THE BELL SYSTEM TECHNICAL JOURNAL

VOLUME XXXV MARCH 1956 NUMBER 2

Copyright 1956, American Telephone and Telegraph Company

An Experimental Remote Controlled Line Concentrator

By. A. E. JOEL, JR.

(Manuscript received June 30, 1955)

Concentration, which is the process of connecting a number of telephone lines to a smaller number of switching paths, has always been a fundamental function in switching systems. By performing this function remotely from the central office, a new balance between outside plant and switching costs may be obtained which shows promise of providing service more economically in some situations.

The broad concept of remote line concentrators is not new. However, its solution with the new devices and techniques now available has made the possibilities of decentralization of the means for switching telephone connections very promising.

Three models of an experimental equipment have been designed and constructed for service. The models have included equipment to enable the evaluation of new procedures required by the introduction of remote line concentrators into the telephone plant. The paper discusses the philosophy, devices, and techniques.

CONTENTS

1. INTRODUCTION

The equipment which provides for the switching of telephone connections has always been located in what have been commonly called "central offices". These offices provide a means for the accumulation of all switching equipment required to handle the telephone needs of a community or a section of the community. The telephone building in which one or more central offices are located is sometimes referred to as the "wire center" because, like the spokes of a wheel, the wires which serve local telephones radiate in all directions to the telephones of the community.

A new development, made possible largely by the application of devices and techniques new to the telephone switching field, has recently been tried out in the telephone plant and promises to change much of the present conception of "central" offices and "wire" centers. It is known as a "line concentrator" and provides a means for reducing the amount of outside plant cables, poles, etc., serving a telephone central office by dispersing the switching equipment in the outside plant. It is not a new concept to reduce outside plant by bringing the switching equipment closer to the telephone customer but the technical difficulties of maintaining complex switching equipment and the cost of controlling such equipment at a distance have in the past been formidable obstacles to the development of line concentrators. With the invention of low power, small-sized, long-life devices such as transistors, gas tubes, and sealed relays, and their application to line concentrators, and with the development of new local switching systems with greater flexibility, it has been possible to make the progress described herein.

2. OBJECTIVES

Within the telephone offices the first switching equipment through which dial lines originate calls concentrates the traffic to the remaining equipment which is engineered to handle the peak busy hour load with the appropriate grade of service.[1] This concentration stage is different for different switching systems. In the step-by-step system[2] it is the line finder, and in the crossbar systems it is the primary line switch.[3] Proposals for the application of remote line concentrators in the step-by-step system date back over 50 years.[4] Continuing studies over the years have not indicated that any appreciable savings could be realized when such equipment is used within the local area served by a switching center.

When telephone customers move from one location to another within a local service area, it is desirable to retain the same telephone numbers. The step-by-step switching system in general is a unilateral arrangement where each line has two appearances in the switching equipment, one for originating call concentration (the line finder) and one for selection of the line on terminating calls (the connector). The connector fixes the line number and telephone numbers cannot be readily reassigned when moving these switching stages to out-of-office locations.

Common-control systems[5] have been designed with flexibility so that the line number assignments on the switching equipment are independent of the telephone numbers. Furthermore, the first switching stage in the office is bilateral, handling both originating and terminating calls through the same facilities. The most recent common-control switching system in use in the Bell System, the No. 5 crossbar,[3] has the further advantage of universal control circuitry for handling originating and terminating calls through the line switches. For these reasons, the No. 5 crossbar system was chosen for the first attempt to employ new techniques of achieving an economical remote line concentrator.

A number of assumptions were made in setting the design requirements. Some of these are influenced by the characteristics of the No. 5 crossbar system. These assumptions are as follows:

1. No change in customer station apparatus. Standard dial telephones to be used with present impedance levels, transmission characteristics, dial pulsing, party identification, superimposed ac-dc ringing,[6] and signaling and talking ranges.

2. Individual and two-party (full or semi-selective ringing) stations to be served but not coin or PBX lines.

3. Low cost could best be obtained by minimizing the per line equipment in the central office. AMA[7] charging facilities could be used but to avoid per station equipment in the central office no message register operation would be provided.

4. Each concentrator would serve up to 50 lines with the central office control circuits common to a number of concentrators. (Experimental equipment described herein was designed for 60 lines to provide additional facilities for field trial purposes.) No extensive change would be made in central office equipment not associated with the line switches nor should concentrator design decrease call carrying capacities of existing central office equipment.

5. To provide data to evaluate service performance, automatic traffic recording facilities to be integrated with the design.

6. Remote equipment designed for pole or wall mounting as an addition to existing outside plant. Therefore, terminal distribution facilities would not be provided in the same cabinet.

7. Power to be supplied from the central office to insure continuity of telephone service in the event of a local power failure.

8. Concentrators to operate over existing types of exchange area facilities without change and with no decrease in station to central office service range.

9. Maintenance effort to be facilitated by plug-in unit design using the most reliable devices obtainable.

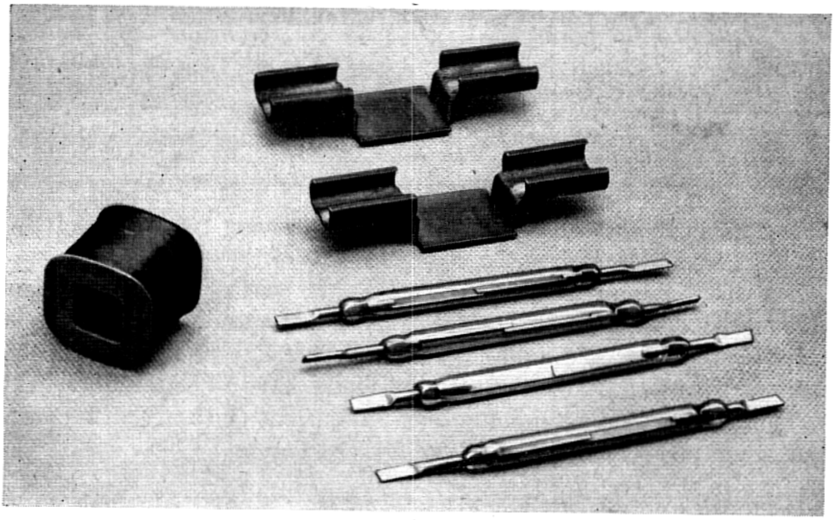
3. NEW DEVICES EMPLOYED

Numerous products of research and development were available for this new approach. Only those chosen will be described.

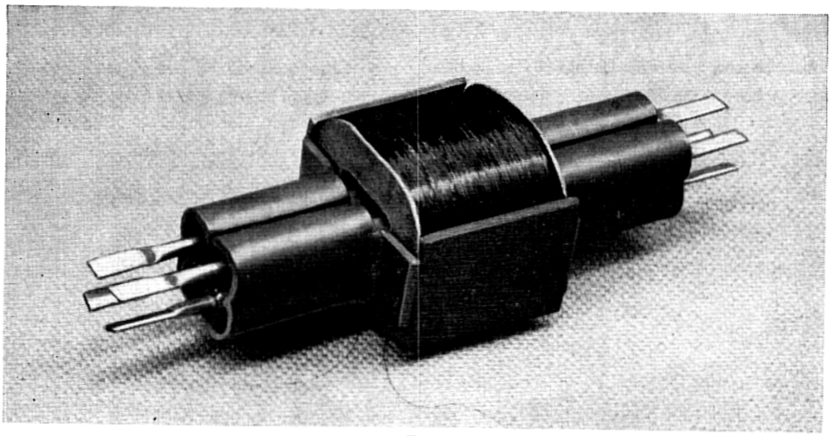
For the switching or "crosspoint" element itself, the sealed reed switch was chosen, primarily because of its imperviousness to dirt.[8] A short coil magnet with magnetic shield for increasing sensitivity of the reed switches were used to form a relay per crosspoint (see Fig. 1).

A number of switching applications[9,10] for crosspoint control using small gas diodes have been proposed by E. Bruce of our Switching Research Department. They are particularly advantageous when used in an "end marking" arrangement with reed relay crosspoints. Also, these diodes have long life and are low in cost. One gas diode is employed for operating each crosspoint (see Fig. 6). Its breakdown voltage is 125v ± 10v. A different tube is used in the concentrator for detecting marking potentials when termination occurs. Its breakdown potential is 100v ± 10v. One of these tubes is used on each connection.

Signaling between the remote concentrator and the central office control circuits is performed on a sequential basis with pulses indicative of the various line conditions being transmitted at a 500 cycle rate. This frequency encounters relatively low attenuation on existing exchange area wire facilities and yet is high enough to transmit and receive information at a rate which will not decrease call carrying capacity of the



A



B

Fig. 1 — Reed switch relay.

central office equipment. To accomplish this signaling and to process the information economically transistors appear most promising.

Germanium alloy junction transistors were chosen because of their improved characteristics, reliability, low power requirements, and margins, particularly when used to operate with relays.[13] Both N-P-N and P-N-P transistors are used. High temperature characteristics are particularly important because of the ambient conditions which obtain on pole mounted equipment. As the trials of this equipment have progressed,

Table I—Transistor Characteristics

Code No.	Type and Filling	Alpha	Max. I_{co} at 28V and 65°C	Emitter Zener Voltage at 20μa
M1868	p-n-p Oxygen	0.9–1.0	150 μa	>735
M1887	n-p-n Vacuum	0.5– .75	100 μa	>735

considerable progress has been made in improving transistors of this type. Table I summarizes the characteristics of these transistors.

For directing and analyzing the pulses, the control employs semiconductor diode gate circuits.[11] The semiconductor diodes used in these circuits are of the silicon alloy junction type.[15] Except for a few diodes operating in the gas tube circuits most diodes have a breakdown voltage requirement of 27v, a minimum forward current of 15 ma at 2v and a maximum reverse current at 22v of 2×10^{-8} amp.

4. NEW TECHNIQUES EMPLOYED

The concentrator represents the first field application in Bell System telephone switching systems which departs from current practices and techniques. These include:

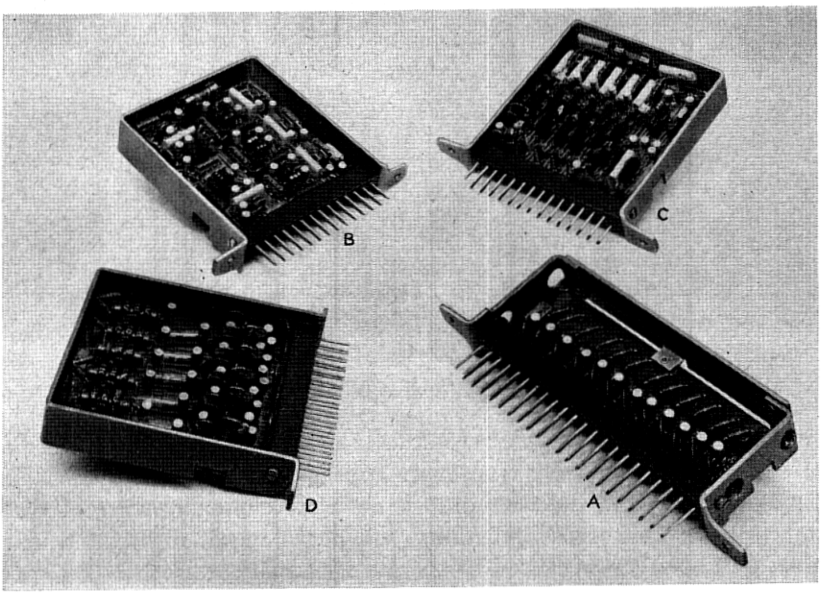


Fig. 2 — Transistor packages. (a) Diode unit. (b) Transistor counter. (c) Transistor amplifiers and bi-stable circuits. (d) Five trunk unit.

1. High speed pulsing (500 pulses per second) of information between switching units.

2. The use of plug-in packages employing printed wiring and encapsulation. (Fig. 2 shows a representative group of these units.)

3. Line scanning for supervision with a passive line circuit. In present systems each line is equipped with a relay circuit for detecting call originations (service requests) and another relay (or switch magnet) for indicating the busy or idle condition of the line, as shown in Fig. 3(a). The line concentrator utilizes a circuit consisting of resistors and semiconductor diodes in pulse gates to provide these same indications. This circuit is shown in Fig. 3(b). Its operation is described later. The pulses for each line appear at a different time with respect to one another. These pulses are said to represent "time slots." Thus a different line is examined each .002 second for a total cycle time (for 60 lines) of .120 second. This process is known as "line scanning" and the portion of the circuit which produces these pulses is known as the scanner. Each of the circuits perform the same functions, viz., to indicate to the central office equipment when the customer originates a call and for terminating calls to indicate if the line is busy.

4. The lines are divided for control and identification purposes into twelve groups of five lines each. Each group of five lines has a different pattern of access to the trunks which connect to the central office. The ten trunks to the central office are divided into two groups as shown in Fig. 4. One trunk group, called the random access group, is arranged in a random multiple fashion, so that each of these trunks is available to approximately one-half of the lines. The other group, consisting of two trunks, is available to all lines and is therefore called the full access group. The control circuitry is arranged to first select a trunk of the random access group which is idle and available to the particular line to which a connection is to be made. If all of the trunks of this random access group are busy to a line to which a connection is desired, an attempt is then made to select a trunk of the full access group. The preference order for selecting cross-points in the random access group is different for each line group, as shown in the table on Fig. 4. By this means, each trunk serves a number of lines on a different priority basis. Random access is used to reduce by 40 per cent the number of individual reed relay crosspoints which would otherwise be needed to maintain the quality of service desired, as indicated by a theory presented some years ago.[12]

5. Built-in magnetic tape means for recording usage data and making call delay measurements. The gathering of this data is greatly facilitated by the line scanning technique.

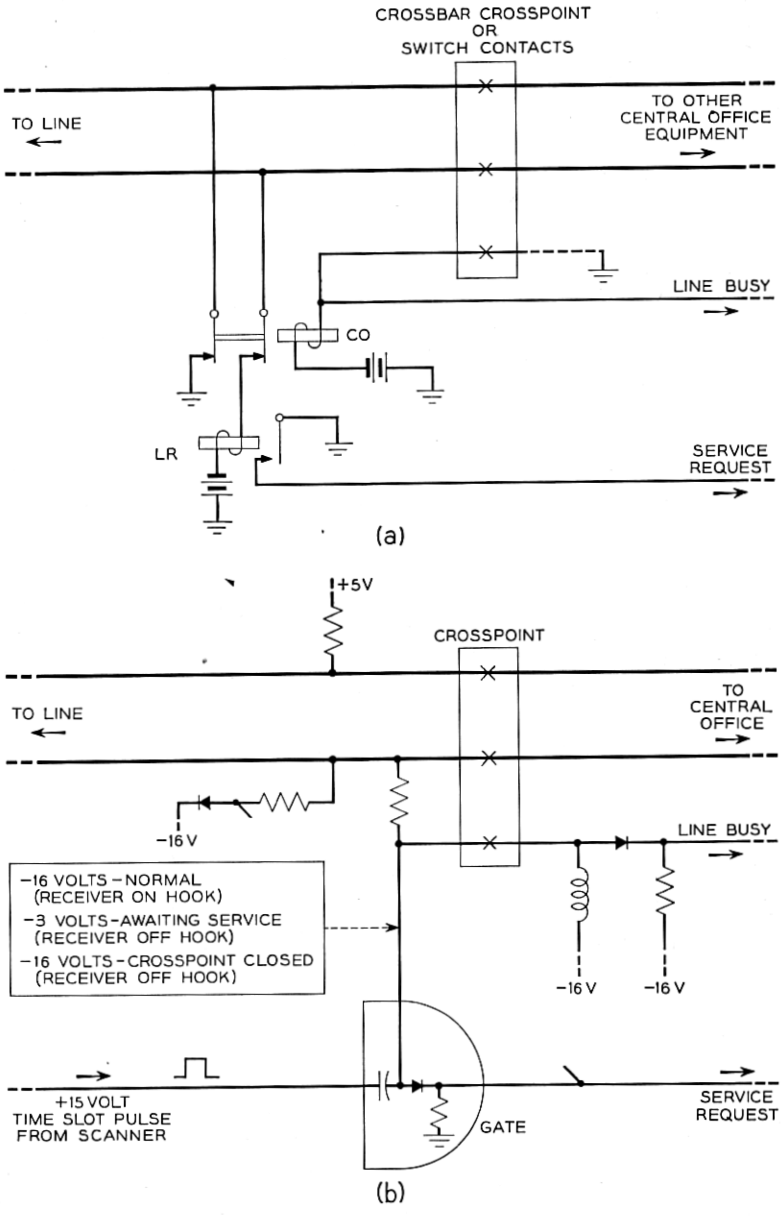


Fig. 3 — (a) Relay line circuit. (b) Passive line circuit.

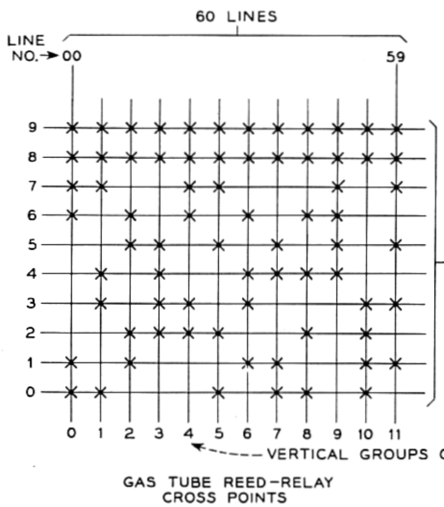
5. SWITCHING PLAN

The plan for serving lines directly terminating in a No. 5 Crossbar office is shown in Fig. 5(a). Each line has access through a primary line switch to 10 line links. The line links couple the primary and secondary switches together so that each line has access to all of the 100 junctors to the trunk link switching stage. Each primary line switch group accommodates from 19 to 59 lines (one line terminal being reserved for no-test calls). A line link frame contains 10 groups of primary line switches.[14]

The remote concentrator plan merely extends these line links as trunks to the remote location. However, an extra crossbar switching stage is introduced in the central office to connect the links to the secondary line switches with the concentrator trunks as shown in Fig. 5(b). Since each line does not have full access to the trunks, the path chosen by the marker to complete calls through the trunk link frame may then be independent of the selection of a concentrator trunk with access to the line. This arrangement minimizes call blocking, simplifies the selection of a matched path by the marker, and the additional crossbar switch hold magnet serves also as a supervisory relay to initiate the transmission of disconnect signals over the trunk.

In addition to the 10 concentrator trunks used for talking paths, 2 additional cable pairs are provided from each concentrator to the central office for signaling and power supply purposes. The use of these two pairs of control conductors is described in detail in Section 6g.

The concentrator acts as a slave unit under complete control of the central office. The line busy and service request signals originate at the



CONCENTRATOR TRUNKS

9	9	9	9	9	9	9	9	9	9	9	9
8	8	8	8	8	8	8	8	8	8	8	8
6	0	5	4	7	5	3	1	4	7	2	1
7	3	1	5	2	0	6	4	6	5	0	3
1	7	2	3	6	2	4	0	0	6	3	5
0	4	6	2	3	7	1	5	2	4	1	7
0	1	2	3	4	5	6	7	8	9	10	11

ORDER OF PREFERENCE

Fig 4. — Concentrator trunk to line crosspoint pattern and preference order

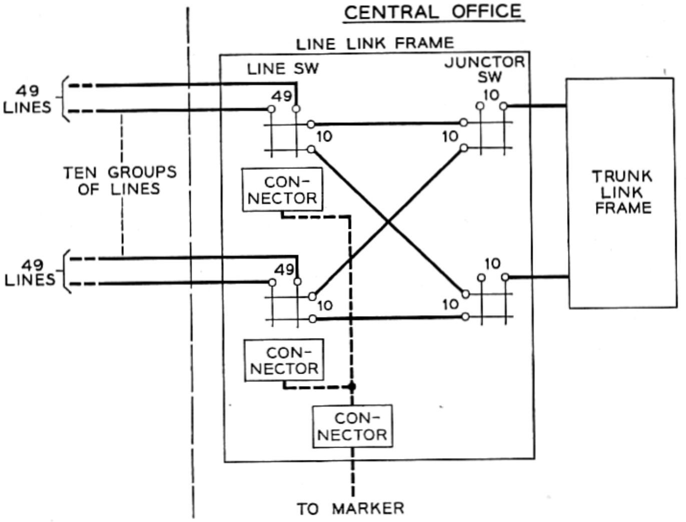


Fig. 5(a) — No. 5 crossbar system subscriber lines connected to line link frame.

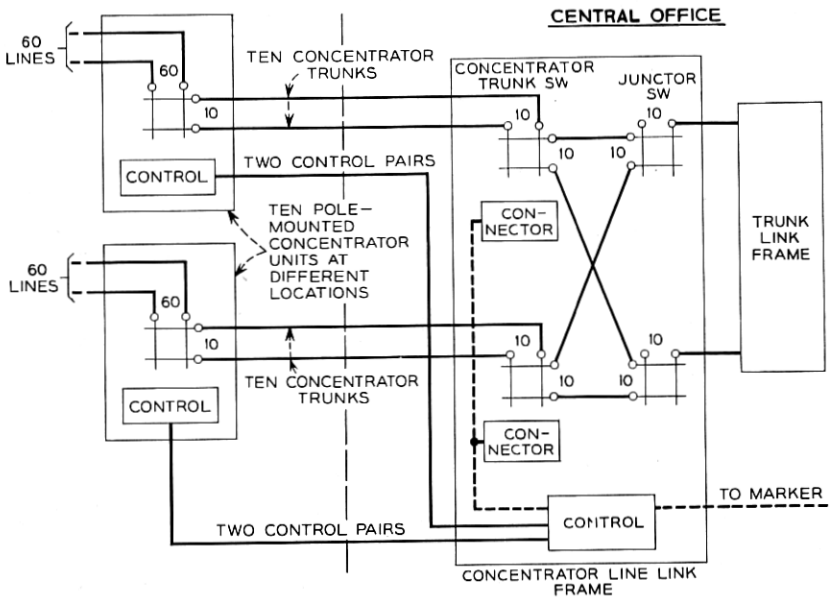


Fig. 5(b) — No. 5 crossbar system subscriber lines connected to remote line concentrators.

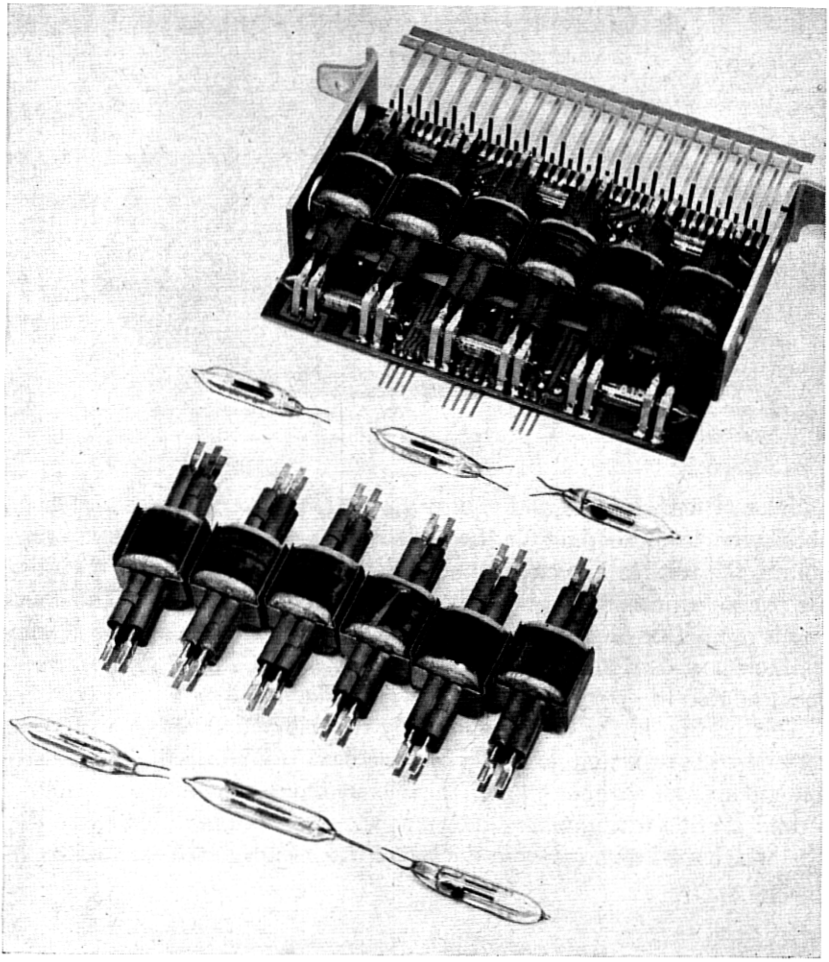


Fig. 6 — Line unit construction.

concentrator only in response to a pulse in the associated time slot or when a crosspoint operates (a line busy pulse is generated under this condition as a crosspoint closure check). The control circuit in the central office is designed to serve 10 remote line concentrators connected to a single line link frame. In this way the marker deals with a concentrator line link frame as it would with a regular line link frame and the marker modifications are minimized.

The traffic loading of the concentrator is accomplished by fixing the

Fig. 7(a) — Line unit.

number of trunks at 10 and equipping or reassigning lines as needed to obtain the trunk loading for the desired grade of service. The six cross-points, the passive line circuit and scanner gates individual to each line are packaged in one plug-in unit to facilitate administration. The cross-points are placed on a printed wiring board together with a comb of plug contacts as shown in Fig. 6. The entire unit is then dipped in rubber and encapsulated in epoxy resin, as shown in Fig. 7(a).

This portion of the unit is extremely reliable and therefore it may be considered as expendable, should a rare case of trouble occur. The passive line circuit and scanner gate circuit elements are mounted on a smaller second printed wiring plate (known as the "line scanner" plate, see Fig. 7(b) which fits into a recess in the top of the encapsulated line unit. Cir-

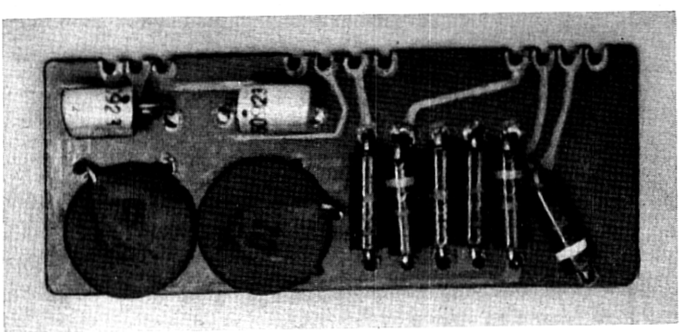


Fig. 7(b) — Scanner plate of the line unit shown in Fig. 7 (a).

cuit connection between printed wiring plates is through pins which appear in the recess and to which the smaller plate is soldered.

6. BASIC CIRCUITS

a. *Diode Gates*

All high speed signaling is on a pulse basis. Each pulse is positive and approximately 15 volts in amplitude. There is one basic type of diode gate circuit used in this equipment. By using the two resistors, one condenser and one silicon alloy junction diode in the gate configuration shown in Fig. 8, the equivalents of opened or closed contacts in relay circuits are obtained. These configurations are known respectively as enabling and inhibiting gates and are shown with their relay equivalents in Figs. 8(a) and 8(b).

In the enabling gate the diode is normally back biased by more than the pulse voltage. Therefore pulses are not transmitted. To enable or

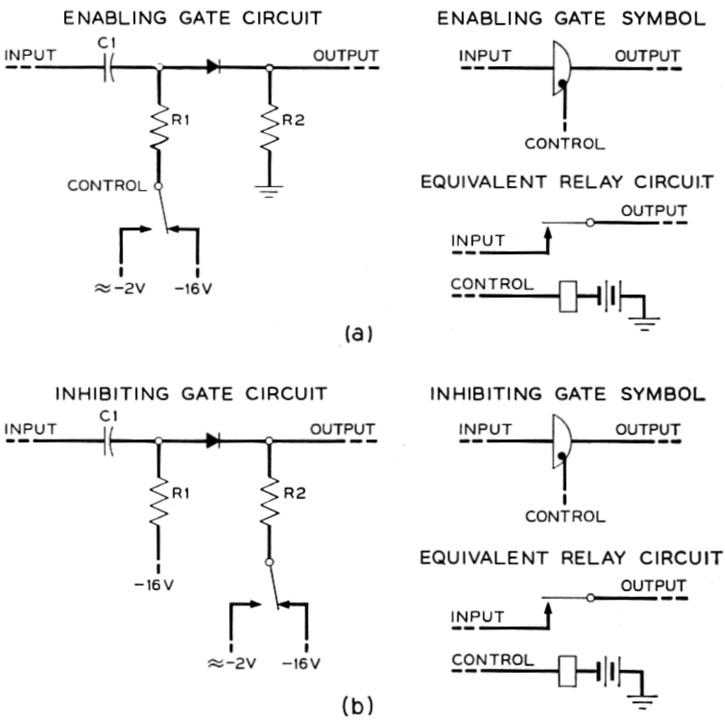


Fig. 8 — Gates and relay equivalents.

open the gate the back bias is reduced to a small reverse voltage which is more than overcome by the signal pulse amplitude of the pulse. The pulse thus forward biases the diode and is transmitted to the output.

The inhibiting gate has its diode normally in the conducting state so that a pulse is readily transmitted from input to output. When the bias is changed the diode is heavily back biased so that the pulse amplitude is insufficient to overcome this bias.

The elements of 12 gates are mounted on a single printed wiring board with plug-in terminals and a metal enclosure as shown in Fig. 2(a). All elements are mounted in one side of the board so that the opposite side may be solder dipped. After soldering the entire unit (except the plug) is dipped in a silicone varnish for moisture protection.

b. *Transistor Bistable Circuit*

Transistors are inherently well adapted to switching circuits using but two states, on (saturated) or off.[16] In these circuits with a current gain greater than unity a negative resistance collector characteristic can be obtained which will enable the transistor to remain locked in its conducting state (high collector current flowing) until turned off (no collector current) by an unlocking pulse. At the time the concentrator development started only point contact transistors were available in quantity. Point contact transistors have inherently high current gains (>1) but the collector current flowing when in the normal or unlocked condition (I_{co}) was so great that at high ambient temperatures a relay once operated in the collector circuit would not release.

Junction transistors are capable of a much greater ratio of on to off current in the collector circuit. Furthermore their characteristics are amenable to theoretical design consideration.[13] However, the alpha of a simple junction transitor is less than unity. To utilize them as one would a point contact transitor in a negative resistance switching circuit, a combination of n-p-n and p-n-p junction transistors may be employed, see Fig. 9(b). Two transistors combined in this manner constitute a "hooked junction conjugate pairs." This form of bi-stable circuit was used because it requires fewer components and uses less power than an Eccles-Jordan bistable circuit arrangement. It has the disadvantage of a single output but this was not found to be a shortcoming in the design of circuits employing pulse gates of the type described. In what follows the electrodes of the transistor will be considered as their equivalents shown in Fig. 9(b).

The basic bi-stable circuit employed is shown in Fig. 10. The set

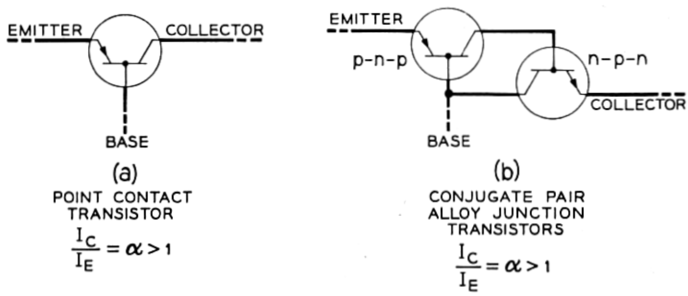


Fig. 9 — Point contact versus hooked conjugate pair.

pulse is fed into the emitter (of the pair) causing the emitter diode to conduct. The base potential is increased thus increasing the current flowing in the collector circuit. When the input pulse is turned off the base is left at about −2 volts thus maintaining the emitter diode conducting and continuing the increased current flow in the collector circuit. The diode in the collector circuit prevents the collector from going positive and thereby limits the current in the collector circuit. To reset, a positive pulse is fed into the base through a pulse gate. The driving of the base positive returns the transistor pair to the off condition.

c. *Transistor Pulse Amplifier*

This circuit (Fig. 11) is formed by making a bi-stable self resetting circuit. It is used to produce a pulse of fixed duration in response to a

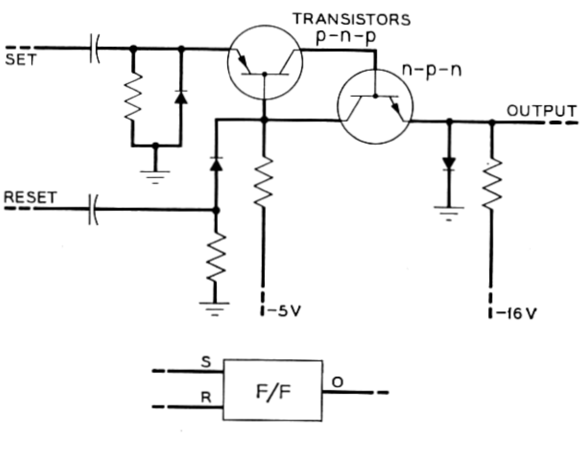


Fig. 10 — Transistor bi-stable circuit.

pulse of variable width (within limits) on the input. Normally the emitter is held slightly negative with respect to the base. The potential difference determines the sensitivity of the amplifier. When a positive input pulse is received, the emitter diode conducts causing an increase in collector current. The change in bias of the diode in the emitter circuit permits it to conduct and charge the condenser. With the removal of the input pulse the discharge of the condenser holds the transistor pair on. The time constant of the circuit determines the on time. When the emitter potential falls below the base potential, the transistor pair is turned off.

The amplifiers and bi-stable circuits or flip-flops, as they are called more frequently, are mounted together in plug-in packages. Each package contains 8 basic circuits divided 7-1, 6-2, or 2-6, between amplifiers and flip-flops. Fig. 2(c) shows one of these packages. They are smaller than the gate or line unit packages, having only 28 terminals instead of 42.

The transistors for the field trial model were plugged into small hearing aid sockets mounted on the printed wiring boards. For a production model it would be expected that the transistors would be soldered in.

d. *Transistor Ring Counter*

By combining bi-stable transistor and diode pulse gate circuits together in the manner shown in Fig. 12 a ring counter may be made, with

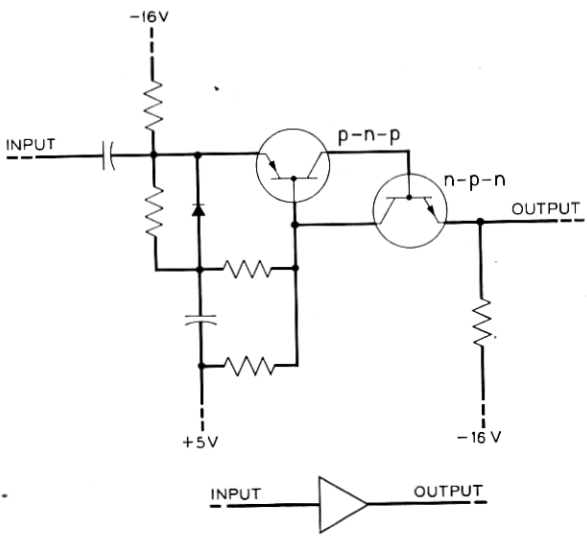


Fig. 11 — Transistor pulse amplifier.

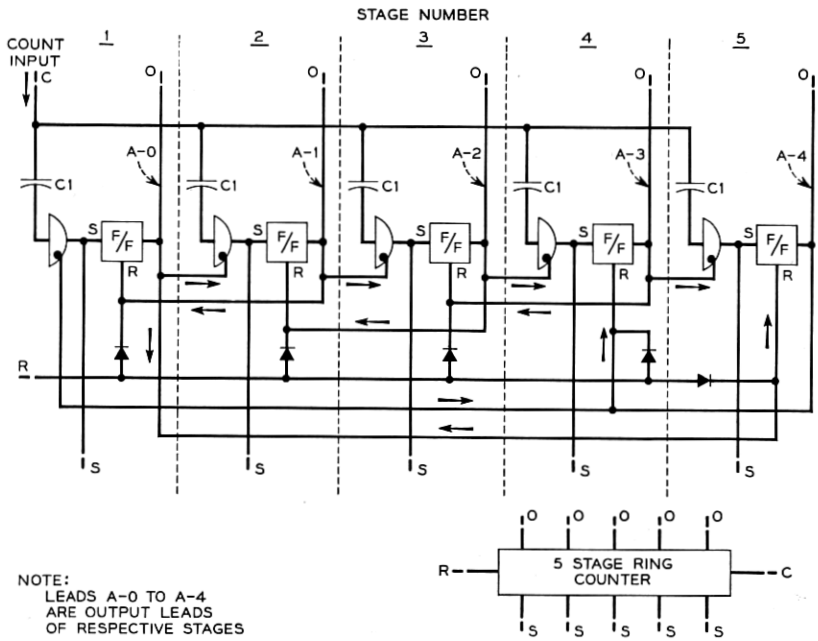


Fig. 12 — Ring counter schematic.

a bi-stable circuit per stage. The enabling gate for a stage is controlled by the preceding stage allowing it to be set by an input advance pulse. The output signal from a stage is fed back to the preceding stage to turn it off. An additional diode is connected to the base of each stage for resetting when returning the counter to a fixed reference stage.

A basic package of 5 ring counter stages is made up in the same framework and with the same size plug as the flip-flop and amplifier packages, see Fig. 2(b). A four stage ring counter is also used and is the same package with the components for one stage omitted. The input and output terminals of all stages are available on the plug terminals so that the stages may be connected in any combination and form rings of more than 5 stages. The reset lead is connected to all but the one stage which is considered the first or normal stage.

Other transistor circuits such as binary counters and square wave generators are used in small quantity in the central office equipment. They will not be described.

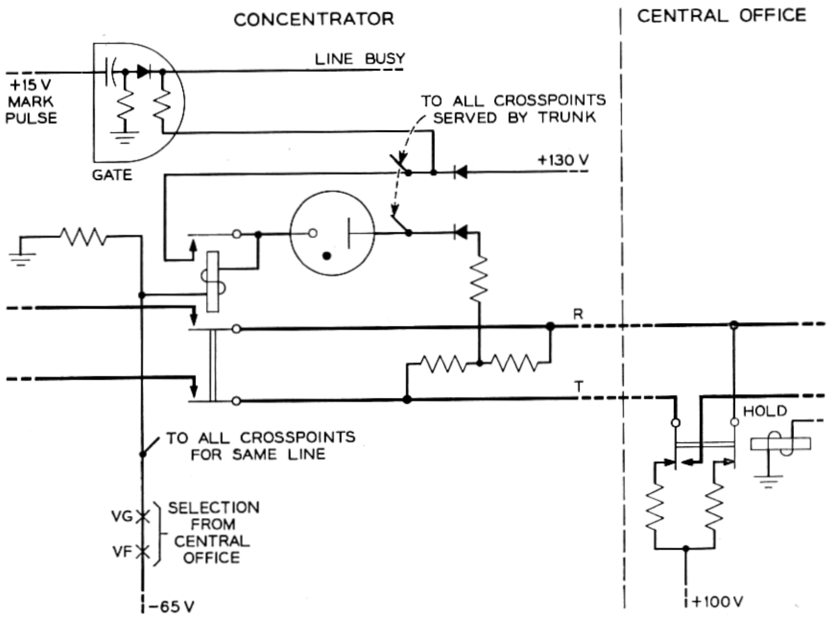


Fig. 13 — Crosspoint operating circuit.

e. *Crosspoint Operating Circuit*

The crosspoint consists of a reed relay with 4 reed switches and a gas diode (Fig. 1). The selection of a crosspoint is accomplished by marking with a negative potential (−65 volts) all crosspoints associated with a line, and marking with a positive potential (+100 volts) all crosspoints associated with a trunk (Fig. 13). The line is marked through a relay circuit set by signals sent over the control pair from the central office. The trunk is marked by a simplex circuit connected through the break contacts of the hold magnet of the crossbar switch associated with the trunk in the central office. Only one crosspoint at a time is exposed to 165 volts which is necessary and sufficient to break down the gas diode to its conducting state. The reed relay operates in series with the gas diode. A contact on the relay shunts out the gas diode. When the marking potentials are removed the relay remains energized in a local 30-volt circuit at the concentrator. The holding current is approximately 2.5 ma.

This circuit is designed so that ringing signals in the presence or absence of line marks will not falsely fire a crosspoint diode. Furthermore, a line or trunk mark alone should not be able to fire a crosspoint diode on a busy line or trunk.

When the crosspoint operates, a gate which has been inhibiting pulses is forward biased by the −65 volt signal through the crosspoint relay winding. The pulse which initiates the mark operations at the concentrator then passes through the gate to return a line busy signal to the central office over this control pairs which is interpreted as a crosspoint closure check signal.

f. *Crosspoint Release Circuit*

The hold magnet of the central office crossbar switch operates, removing the +100-volt operate mark signal after the crosspoint check signal is received. A slow release relay per trunk is operated directly by the hold magnet. When the central office connection in the No. 5 crossbar system releases, the hold magnet is released. As shown in Fig. 14, with the hold magnet released and the slow release relay still operated, a −130-volt signal is applied in a simplex circuit to the trunk to break down a gas tube provided in the trunk circuit at the concentrator. This tube in

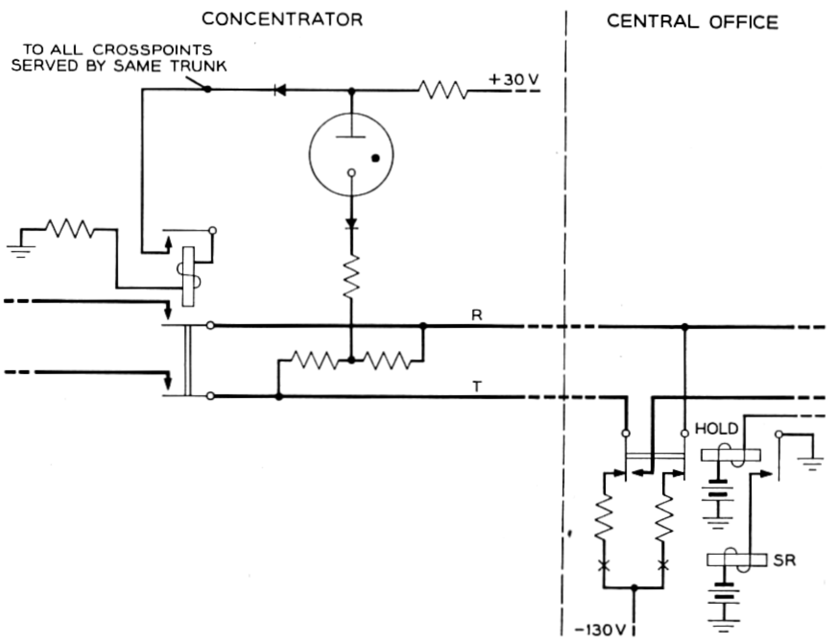


Fig. 14 — Crosspoint release circuit.

breaking down shunts the local holding circuit of the crosspoint causing it to release. The −130-volt disconnect signal is applied during the release time of the slow release relay which is long enough to insure the release of the crosspoint relay at the concentrator.

The release circuit is individual to the trunk and independent of the signal sent over the control pairs.

g. *Pulse Signalling Circuits*

To control the concentrator four distinct pulse signals are transmitted from the central office. Two of these at times must be transmitted simultaneously, but these and the other two are transmitted mutually exclusively. In addition, service request and line busy signals are transmitted from the concentrator to the central office. The two way transmission of information is accomplished on each pair by sending signals in each direction at different times and inhibiting the receipt of signals when others are being transmitted.

To transmit four signals over two such pairs, both positive and nega-

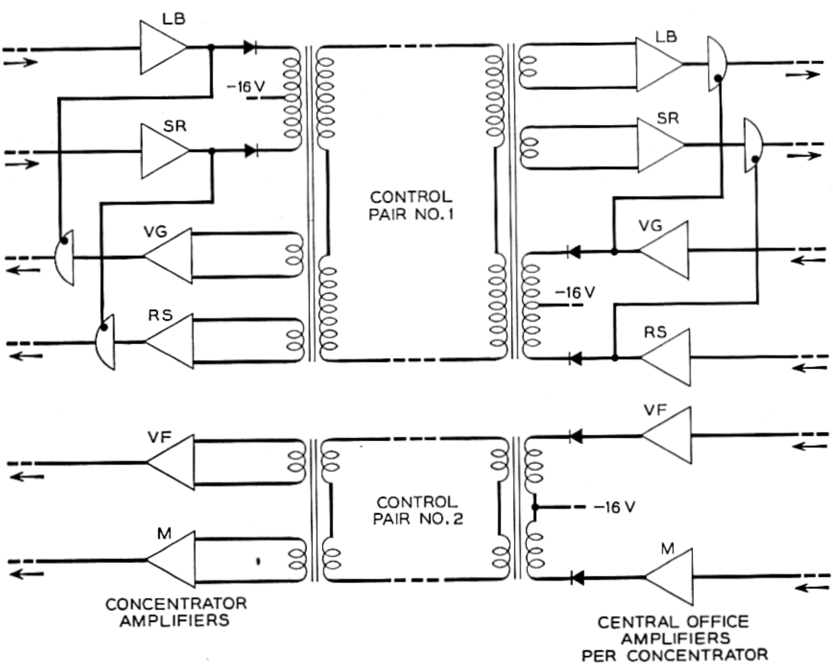


Fig. 15. — Signal transmission circuit.

tive pulses are employed. Diodes are placed in the legs of a center tapped transformer, as shown in Fig. 15, to select the polarity of the transmitted pulses. At the receiving end the desired polarity is detected by taking the signal as a positive pulse from a properly poled winding of a transformer. The amplifier, as described in Section 6c responds only to positive pulses. If pulses of the same polarity are transmitted in the other direction over the same pair, as for control pair No. 1, the outputs of the receiving amplifier for the same polarity pulse are inhibited whenever a pulse is transmitted.

As shown in Fig. 15, the service request and line busy signals are transmitted from the concentrator to the central office over one pair of conductors as positive and negative pulses respectively. The transmission of these pulses gates the outputs of two of the receiving amplifiers at the concentrator to permit the receipt of the polarized signals from the central office. This prevents the pulses from being used at the sending end. A similar gating arrangement is used with respect to the signals when sent over this control pair from the central office. The pulses designated VG or RS never occur when a pulse designated SR or LB is sent in the opposite direction. The transmission of the VF pulse over control pair No. 2 is processed by the concentrator circuit and becomes the SR or LB pulses. In section 7 the purpose of these pulses is described.

The signaling range objective is 1,200 ohms over regular exchange area cable including loaded facilities from station to central office.

h. *Power Supply*

Alternating current is supplied to the concentrator from a continuous service bus in the central office. The power supply path is a phantom circuit on the two control pairs as shown in Fig. 16. The power transformer has four secondary windings used for deriving from bridge rectifiers four basic dc voltages. These voltages and their uses are as follows: -16 volts (regulated) for transistor collector circuits and gate biases, $+5$ volts (regulated) for transistor base biases, $+30$ volts (regulated) for crosspoints holding circuits and -65 volts for the marking and operating of the line crosspoints. For this latter function a reference to the central office applied $+100$ volt trunk mark is necessary. The reference ground for the concentrator is derived from ground applied to a simplex circuit on the power supply phantom circuit. Series transistors and shunt silicon diodes with fixed reference breakdown voltages are used to regulate dc voltages.

Total power consumption of the concentrator is between 5 and 8 watts depending upon the number of connections being held.

7. CONCENTRATOR OPERATION

a. *Line Scanning*

The sixty lines are divided into 12 groups of 5 lines each. These groupings are designated VG and VF respectively corresponding to the vertical group and file designations used in the No. 5 crossbar system. Each concentrator corresponds to a horizontal group in that system.

To scan the lines two transistor ring counters, one of 12 stages and one of 5 stages, are employed as shown in Fig. 17. These counters are driven from pulses supplied from the central office control circuits and only one stage in each is on at any one time. The steps and combinations of these counters correspond to the group and file designation of a particular line. Each 0.002 second the five stage counter (VF) takes a step and between the fifth and sixth pulse the 12-stage counter (VG) is stepped. Thus the 5-stage counter receives 60 pulses or re-cycles 12 times in 120 milliseconds while the 12-stage counter cycles but once.

Each line is provided with a scanner gate. The collector output of each each stage of the VG counter biases this gate to enable pulses which are generated by the collector circuit of the 5-stage counter to pass on

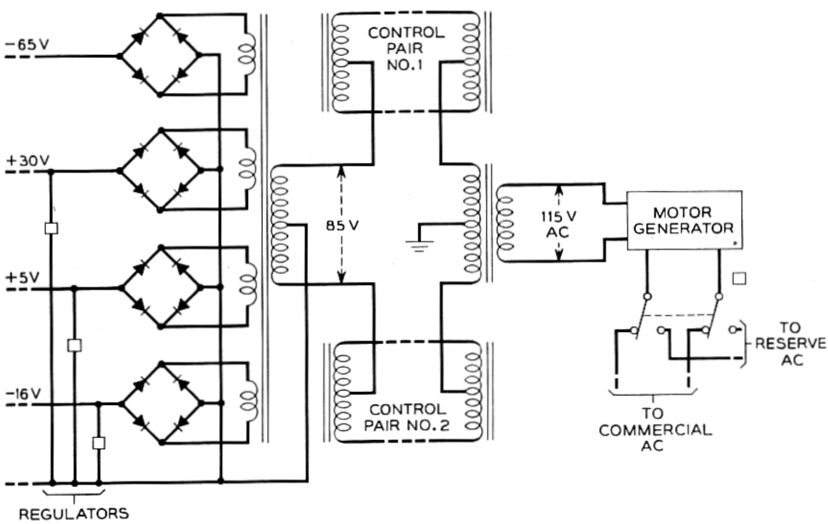


Fig. 16 — Power supply transmission circuit.

to the gate of the passive line circuit, Fig. 3(b). If the line is idle the pulses are inhibited. If the receiver is off-hook requesting service (no crosspoint closed) then the gate is enabled, the pulse passes to the service request amplifier and back to the central office in the same time slot as the pulse which stepped the VF counter. If the line has a receiver off-hook and is connected to a trunk the pulse passes through a contact of the crosspoint relay to the line busy amplifier and then to the central office in the same time slot.

At the end of each complete cycle a reset pulse is sent from the central office. This pulse instead of the VG pulse places the 12-stage counter in its first position. It also repulses the 5 stage VF counter to its fifth stage so that the next VF pulse will turn on its first stage to start the next cycle. The reset pulse insures that, in event of a lost pulse or defect in a counter stage, the concentrator will attempt to give continuous service without dependence on maintaining synchronism with the central office scanner pulse generator. Fig. 18(a) shows the normal sequence of line scanning pulses.

When a service request pulse is generated, the central office circuits

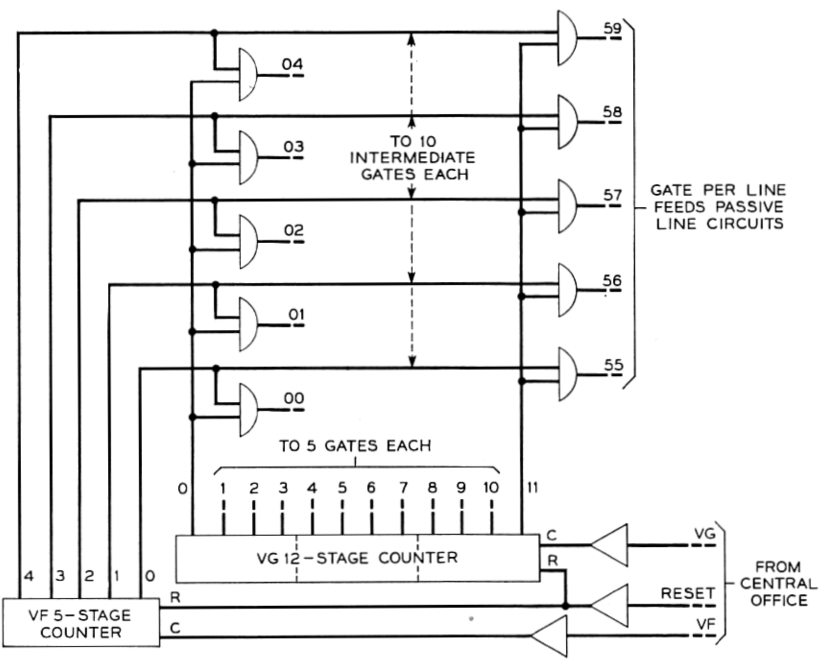


Fig. 17 — Diode matrix for scanning lines.

common to 10 concentrators interrupt the further transmission of the vertical group pulse so that the line scanning is confined to the 5 lines in the vertical group in which the call originated. In this way the central office will receive a service request pulse at least every 0.010 sec as a check that the call has not been abandoned while awaiting service. Fig. 18(b) shows the detection of a call origination and the several short scan cycles for abandoned call detection.

b. *Line Selection*

When the central office is ready to establish a connection at the concentrator a reset pulse is sent to return the counters to normal. In general, the vertical group and vertical file pulses are sent simultaneously to reduce holding time of the central office equipment and to minimize marker delays caused by this operation. For this reason the VG and VF pulses are each transmitted over different control pairs from the central office. The same polarity is used.

On originating calls it is desirable to make one last check that the call has not been abandoned, while on terminating calls it is necessary

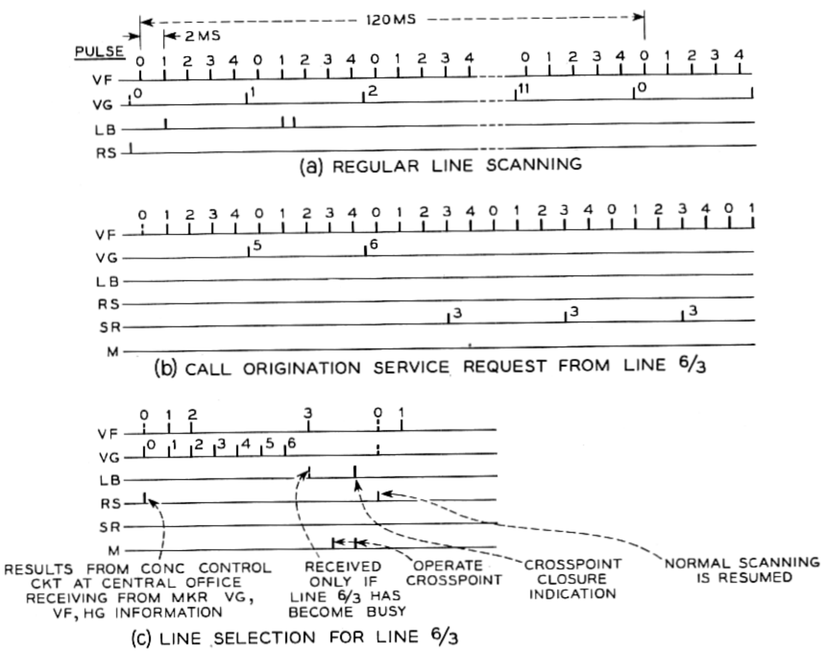


Fig. 18 — Pulse sequences. (a) Regular. (b) Call origination. (c) Line selection.

to determine if the line is busy or idle. These conditions are determined in the same manner as described for line scanning since a service request condition would still prevail on the line if the call was not abandoned. If the line was busy, a line busy condition would be detected. However to detect these conditions a VF pulse must be the last pulse transmitted since the stepping of the VF counter generates the pulse which is transmitted through an enabled line selection and passive line circuit gates. Fig. 18(c) shows a typical line selection where the number of VF pulses is equal to or less than the number of VG pulses. In all other cases there is no conflict and the sending of the last VF pulse need not be delayed. On terminating calls, the line busy indication is returned to the central office within 0.002 sec after the selection is complete. During selections the central office circuits are gated to ignore any extraneous service request or line busy pulses produced as a result of steps of the VF counter prior to its last step.

c. *Crosspoint Operation and Check*

Associated with each concentrator transistor counter stage is a reed relay. These relays are connected to the transistor collector circuits through diodes of the counter stages when relay M operates. The contacts of these reed relays are arranged in a selection circuit as shown in Fig. 19 and apply the −65 volt mark potential to the crosspoint relays of the selected line.

After a selection is made as described above a "mark" pulse is sent from the central office. This pulse is transmitted as a pulse of a different polarity over the same control pair as the VF pulses. The received pulse after amplification actuates a transistor bistable circuit which has the M reed relay permanently connected in its collector circuit. The bi-stable circuit holds the M relay operated during the crosspoint operation to maintain one VF and one VG relay operated, thereby applying −65 volts to mark and operate one of the 6 crosspoint relays of the selected line as described in section 6e, and shown on Fig. 13.

The operation and locking of the crosspoint relay with the marking potentials still applied enables a pulse gate associated with the holding circuit of the crosspoint relays in each trunk circuit. The mark pulses are sent out continuously. This does not affect the bi-stable transistor circuit once it has triggered but the mark pulse is transmitted through the enabled crosspoint closure check gate shown in Fig. 20 and back to the central office as a line busy signal.

With the receipt of the crosspoint closure check signal the sending of the mark pulses is stopped and a reset pulse is sent to the concentrator to return the mark bi-stable circuit, counters and all operated selector relays to normal. The concentrator remains in this condition until it is resynchronized with the regular line scanning cycle.

A complete functional schematic of the concentrator integrating the circuits described above is shown in Fig. 21. Fig. 22(a) and (b) show an experimental concentrator built for field tests.

8. CENTRAL OFFICE CIRCUITS

The central office circuits for controling one or more concentrators are composed of wire spring relays as well as transistors, diode and reed

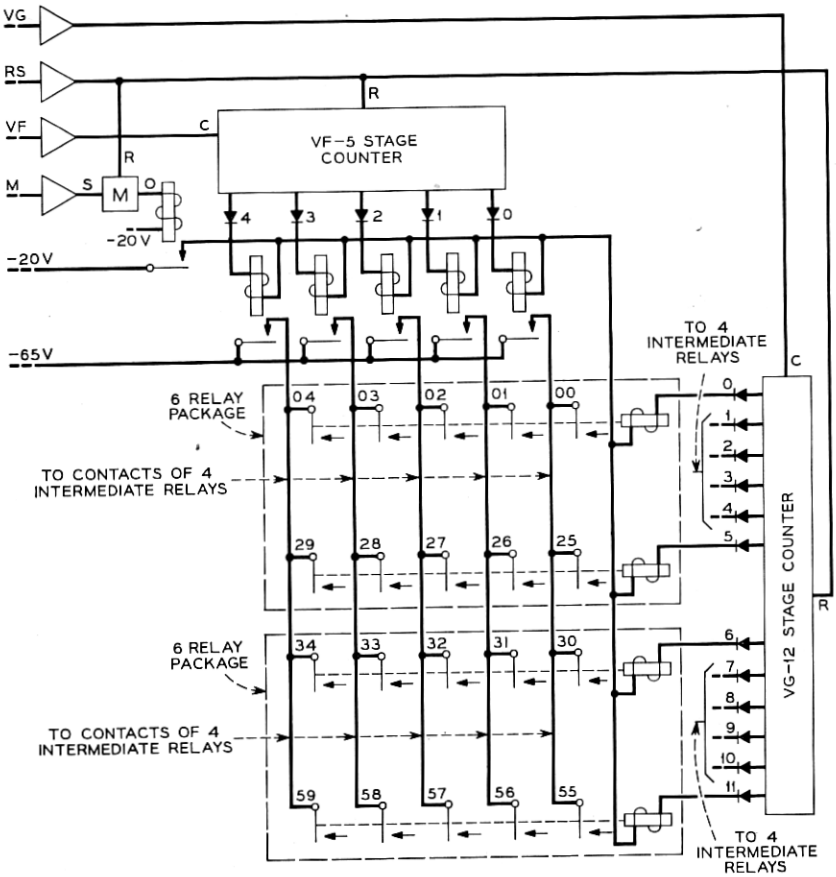


Fig. 19 — Line selection and marking.

relay packages similar to those used in the concentrator. The reed relays are energized by transistor bi-stable circuits in the same manner as described in Section 7c. The reed relay contacts in turn operate wire spring relays or send the dc signals directly to the regular No. 5 crossbar marker and line link marker connector circuits.

Fig. 23 shows a block diagram of the central office circuits. A small amount of circuitry is provided for each concentrator. It consists of the following:

1. The trunk connecting crossbar switch and associated slow relays for disconnect control.

2. The concentrator control trunk circuits and associated pulse amplifiers.

3. An originating call detector to identify which concentrator among the ten served by the frame is calling.

4. A multicontact relay to connect the circuits individual to each concentrator with the common control circuits associated with the line link frame and markers.

The circuits associated with more than one concentrator are blocked out in the lower portion of Fig. 23. Much of this circuitry is similar to the relay circuits now provided on regular line link frames in the No. 5 crossbar system.[3] Only those portions of these blocks which employ the new techniques will be covered in more detail. These portions consist of the following:

1. The scanner pulse generator.

2. The originating line number register.

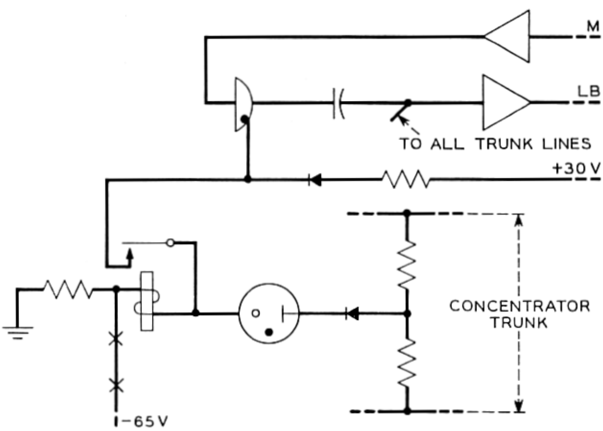
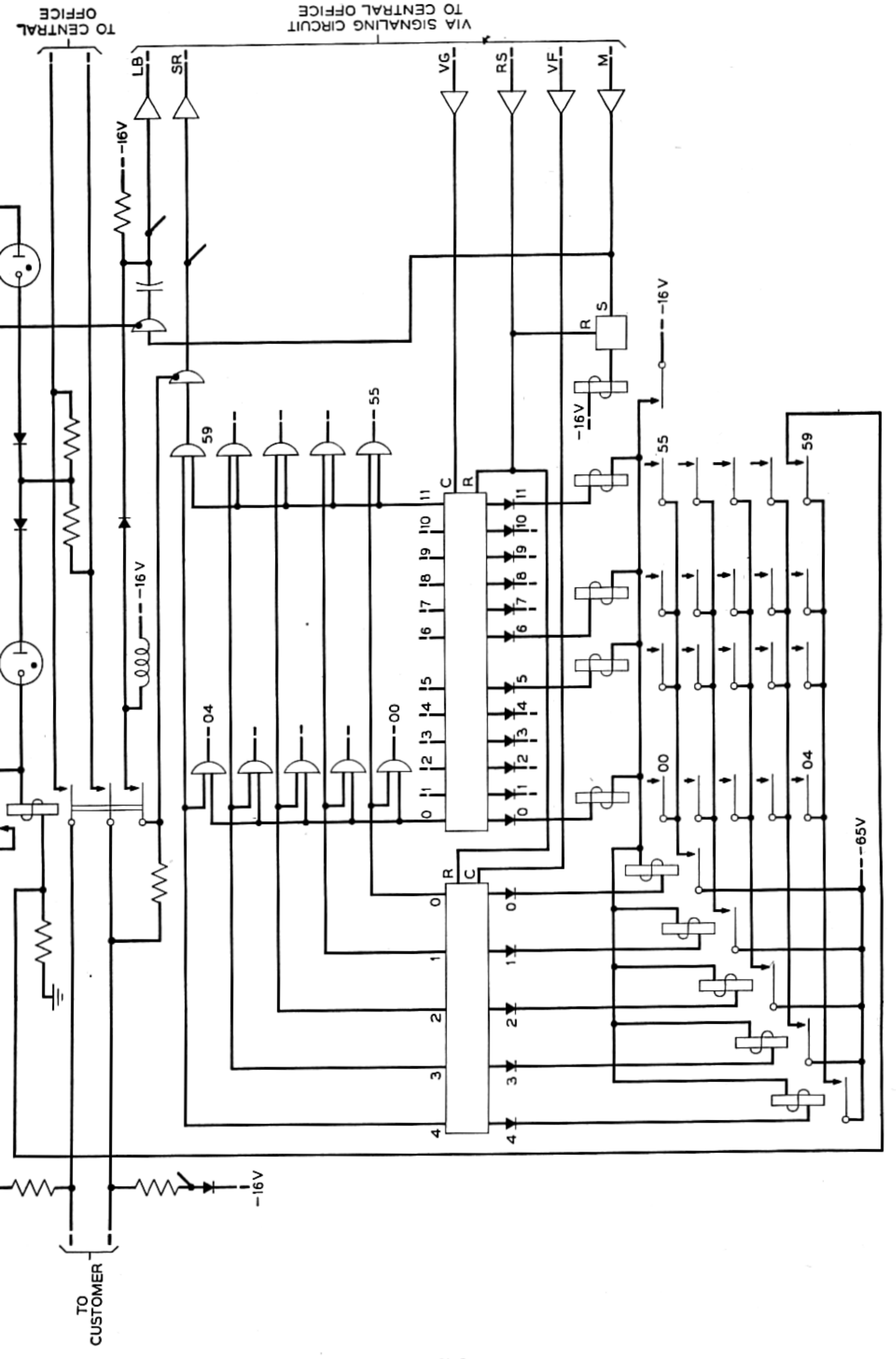


Fig. 20 — Crosspoint closure check.


TO CENTRAL OFFICE
VIA SIGNALING CIRCUIT TO CENTRAL OFFICE
LB
SR
VG
RS
VF
M
-16V
-65V
55
59
00
04
C
R
S
TO CUSTOMER

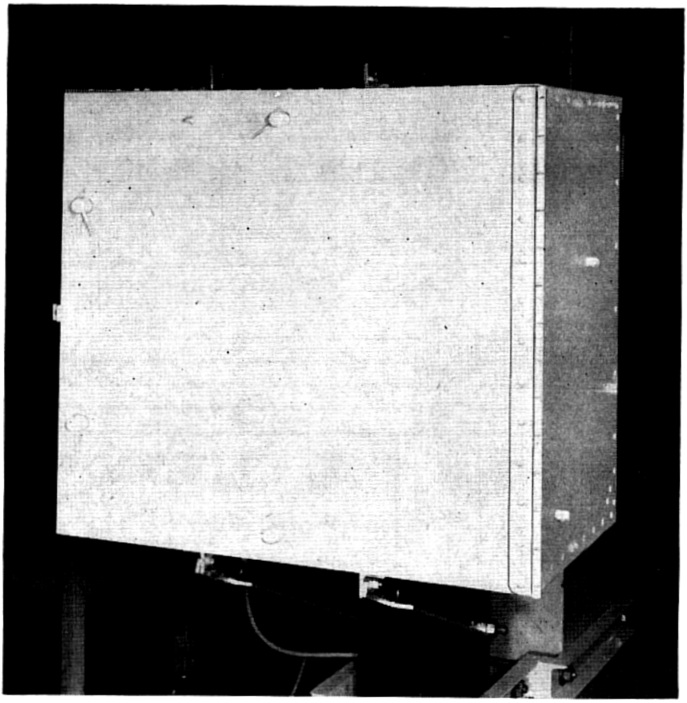


Fig. 22(a) — Complete line concentrator unit.

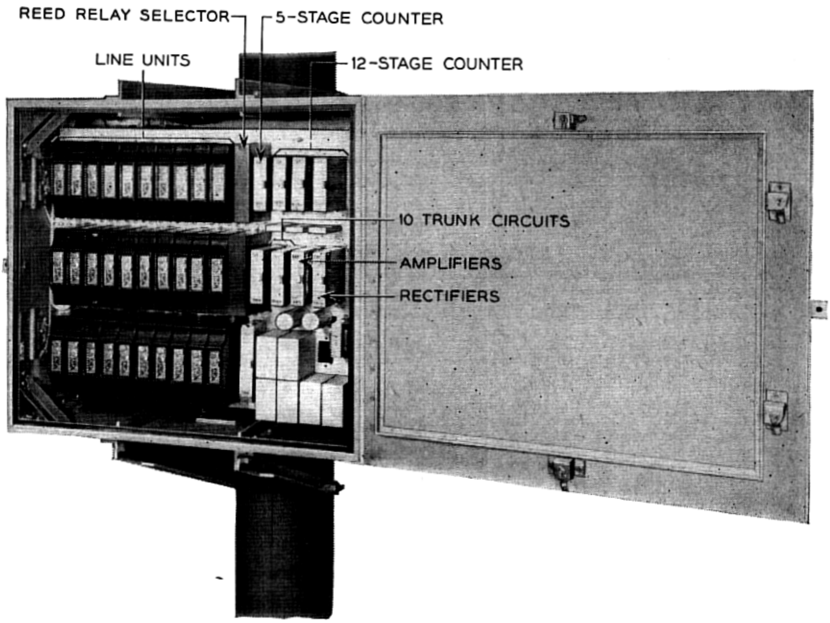


Fig. 22(b) — Identification of units within the line concentrator.

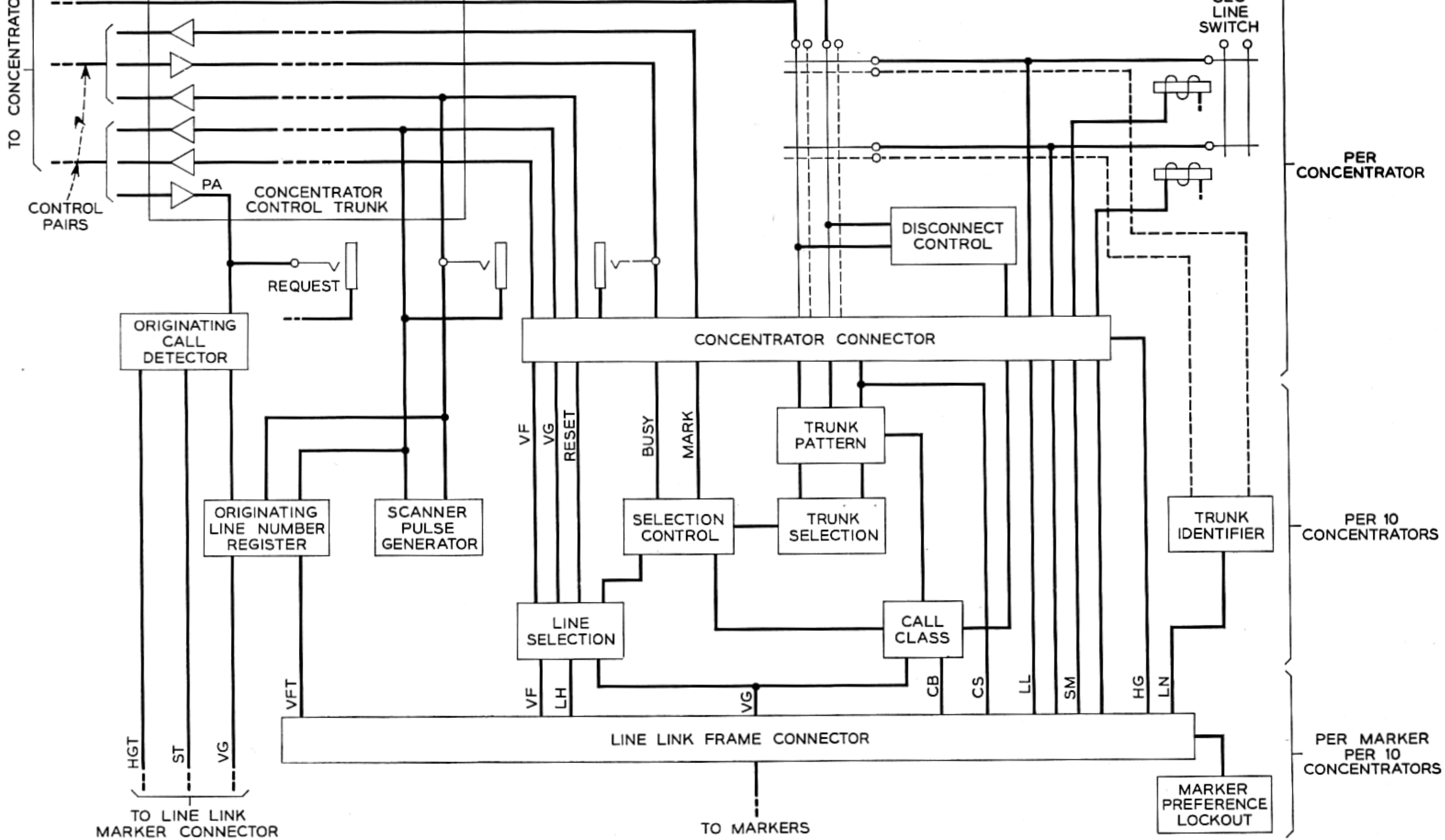


Fig. 23 — Block diagram of central office circuits.

3. The line selection circuit.
4. The trunk identifier and selection relay circuits.

(For an understanding of how these frame circuits work through the line link marker connector and markers in the No. 5 system, the reader should consult the references.)

The common central office circuits will be described first.

a. *Scanner Pulse Generator*

The scanner pulse generator, shown in Fig. 24, produces continuously the combination of VG, VF and RS or reset pulses, described in connection with Fig. 18(a), required to drive the scanners for a number of concentrators. The primary pulse source is a 1,000-cycle transistor oscillator. This oscillator drives a transistor bi-stable circuit arranged as a binary counter such that on each cycle of the oscillator output it alternately assumes one of its states. Pulses produced by one state drive a 5-stage counter. Pulses produced by the other state through gates drive a 12-stage counter.

The pulses which drive the 5-stage counter are the same pulses which are used for the VF pulses to drive scanners. Each time the first stage of the 5-stage counter is on, a gate is opened to allow a pulse to drive the 12-stage counter. The pulses which drive the 12-stage counter are also the pulses used as the VG pulses for driving the scanners. They are out of phase with the VF pulses.

When the last stage of the 12-stage counter is on, the gate which

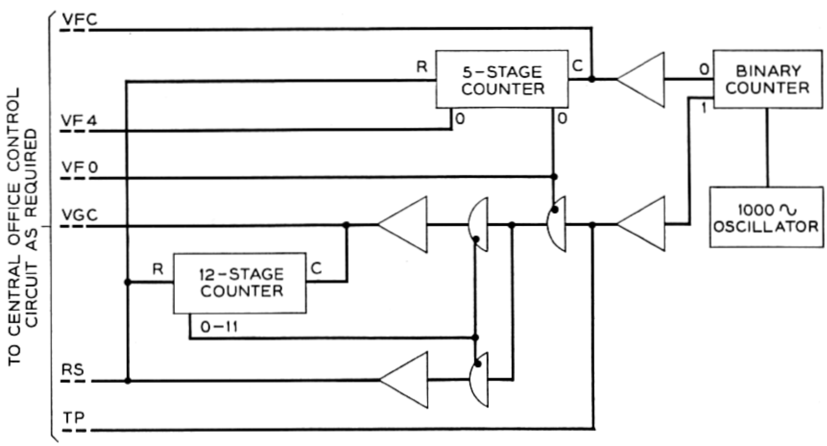


Fig. 24 — Scanner pulse generator.

transmits pulses to the 12-stage counter is closed and another gate is opened which produces the reset pulse. The reset pulse is thereby transmitted to the scanners in place of the first vertical group pulse. At the same time the 5 and 12-stage counters in the scanner pulse generator are reset to enable the starting of a new cycle.

In the central office control circuits, out of phase pulses on lead TP similar to those which drive the VG counters at the concentrator are used for various gating operations.

b. *The Originating Call Detection and Line Number Registration*

The originating call detector (Fig. 25) and the originating line number register (Fig. 26) together receive the information from the line concentrator used to identify the number of the line making a service request. The receipt of the service request pulse from a concentrator in a particular time slot will set a transistor bi-stable circuit HGT of Fig. 25 associated with that concentrator if no other originating call is being served by the frame circuits at this time.

The originating line number register consists of a 5 and 12-stage counter. These counters are normally driven through gates in synchronism with the scanning counters at concentrators with pulses supplied from the scanner pulse generator. When a service request pulse is received from any of the concentrators served by a line link frame, a pulse is sent to the originating line number register which operates a bi-stable circuit over a lead RH in Fig. 26. This bi-stable circuit then closes the gates through which the 5- and 12-stage counters are being driven, and also closes a gate which prevents them from being reset.

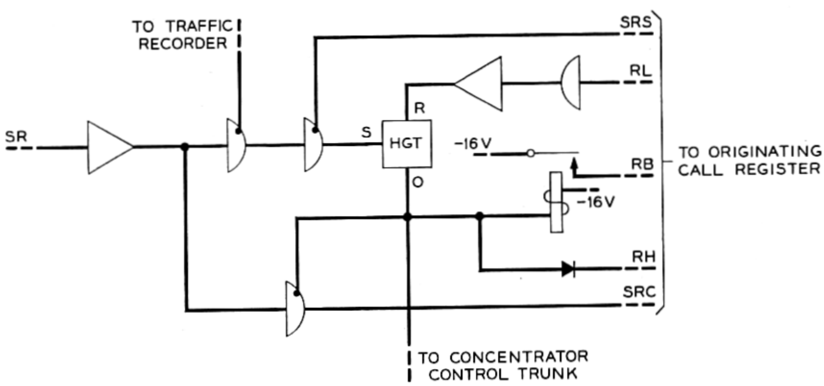


Fig. 25 — Originating call detector.

In this way, the number of the line which originated a service request is locked into these counters until the bi-stable circuit is restored to normal.

The HGT bi-stable circuit of Fig. 25 indicates which particular concentrator has originated a service request. A relay in the collector circuit has contacts which pass this information on to the other central office control circuits to indicate the number of the concentrator on the frame which is requesting service. This is the same as a horizontal group on a regular line link frame and hence the horizontal group designation is used to identify a concentrator.

With the operation of this relay, relays associated with the counters of the originating line number register are operated. These relays indicate to the other central office circuits the vertical file and vertical group identification of the calling line. Contacts on the vertical group relays are used to set a bi-stable circuit associated with lead RL of Fig. 25 each time the scanner pulse generator generates a pulse corresponding to the vertical file of the calling line number registered.

The operation of the HGT bi-stable circuit inhibits in the concentrator control trunk circuit (Fig. 27) the transmission of further VG and

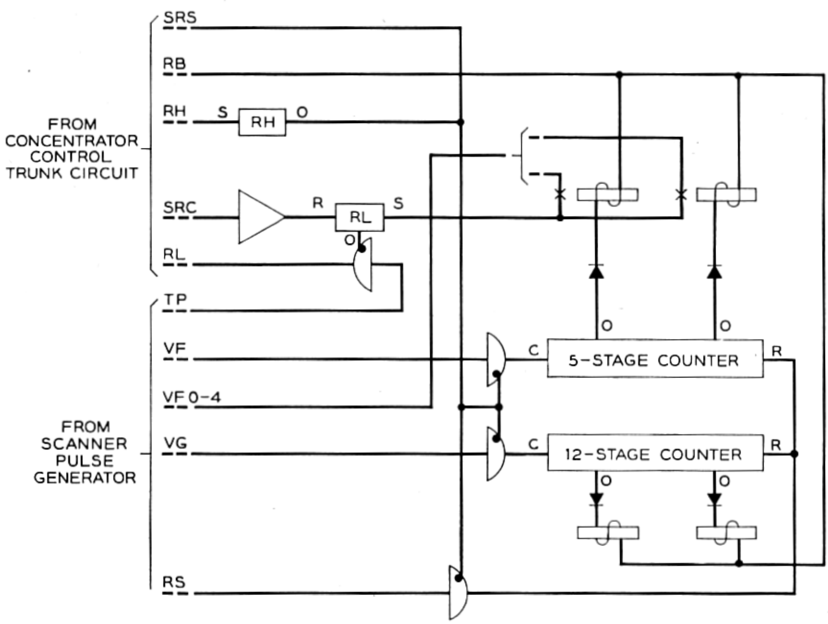


Fig. 26 — Originating line number register.

reset pulses to the concentrator so that, as described in Section 7a, only the VF counter continues to step once each 0.010 sec. So long as the line continues to request service this service request pulse is gated to reset the RL bi-stable circuit within the same time slot that it was set. If, however, a request for service is abandoned the RL bi-stable circuit of Fig. 26 will remain on and permit a TP pulse from the scanner pulse generator to reset the HGT bi-stable circuit which initiated the service request action.

Whenever the RH bi-stable circuit of Fig. 26 is energized it closes a gate over lead SRS for each concentrator to prevent any further service request pulses from being recognized until the originating call which has been registered is served. The resetting of the RH bi-stable circuit occurs once the call has been served. When more than one line concentrator is being served it is possible that the HGT bi-stable circuit of more than one concentrator will be set simultaneously as a result of coincidence in service requests from correspondingly numbered lines in these concentrators. The decision as to which concentrator is to be served is left to the marker, as it would normally decide which horizontal group to serve.

c. *Line Selection*

On all calls, originating and terminating, the marker transmits to the frame circuits the complete identity of the line which it will serve. In the case of originating calls it has received this information in the manner described in Section 8b. In either case, it operates wire spring relays VGO-11 and VFO-4, which enable gates so that the information may be stored in the 5- and 12-stage counters of the line selection circuit shown in Fig. 28.

The process of reading into the line selection counters starts when selection information has been received by the actuation of the HGS bi-stable circuit in the concentrator control trunk circuit of Fig. 27. This action stops the regular transmission of scanner pulses if they have not been stopped as a result of a call origination. At the same time it enables gates for transmission of information from the line selection circuit, Fig. 28.

The ST bi-stable circuit of the line selection circuit is also enabled to start the process of setting the line selection counters. The next TP pulse sets the R1 bi-stable circuit. This bi-stable circuit enables a gate which permits the next TP pulse to set the counters and transmit a reset pulse to the concentrator through pulse amplifier R1A. At the same time bi-stable circuit ST is reset to prevent the further read-in or reset pulses and to permit pulses through amplifier OPA to start the outpulsing of line selections. These pulses pass to the VGP and VFP leads as long as the VG and VF line selection counters have not reached their first and last stages respectively. The output pulses to the concentrator are also fed into the drive leads of these counters so that, as the counters in the concentrator are stepped up, the counters in the central office line selection circuit are stepped down. When the first stage of the VF counter goes on, the VF pulses are no longer transmitted until the first stage of the VG counter goes on. This insures that a VF pulse is the last to be transmitted. Also this pulse is not transmitted until the other frame circuits have successfully completed selections of an idle concentrator trunk. Then bi-stable circuit VFLD is energized,

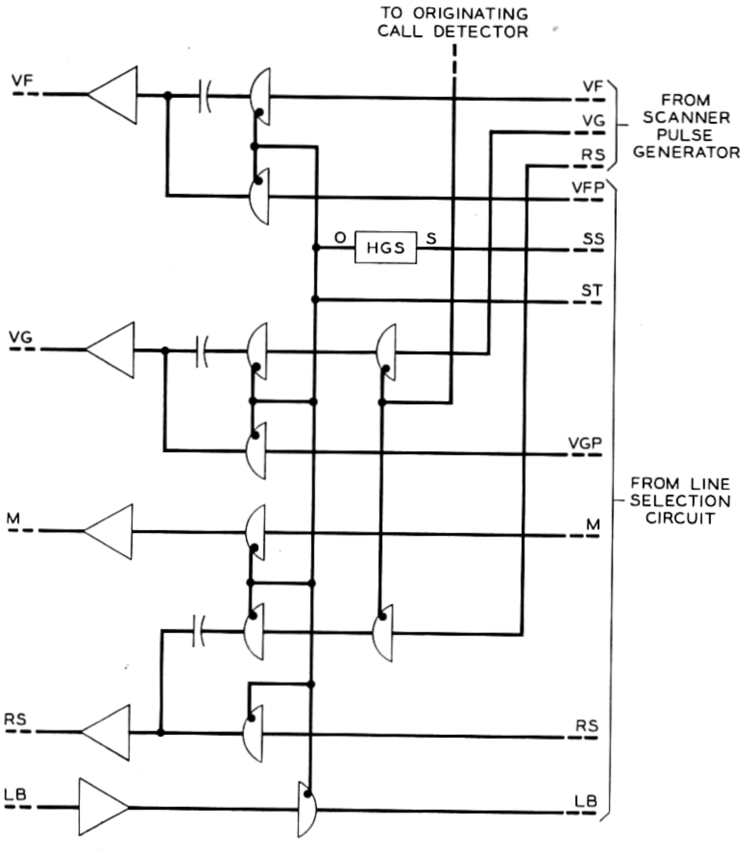


Fig. 27 — Concentrator control trunk circuit.

producing, during its transition, the last VF pulse for transmission to the concentrator.

d. *Trunk Selection and Identification*

The process of selecting an idle concentrator trunk to which the line has access utilizes familar relay circuit techniques.[19] This circuit, in Fig. 29, will not be described in detail. One trunk selection relay, TS, is operated indicating the preferred idle trunk serving a line in the particular vertical group being selected as indicated by the VG relay which has been operated by the marker.

The TS4 and TS5 relays select trunks 8 and 9 which are available to each line while the 4 trunks available to only half of the lines are selected by relays TS0-TS3. The busy or idle condition of each trunk is indicated by a contact on the hold magnet associated with each trunk through

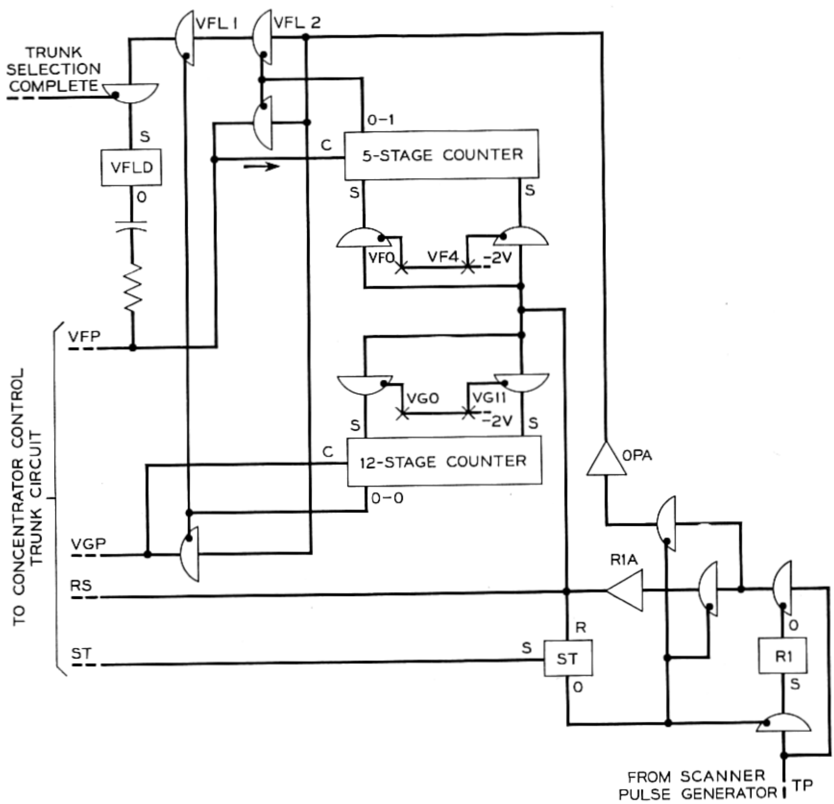


Fig. 28 — Line selection circuit.

relay HG which operates on all originating and terminating calls to the particular concentrator served by these trunks. The end chain relay TC of the lockout trunk selection circuit[19] connects battery from the SR relay windings of idle trunks to the windings of the TS relays to permit one of the latter relays to operate and to steer circuits, not shown on Fig. 29, to the hold magnet of the trunk and to the tip-and-ring conductors of the trunk to apply the selection voltages shown on Figs. 13 and 14.

The path for operating the hold magnet originates in the marker. The path looks like that which the marker uses on the line hold magnet when setting up a call on a regular line link frame. For this reason and other similar reasons this concentrator line link frame concept has been nicknamed the "fool-the-marker" scheme.

Should a hold magnet release while a new call is being served the ground from the TC relay normal or the TS relay winding holds relay

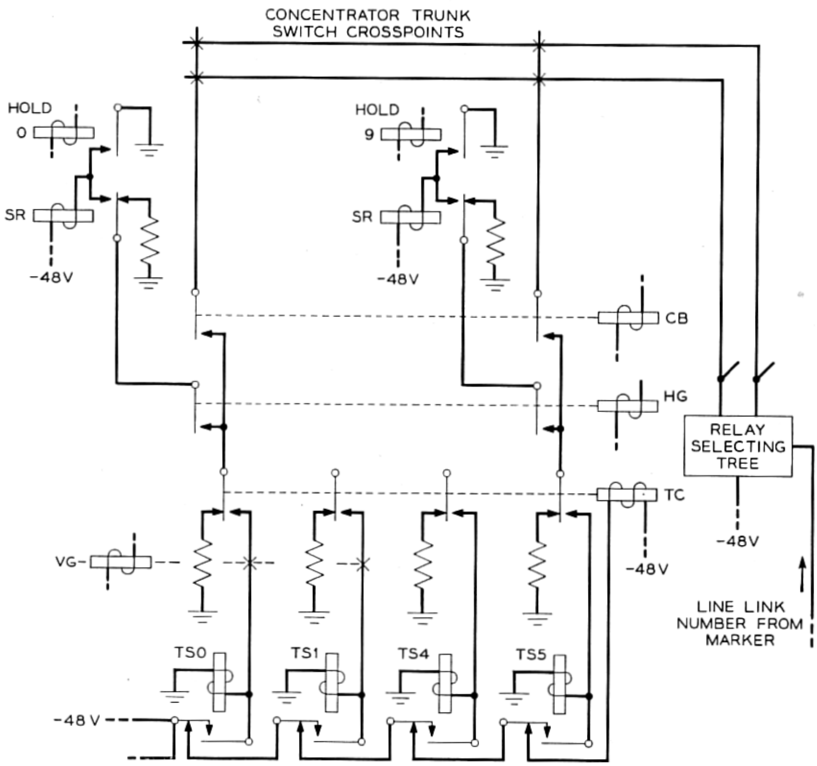


Fig. 29 — Trunk selection and identification.

SR operated through its own contact until the new call has been set up. This prevents interference of disconnect pulses applied to the trunk when a selection is being made and insures that a disconnect pulse is transmitted before the trunk is reused.

A characteristic of the No. 5 crossbar system is that the originating connection to a call register including the line hold magnet is released and a new connection, known as the "call back connection", is established to connect the line to a trunk circuit after dialing is completed.

With concentrator operation the concentrator trunk switch connection is released but the disconnect signal is not sent to the concentrator as a result of holding the SR relay as described above. However, the marker does not know to which trunk the call back connection is to be established. For this reason the frame circuits include an identification process for determining the number of the concentrator trunk to be used on call back prior to the release of the originating register connection.

Identification is accomplished by the marker transmitting to the frame circuits the number of the link being used on the call. This information is already available in the No. 5 system. The link being used is marked with −48 volts by a relay selecting tree[20] to operate the TS relay associated with the trunk to which the call back connection is to be established. Relay CB (Fig. 29) is operated on this type of call instead of relay HG. The circuits for reoperating the proper hold magnet are already available on the TS relay which was operated, thereby reselecting the trunk to which the customer is connected. The concentrator connection is not released when the hold magnet releases and again the marker operates as it would on a regular line link frame call.

9. FIELD TRIALS

Three sets of the experimental equipment described here have been constructed and placed in service in various locations. The equipment for these trials is the forerunner of a design for production which will incorporate device, circuit and equipment design changes based on the trial experiences. Fig. 30 shows the cabinet mounted central office trial equipment with the designation of appropriate parts.

For the field trials described, the line links on a particular horizontal level of existing line link frames were extended to a separate cross-bar switch provided for this purpose in the trial equipment. The regular line link connector circuits were modified to work with the trial control circuits whenever a call was originated or terminated on this level. No lines were terminated in the regular primary line switches for this level.

10. MISCELLANEOUS FEATURES OF TRIAL EQUIPMENT

There are a number of auxiliary circuits provided with the trial equipment to aid in the solutions of problems brought about by the concepts of concentrator service. One of the purposes of the trials was to determine the way in which the various traffic, plant and commercial ad-

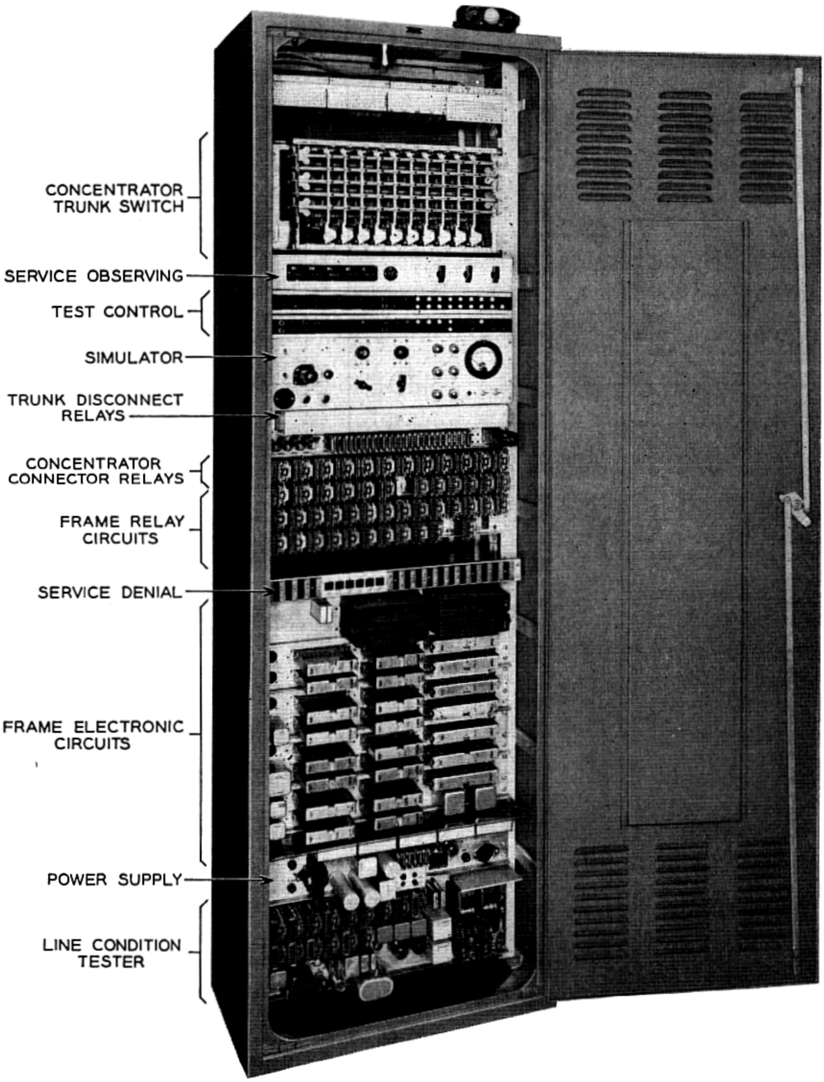


Fig. 30 — Trial central office equipment.

ministrative functions could be economically performed when concentrators become common telephone plant facilities. The more important of these miscellaneous features are discussed under the following headings:

a. *Traffic Recording*

To measure the amount and characteristics of the traffic handled by the concentrator a magnetic tape recorder, Fig. 31, was provided for each trial. The number of the lines and trunks in use each 15 seconds during programmed periods of each day were recorded in coded form with polarized pulses on the 3-track magnetic tape moving at a speed of 7½″ per second. Combinations of these pulses designate trunks busy on intra-concentrator connections and reverting calls.

The line busy indications were derived directly from the line busy information received during regular scanning at the concentrator. During one cycle in each 15 seconds new service requests were delayed to insure that a complete scan cycle would be recorded. Terminating calls were not delayed since marker holding time is involved. Trunk conditions are derived for a trunk scanner provided in the recorder.

In addition to recording the line and trunk usage, recordings were made on the tape for each service request detected during a programmed period to measure the speed with which each call received dial tone and the manner in which the call was served. In this type of operation the length of the recording for each request made at a tape speed of only ¼″ per second is a measure of service delay time.

As may be observed from Fig. 31 the traffic recorder equipment was built with vacuum tubes and hence required a rather large power supply. It is expected that a transistorized version of this traffic recorder serving all concentrators in a central office will be included in the standard model of the line concentrator equipment. With this equipment, traffic engineers will know more precisely the degree to which each concentrator may be loaded and hence insure maximum utilization of the concentrator equipment.

b. *Line Condition Tester*

It has been a practice in more modern central office equipment to include automatic line testing equipment.[21] An attempt has been made to include similar features with the concentrator trial equipment. The line condition tester (see Fig. 30) provides a means for automatically connecting a test circuit to each line in turn once a test cycle has been

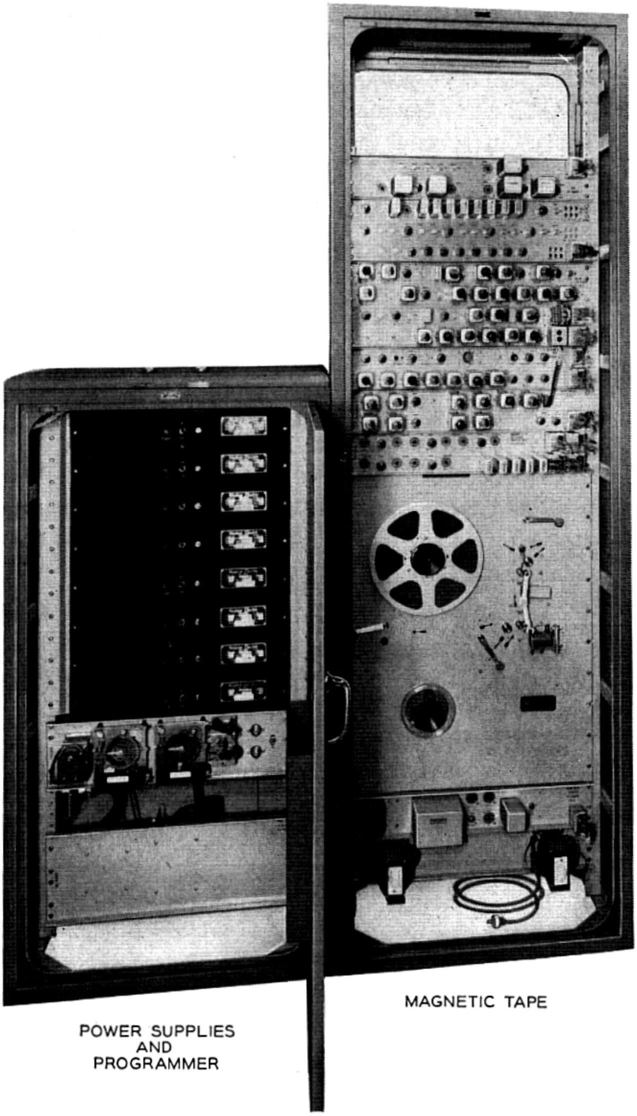


Fig. 31 — Traffic recorder.

manually initiated. This test is set up on the basis of the known concentrator passive line circuit capabilities. Should a line fail to pass this test, the test circuit stops its progress and brings in an alarm to summon central office maintenance personnel. The facilities of the line tester are also used to establish, under manual control, calls to individual lines as required to carry out routine tests.

c. *Simulator*

As the central office sends out scanner control pulses either no signal, a line busy or service request pulse is returned to the central office in each time slot. The simulator test equipment, shown in Fig. 30, was designed to place pulses in a specific time slot to simulate a line under test at the concentrator.

In addition to transmitting the equivalent of concentrator output pulses the simulator can receive the regular line selection pulses transmitted to the concentrator for purposes of checking central office operations. It is possible by combined use of the line tester and simulator to observe the operation of the concentrator and to determine the probable cause when a fault occurs.

d. *Service Observing*

The removal of the line terminals from the central office poses a number of problems in conjunction with the administration of central office equipment. One of these is service observing.

To maintain a check on the quality of service being rendered by the telephone system, service observing taps are made periodically on telephone lines. This is normally done by placing special connector shoes on line terminations in the central office.

To place such shoes at the remote concentrator point would lead to administrative difficulties and added expense. Therefore, a method was devised to permit service observing equipment to be connected to concentrator trunks on calls from specific lines which were to be observed. This method consisted of manual switches on which were set the number of the line to be observed in terms of vertical group and vertical file. Whenever this line originated a call and the call could be placed over the first preferred trunk, automatic connection was made to the service observing desk in the same manner as would occur for a line terminated directly in the central office.

In addition, facilities were provided for trying a new service observing technique where calls originating over a particular concentrator trunk would be observed without knowledge of the originating line number. For this purpose a regular line observing shoe was connected to one of the ten concentrator trunk switch verticals in the trial equipment and from here connected to the service observing desk in the usual manner.

The basic service observing requirements in connection with line concentrator operation have not as yet been fully determined. However, it appears at this time that the trunk observing arrangement may be preferable.

e. *Service Denial*

In most systems denial of originating service for non-payment of telephone service charges, for trouble interception and for permanent signals caused by cable failures or prolonged receiver-off-hook conditions may be treated by the plant forces at the line terminals or by blocking the line relay. To avoid concentrator visits and to enable the prompt clearing of trouble conditions which tie up concentrator trunks, a service denial feature has been included in the design of the central office circuits.

This feature consists of a patch-panel with special gate cords which respond to particular time slots and inhibit service request signals produced by a concentrator during this period. In this way service requests can be ignored and prevent originating call service on particular lines until a trouble locating or other administrative procedure has been invoked.

f. *Display Circuit*

A special electronic switch was developed for an oscilloscope. This arrangement permited the positioning of line busy and service request pulses in fixed positions representing each of the 60 lines served. Line busy pulses were shown as positive and service request pulses as negative. This plug connected portable aid, see Fig. 32, was useful in tracing calls and identifying lines to which service may be denied, due to the existence of permanent signals.

Other circuits and features, too detailed to be covered in this paper, have been designed and used in the field trials of remote line concentrators. Much has been learned from the construction and use of this equipment which will aid in making the production design smaller, lighter, economical, serviceable and reliable.

Results from the field trials have encouraged the prompt undertaking

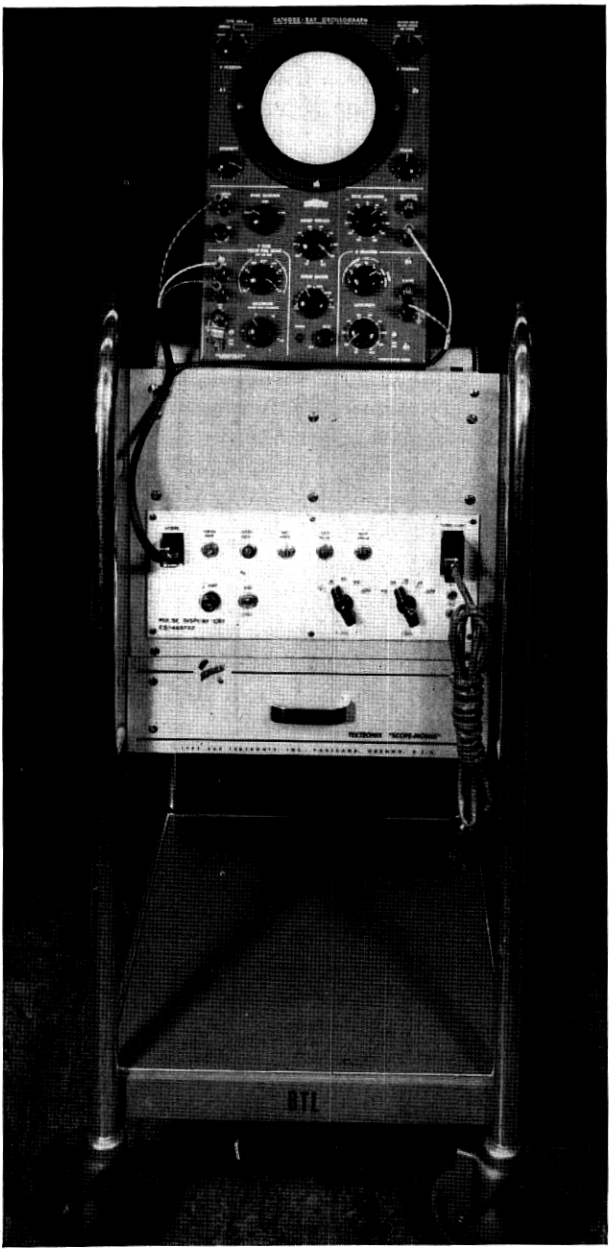


Fig. 32 — Pulse display oscilloscope.

of development of a remote line concentrator for quantity production. The cost of remote line concentrator equipment will determine the ultimate demand. In the meantime, an effort is being made to take advantage of the field trial experiences to reduce costs commensurate with insuring reliable service.

The author wishes to express his appreciation to his many colleagues at Bell Telephone Laboratories whose patience and hard work have been responsible for this new adventure in exploratory switching development. An article on line concentrators would not be complete without mention of C. E. Brooks who has encouraged this development and under whose direction the engineering studies were made.

BIBLIOGRAPHY

1. E. C. Molina, The Theory of Probabilities Applied to Telephone Trunking Problems, B.S.T.J., **1,** pp. 69–81, Nov., 1922.
2. Strowger Step-by-Step System, Chapter 3, Vol. 3, Telephone Theory and Practice by K. B. Miller. McGraw-Hill 1933.
3. F. A. Korn and J. G. Ferguson, Number 5 Crossbar Dial Telephone Switching System, Elec. Engg., **69,** pp. 679–684, Aug., 1950.
4. U. S. Patent 1,125,965.
5. O. Myers, Common Control Telephone Switching Systems, B.S.T.J., **31,** pp. 1086–1120, Nov., 1952.
6. L. J. Stacy, Calling Subscribers to the Telephone, Bell Labs. Record, **8,** pp. 113–119, Nov., 1929.
7. J. Meszar, Fundamentals of the Automatic Telephone Message Accounting System, A. I. E. E. Trans., **69,** pp. 255–268, (Part 1), 1950.
8. O. M. Hovgaard and G. E. Perreault, Development of Reed Switches and Relays, B.S.T.J., **34,** pp. 309–332, Mar., 1955.
9. W. A. Malthaner and H. E. Vaughan, Experimental Electronically Controlled Automatic Switching System, B. S.T.J., **31,** pp. 443–468, May, 1952.
10. S. T. Brewer and G. Hecht, A Telephone Switching Network and its Electronic Controls, B.S.T.J., **34,** pp. 361–402, Mar., 1955.
11. L. W. Hussey, Semiconductor Diode Gates, B.S.T.J., **32,** pp. 1137–54, Sept., 1953.
12. U. S. Patent 1,528,982.
13. J. J. Ebers and S. L. Miller, Design of Alloyed Junction Germanium Transistor for High-Speed Switching, B.S.T.J., **34,** pp. 761–781, July, 1955.
14. W. B. Graupner, Trunking Plan for No. 5 Crossbar System, Bell Labs. Record, **27,** pp. 360–365, Oct., 1949.
15. G. L. Pearson and B. Sawyer, Silicon p-n Junction Alloy Diodes, I.R.E. Proc., **42,** pp. 1348–1351, Nov., 1952.
16. A. E. Anderson, Transistors in Switching Circuits, B.S.T.J., **31,** pp. 1207–1249, Nov., 1952.
17. J. J. Ebers and J. L. Moll, Large-Signal Behavior of Junction Transistors, I. R. E. Proc., **42,** pp. 1761–1784, Dec., 1954.
18. J. J. Ebers, Four-Terminal p-n-p-n Transistors, I. R. E. Proc., **42,** pp. 1361–1364, Nov., 1952.
19. A. E. Joel, Relay Preference Lockout Circuits in Telephone Switching, Trans. A. I. E. E., **67,** pp. 720–725, 1948.
20. S. H. Washburn, Relay "Trees" and Symmetric Circuits, Trans. A. I. E. E., **68,** pp. 571–597, 1949.
21. J. W. Dehn and R. W. Burns, Automatic Line Insulation Testing Equipment for Local Crossbar Systems, B.S.T.J., **32,** pp. 627–646, 1953.