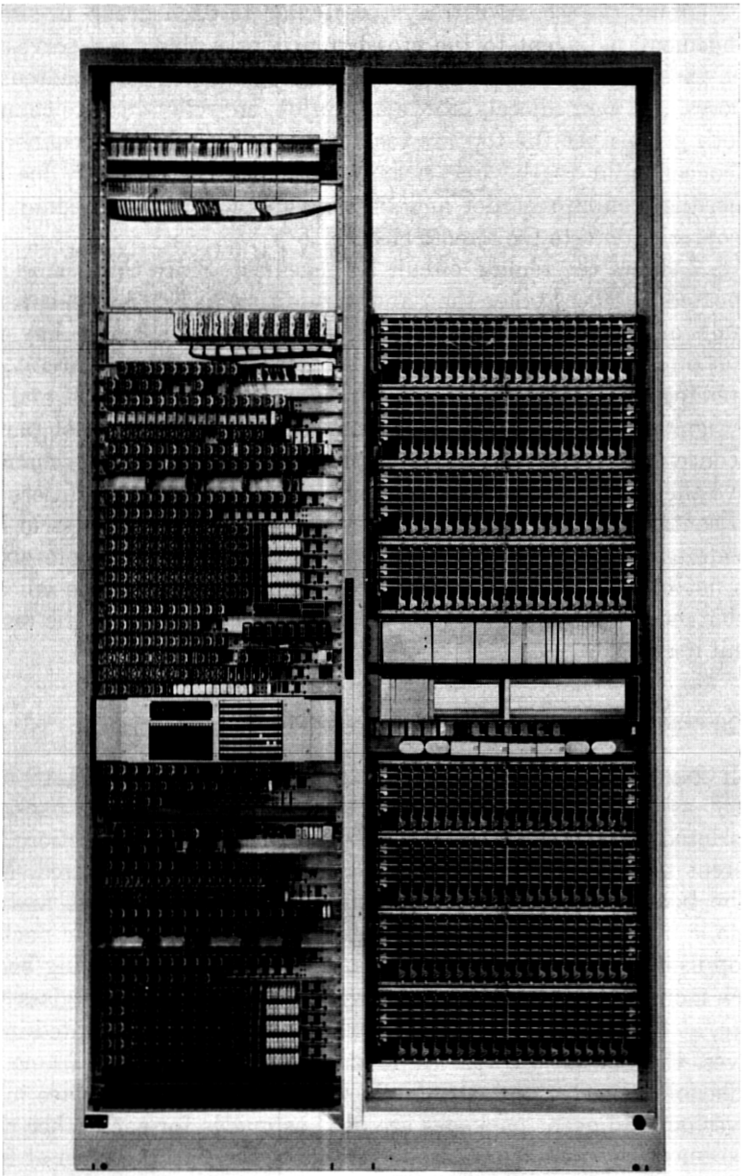

Fig. 6 — Laboratory model of control circuit.

select circuits and control relays particular to each group in similar arrangements adjacent to the crossbar networks that they serve. Between these two groups of relays is a panel provided for maintenance purposes, and immediately above and below are relay circuits common to both groups. At the top are located the terminal strips connecting the concentrator to the line circuits of the No. 5 crossbar line link frame, the trouble recorder and the transmission facilities connecting the control circuit to the remote circuit.

Fig. 7 shows the remote circuit arrangement. Since this frame may be located in offices other than and in addition to No. 5 crossbar, it is of bulb angle construction. All equipment fits on a single bay unit and is similar in description to that located at the control circuit. (In the photograph, lower right-hand corner, are shown two E1L and two E1S signaling units used in laboratory testing. These are not part of the concentrator but were mounted there as a matter of convenience.) Above the mounting plate containing the transformers and filters is a strip containing lamps, jacks and keys. The purpose of this strip is to provide test facilities and a trouble lamp display. The remote circuit does not connect to any trouble recording device within the office. A trouble record is made on a lamp display panel mounted on the remote circuit itself.

6.3 *Solid-State Circuit Packaging and Mounting*

All solid-state circuits with the exception of a few AMPLAS component assemblies mounting a special long-period timer are packaged on printed wiring boards of phenolic or fiberglass construction. The different substrates result from the different strengths required. Most of the boards mount very small, light-weight components, and the phenolic material is satisfactory. Fig. 8 shows a typical logic package at top using the phenolic substrate and one of the ac signaling boards which mounts three relatively massive inductors on the fiberglass substrate, at the bottom. For rigidity and separation when mounted in the shelves, the boards are riveted to an extruded aluminum frame. An Amphenol connector and spring clip hold the packages in place in the shelves, and adjacent packages are used as guides for each other when replacement is necessary. The shelves are of sheet metal, open at front and rear. Notched lips at the rear facilitate mounting of the Amphenol connectors at required positions. At the front, top and bottom, a bronze spring riveted to the frame holds the packages in place in the connectors. In production models, dummy frames have been provided

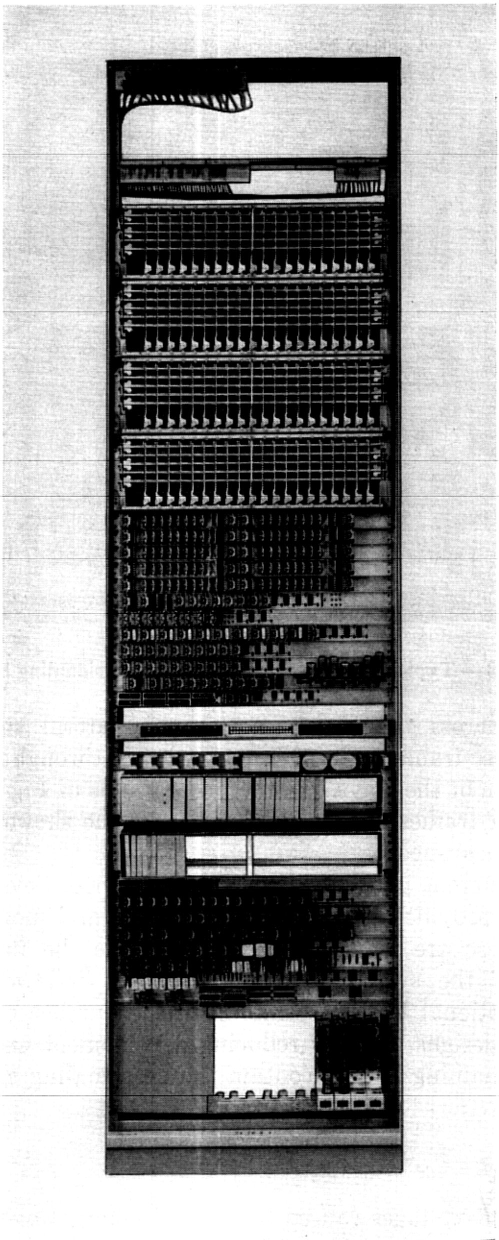

Fig. 7 — Remote circuit arrangement.

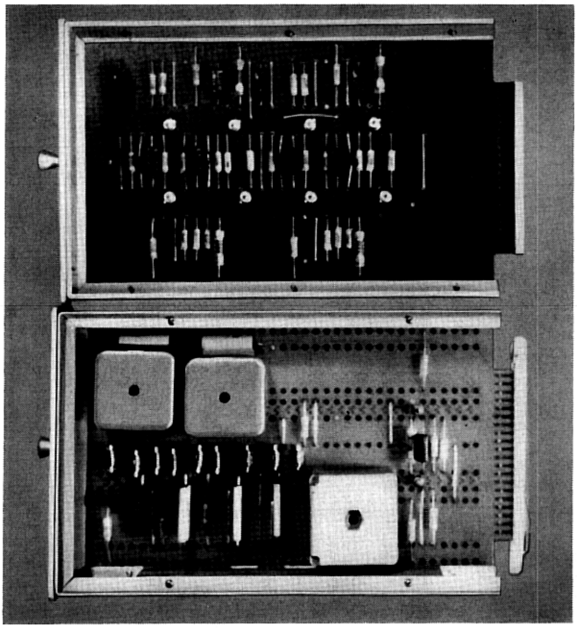

Fig. 8 — Typical logic package (top) and ac signaling board.

at intervals across the shelves to provide lateral stability of the packages. These frame positions are adjustable through slots cut in the top and bottom of the trays. (In the photographs of Figs. 6 and 7 these dummy spacer frames are not present; hence the skewed and variable separation appearance.)

Thirteen different packages have been designed. Seven of these are boards which provide logic gates and bistable and monostable multivibrators. These are interconnected to provide the functional solid-state logic of the system. This method was followed rather than design of functional boards to minimize the number of different circuit package designs, thereby reducing development and maintenance costs. The remaining boards contain the ac signaling circuits and the 3200-pps clock.

6.4 *Noise Interference*

The transient voltages caused by the switching of electromechanical devices create a severe problem in any electronic switching application. Since the packages used in such an application must be interconnected by surface wiring and local cabling, many points of entry exist for noise voltages. Resistor-capacitor filters applied to the critical points have satisfactorily minimized this problem. A second source of noise interference was determined to be through the ground wiring of the system. Potentials as high as several volts existed in the same run during switching operations, and the wiring was found to support high induced voltages at sufficient distances from frame ground. To overcome this problem a solid copper bar 1 inch by $\frac{1}{8}$ inch has been mounted between the two solid-state shelves, and each package is provided with its own connection to this bar. The bar is maintained at frame ground by adequate wiring to the ground supply at the point where the frame is supplied.

6.5 *Relay–Solid-State Interface*

At some point between the reception of information by the ac signaling circuit and the application of this information to operation of the crossbar network, an interface from transistor to relay logic must exist. In the LC2A this interface problem has been satisfied by using a dry reed relay package specially coded for operation with low-current transistors. The relay operates at 40 milliamperes delivered from a twelve-volt supply. The 16A transistor used in the LC2A has a maximum dc current rating of 50 milliamperes; hence is adequate with margin to switch the reed relay.

As information must be passed from the solid-state to the electromechanical circuit, the opposite direction of information transfer also must be achieved. General purpose wire spring relays, reed relays, etc., have the characteristic of contact bounce associated with dry contacts. This bounce can result in interpretation by the solid-state logic as two or more equally valid sequential signals when only one is meant. To prevent such interpretation, mercury contact relays are used wherever such misinterpretation might result in false operation.

VII. MAINTENANCE AND TEST FEATURES

7.1 *General*

Maintenance of the Line Concentrator No. 2A involves problems normally not encountered in local central offices. The system itself may cross operating company boundaries since operation over a range of up to 1000 miles is possible. Remote circuits may be located in unattended offices. These two factors indicate that coordination of maintenance personnel at short notice might be difficult if not impossible.

The combination of relay and transistor switching logic places an extra burden on the maintenance forces if straightforward, relatively simple testing facilities and maintenance practices are not provided. Detection and replacement of a single inoperative component in an electronic circuit can be vexing and time-consuming at best, and in some cases may defy the most experienced engineer equipped with sophisticated test equipment for intolerable periods.

To circumvent this need for detailed diagnosis and repair, the maintenance of the LC2A has been simplified as much as practicable. Facilities for establishing test calls from either the remote or control circuit are provided. Trouble recording is included to narrow the range of speculation when trouble shooting. Test points are extended to test terminals from every logic element of the solid-state circuit in order that suspect units may be monitored. Monitoring is done by a simple logic test set which responds to ac signals, dc levels and short duration (microsecond) dc pulses. When a trouble has been localized to a circuit package, the malfunctioning circuit is replaced by simply removing the bad package and plugging in a spare of the proper type. If trouble is localized to the relay circuits, established procedures for relay circuit maintenance are followed.

7.2 *Test Sets*

For routine maintenance and trouble-detection, a test set designed for use on the B1 data carrier terminal is used. The unit uses solid-state circuits arranged to provide low load on the monitored circuit by presenting a high impedance level. When in use as a pulse or level detector, the test set detects on a go, no-go basis the presence or absence of a minimum voltage and displays the result by causing appropriate lamp indications. The set also may be used to obtain a good approximation of the frequency of sinusoidal signals or the repetition rate of nonsinusoidal periodic waveforms. Thus, every part of the solid-state circuit may be monitored and an indication obtained of proper or improper operation.

One of the "gray" areas in the subject of routine maintenance results from the close tolerance which must be held by the clock circuit. As mentioned before, a variation of more than ± 1 per cent in the clock repetition rate may lead to lost calls or a totally inoperative condition. This indicates periodic checks of the clock repetition rate to insure that tolerance limits are not exceeded. The design of the clock circuit is such that temperature excursions and voltage variations normally occurring in a central office environment will not push operation beyond the limits. What remains an unknown factor is aging of the time-determining components. At any rate, periodic checks of the clock circuit repetition rate with an accurate instrument are required — the required frequency of checks has not as yet been ascertained.

Use of an oscilloscope by experienced personnel may be required under certain conditions where the determination of time relationship of events is necessary to ascertain the trouble. In relay circuits, blocking of key relays and observation of others corresponds to some degree to this use of the oscilloscope. No simple technique is available as a replacement for this method of trouble detection.

VIII. LABORATORY TESTING

8.1 *General*

Laboratory testing of the LC2A was accomplished in three distinct phases. A test to verify the signaling capabilities in the presence of noise was conducted on noise simulator facilities. Following completion of the noise tests, complete system testing of two remote circuits connected back-to-back with the control circuit was conducted. Finally, the system was tested over facilities that were composites of the types of facilities the concentrator would encounter in normal service.

8.2 *Noise Testing*

Testing of the solid-state signaling and logic circuits was conducted to determine the levels of white and in-band impulse noise which would interfere with signaling between two concentrator units. Every valid message combination possible between a remote and control circuit was established; the signaling level was varied beyond the design limits; and noise of varying amplitude and structure was introduced into the signaling channel. The results of these tests showed the signaling capability to be in excess of the requirements, which are:

> The operation of the limiter-demodulator, in a noise environment consisting of in-band noise pulses in the range of 48–53 dbRN and at a rate of 35 counts in 30 minutes, is such that the error rate of received information shall be less than one error in 10^5 bits. The range of operation of the limiter-demodulator is -10 dbm to -30 dbm.

8.3 *Laboratory System Tests*

To insure that all features of the LC2A system functioned properly, back-to-back testing was performed. Both remote circuits were wired directly to the control circuit over zero loop trunks, and signaling circuits and load tests were applied. Upon completion of these tests, repeatered facilities were tested by connecting the concentrator trunks through E-type repeaters and reapplying the load tests. These tests were followed by a much more realistic situation. Long-haul facilities were leased from an operating company with both ends of each of two loops terminated appropriately on both remote circuits, and the control circuit and the load tests were once again applied. Testing over these facilities (shown in Fig. 9) was conducted over a period of one month.

As a result of the entire testing program, several minor deficiencies

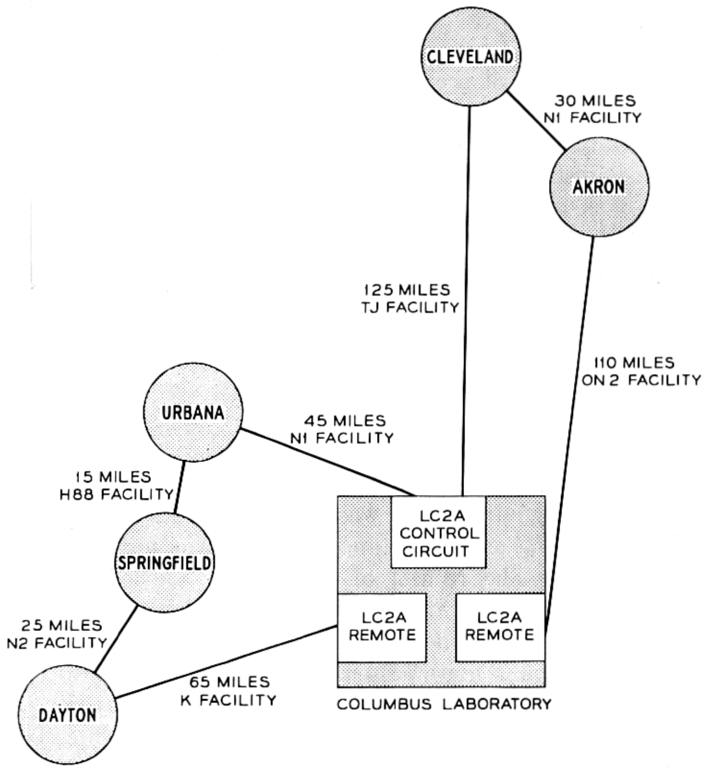

Fig. 9 — Facilities involved in long-haul testing.

which otherwise would not have been detected until after installation in the field were exposed and remedied. Though these shortcomings were minor, the value of the complete testing program undertaken is reflected in the savings obtained through changes made in the shop rather than in the field.

IX. FIELD TESTING

9.1 *General*

Under normal circumstances, a field trial is conducted when a new service or system is introduced to ascertain the adequacy of the design in regard to its performance and customer satisfaction. However, early in the development of the LC2A it was determined that in order to meet the short schedules anticipated, a field trial would not be conducted, but rather an initial installation trial conducted cooperatively by Bell Telephone Laboratories and the operating company would be substituted. Though the time requirement was eased at the completion of the development, it was decided to follow through with the initial installation trial plan.

The first LC2A was installed in Wisconsin and placed in service on April 30, 1964. The control circuit is located in Milwaukee with its two associated remote circuits located in Appleton and Green Bay, Wisconsin. The distances (air miles) between the control and remote circuits are approximately 100 and 125 miles, respectively. The facilities over which the concentrator trunks and the signaling circuits operate are ON carrier. All three circuits (both remote and the control) are located in toll equipment rooms at their respective locations.

Initial system testing was begun in January, 1964, and completed in February, 1964. Load testing similar to that accomplished in the laboratory was first applied, followed by placing dial TWX customers in service on the system after satisfaction that proper operation was being achieved.

The initial installation trial terminated in March, 1965. During the eleven month trial period, status reports, line and trunk development and trouble reports were made by the operating company.

X. CONCLUSION

The LC2A system has met the objectives of providing a longer range for concentration of customers' lines without a penalty of excessive concentrator work time. This has been done through the combination of solid-state logic circuitry, electromechanical switching networks, and frequency shift signaling technique. It was not intended nor should it be construed to be the ultimate in concentrator systems. Rather it can be viewed as the specialized forerunner of a more sophisticated system which, by taking advantage of past, current and future developments in switching techniques, may provide a much wider range of general application.

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