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A New Carrier System for Rural Service

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A study of the problem of providing telephone service to rural customers indicated the need for a flexible carrier system that could be used economically on new and existing rural cable and open wire lines. The desire for low cost required new approaches to almost every phase of the carrier system design for rural service, which has been designated Type P1.

Use of transistors led to sweeping changes in the detailed circuitry and also created demand for other new components. Mounting and interconnecting the circuit components by means of printed wiring boards emphasized the necessity for close coordination between design and manufacturing objectives. The low power-drain requirements of transistor circuitry were supplied economically by the use of similar solid state devices, a new storage battery, and efficient packaging.

A fast, accurate and simple method has been evolved for applying the P1 carrier system to rural lines with a minimum of line treatment or rearrangement. Plug-in equipment, readily accessible test points, and a carrier test set provide the ease of maintenance needed in the use of telephone equipment at remote locations. Use of the P1 carrier system will extend the application of electronic equipment outside of the telephone central office and provide a carrier system whose performance will be consistent with requirements for high quality communication service at low cost.

1. INTRODUCTION

Although carrier has been used successfully to provide trunks in the Bell System for more than 35 years, it has not been economically feasible, up to the present time, to apply carrier telephone techniques extensively to the rural telephone plant. The technical and economic problems associated with providing telephone service to customers in rural areas has long been one of the most difficult problems facing the telephone industry. The widely scattered locations of customers in rural areas have led to a large number of rural telephone routes with only a few customer lines per route. This has precluded the use of large cables on any one route, which would be economically attractive in urban areas. The extensive use of carrier has not been feasible because the distances from the rural customers to the Central Office are in the 5- to 20-mile range in which carrier has not been generally economical in the past.

The two lines of attack which were taken on this problem were to reduce the cost of telephone plant through less expensive small cables and open-wire plant,[1] and to provide an economically attractive carrier system designed to meet the particular needs of rural telephone service.

This paper discusses the broad objectives for a rural customer carrier system, the major parameters of the P1 system which was developed to meet those objectives, and its circuit, equipment, and power arrangements. It also covers the engineering and maintenance methods to be used by the Bell System Operating Companies to install and operate the system.[2]

2. BROAD OBJECTIVES FOR P1 CARRIER SYSTEM

The broad objectives for the Type P1 carrier system resulted from the stringent economic limits imposed on the system to enable it to prove in over conventional rural plant of the latest and most economical design, from the requirements of rural telephone transmission and signaling, and from Bell System experience gained with earlier carrier systems for customer and trunk use. The low cost objective for this system also implied the need to achieve an appropriate balance among an economic first cost of equipment, low in-place cost due to simplified engineering and installation practices, and accompanying low annual costs due in part to simplified system maintenance.

To achieve an economic carrier system for rural telephone use, the dc power requirements of the terminals and repeaters had to be kept low.

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[1] Lester Hochgraf and R. G. Watling, Telephone Lines for Rural Subscriber Service, A.I.E.E. Communication and Electronics, No. 18, p. 171, May, 1955.

[2] These aspects of the P1 system are covered in more detail in four papers on "The P1 Carrier System." A.I.E.E. Communication and Electronics, No. 24, pp. 188, 191, 195, 205, May, 1956.

This was especially important since previous Bell System experience indicated that where commercial power is used to supply the system, some form of reserve must be provided, and where commercial power is not available, the use of primary batteries places a premium on minimizing the power required.

From these considerations two additional major objectives were derived: low manufacturing costs for the components and assembled equipment, and the use of transistors to minimize power supply drains. In addition, flexibility was needed in the proposed carrier system because of the difficulty of accurately forecasting the demand for rural service.

These objectives have been met in the design of the Type P1 rural customer telephone system. It is a fully-transistorized system consisting of independent two-way carrier channels applicable in increments of one to four at a time in the frequency band above the regular voice frequency circuit. Each channel uses a terminal at the central office and at a remote point with intermediate repeaters as necessary. Between terminals, the system is equivalent to a rural voice frequency line with no changes required in the central office or rural customer equipment. Beyond the outlying terminal, distribution is by voice frequency wire on a single or multiparty basis. The system can be applied to existing and new lines utilizing combinations of fine gauge exchange cable and copper or steel open-wire. Systems can be used on each of several pairs on a given pole line, the number depending on the line characteristics.

3. MAJOR PARAMETERS OF P1 CARRIER SYSTEM

This section summarizes the important features incorporated in the P1 carrier system and the reasons governing their choice. The system has a number of features in common with Bell System toll carrier systems, but it also differs in several important aspects because of specific rural requirements. One aspect is the signaling, which requires different arrangements at the two ends of the circuit because of the widely different signals carried in the two directions. Another is that the remote terminals of the individual channels are usually distributed along the line rather than grouped at a common location.

3.1 *Transmission Plan*

It is difficult to divorce the considerations leading to the choice of carrier frequency range from those affecting the choice of modulation in the carrier system. Studies of growth on rural lines indicated that a system giving three or four channels (customer circuits) on one pair of wires, in addition to the physical circuit, should be sufficient if systems could be applied to each of several pairs on a given open-wire line.

The blocking out of the frequency range was controlled by a number of factors. Cost considerations required that the carrier frequencies be kept above the voice frequency range. If carrier extended into the voice range, the voice frequency circuit would be lost on a carrier pair. One of the carrier channels applied to that pair would have to be used to replace it. Thus, the addition of four carrier channels to a pair would yield a net gain of only three channels. This in turn would increase the net cost per gained channel. Filter costs determined how close to the voice frequency band the carrier frequency range could be placed and in conjunction with the number of channels required how closely the channels could be placed to each other.

Crosstalk considerations restricted the carrier frequency range to below about 100 kc in order to reduce the cost of line treatment and rearrangement of pairs on existing rural lines. By using this frequency range it appeared possible to apply more than one carrier system to crossarms on an open-wire route. The rapid rise in attenuation with frequency of steel wire used on rural lines dictated that the range of frequencies be kept low. As a result of these two sets of considerations, development work on the P1 carrier system was concentrated in the 8- to 100-kc range.

Amplitude modulation of the carrier frequencies was chosen over other forms of modulation because of the simpler terminal circuitry and equipment and because of the saving in bandwidth. Use of amplitude modulation and the use of compandors, discussed in a later section, were felt to compensate for possible transmission advantages that could

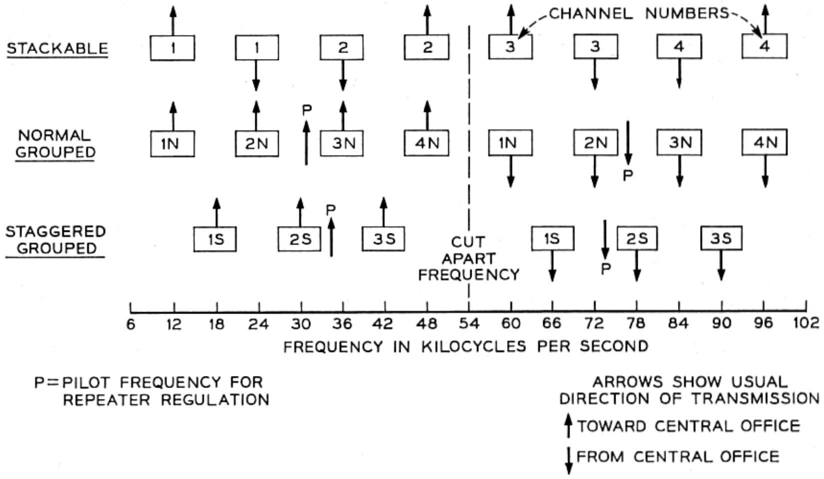

Fig. 1 — Type P1 Carrier Frequency Plan.

be obtained by using angular modulation (frequency or phase) with a large modulation coefficient.

Cost was again a major factor in the choice between double sideband and single sideband amplitude modulation. Past experience with other carrier systems has indicated that filters are a major part of the cost of a system and, when frequency space is available, double sideband filters are, in general, less expensive than those for single sideband. In addition, the cost of a single sideband system would be increased because of the problem of obtaining the necessary carrier supply at the terminal.

The frequency plan developed for the P1 carrier system is shown in Fig. 1. The unusually wide carrier spacing of 12 kc was adopted in order to minimize filter costs. Since the remote terminals are generally distributed along the line, it was not practical to use double modulation to accomplish filtering in the most efficient frequency range. Instead, filtering was done at line frequencies. Every effort was made to achieve channel filter designs with maximum efficiency of element utilization. Advantage was taken of the more leisurely rising characteristics of the double sideband filters permitted by the wide frequency spacing.

The stackable frequency arrangement was provided for non-repeatered operation, because when the lowest two carrier frequencies are used to provide a channel, it can be used over substantially longer distances than channels using higher frequencies. The grouped arrangements were provided for repeatered systems to reduce the cost and number of the repeater filters and amplifers needed to separate the two directions of transmission. The staggered grouped arrangement can be used with the normal grouped arrangement on a pole line having poor crosstalk coupling in order to increase the effective coupling loss between carrier channels on different pairs. The grouped and stackable arrangements cannot be used on the same pole line, because certain frequencies would be used for both directions of transmission. This would produce large differences between transmitted and received carrier power at terminals and repeaters which would lead to intolerable crosstalk.

A number of terminal arrangements were studied in order to implement the above frequency plan. The arrangement for a remote terminal shown in Fig. 2 was chosen as the simplest terminal meeting all of the system requirements. It is very similar to the channel terminal arrangement used in the Type N1 carrier system, another double sideband amplitude modulation system used for long distance trunks of the Bell System. The several shaded portions in the figure show the breakdown of the terminal functions into individual sub-units, which are the basis for the equipment arrangements discussed in Section 5 of this paper. A number of the other important features that make up the terminal arrangement are discussed in the following sections.

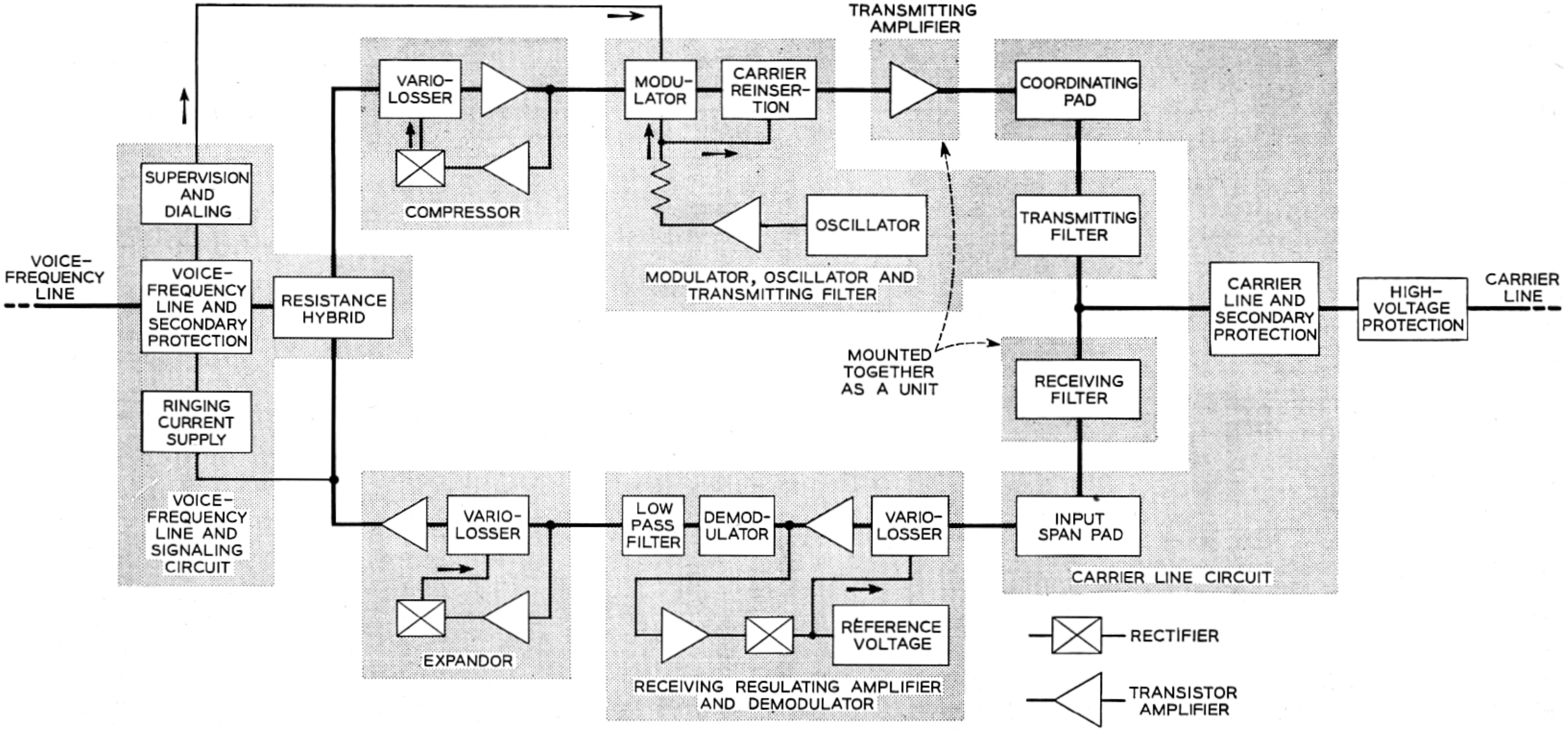

Fig. 2 — P1 Carrier remote terminal block diagram.

3.2 *Use of Transistors*

Transistors were chosen for use in the P1 system because they are low voltage, low power devices as compared to electron tubes suitable for transmission circuitry. Also, transistors are expected to be lower in cost and inherently longer life devices than electron tubes, thus contributing to reduced initial and operating costs.

The dc power requirements for the P1 system, using transistors, may be compared to those for a channel terminal in the Type N1 system as an indication of the dc power saving that has been achieved with the P1 system. A transistorized P1 terminal requires about 1.2 watts while it is in operation compared to 40 watts required for an N1 terminal, which represents a substantial power reduction achieved by the use of transistors. Because part of the P1 terminal is turned off during idle periods, the average power required over a day is about 0.9 watt.

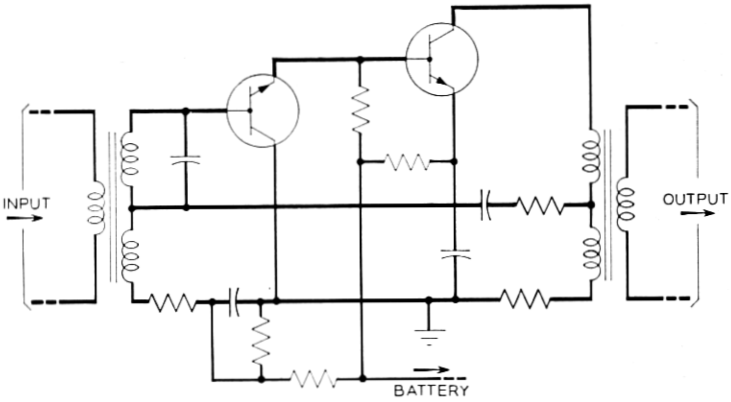

Fig. 3. — P1 transistor transmitting amplifier circuit.

During the development of the P1 terminals it was found that a single design of a transistor amplifier could be used in several different places. These included the compressor and expandor amplifiers, the transmitting amplifier and the input portion of the receiving amplifier. The circuit for that amplifier is shown in Fig. 3.

The amplifier uses Western Electric NPN grown junction type transistors coded 4B for the voice frequency amplifiers and 4C transistors for the carrier amplifiers. The first transistor is connected as a common collector and the second as a common emitter. By using them in this manner it is possible to employ the same type of transistor in both stages. Feedback is obtained by using hybrid coils at both the input and output of the circuit in much the same manner as for electron tube circuits. One significant difference is that in this transistor circuit only the second transistor introduces a 180-degree phase shift. This permits both input and output coils to return to a common ground as in a three-tube electron-tube circuit and thereby avoids the circuit complications of a two-tube circuit where one of the coils must float off ground. A simple resistance interstage is used and battery filtering completes the circuit.

3.3 *Low Voltage Protection*

Use of transistors gave rise to the need for supplementary protection from voltage surges on the line below those for which conventional carbon blocks afford protection. This additional protection was obtained by using the reverse voltage breakdown characteristics of newly developed silicon-aluminum junction diodes as shown in Fig. 4. Protection is provided in the 50- to 1,000-volt range by the diodes and above a nominal value of 750 volts by the carbon blocks. During the normally short period of operation the small diodes carry a current of up to 10 amperes.

3.4 *System Levels and Carrier Line Loss*

The carrier frequency output power of the transistorized transmitting amplifier in the terminals was set at +6 dbm. This level was limited primarily by the power handling capabilities of the transistors used. Because of the loss of the secondary protection circuitry, band filters, and the line transformer, this became +4 dbm at the carrier line terminals. This is equal to the highest carrier power transmitted by the Type N1 carrier system. With 50 per cent modulation of the carrier, the effective sideband level at the transmitting line terminals is only 2 db below that transmitted by the Type O carrier system, the most recent carrier system used for open-wire long distance trunks of the Bell System.

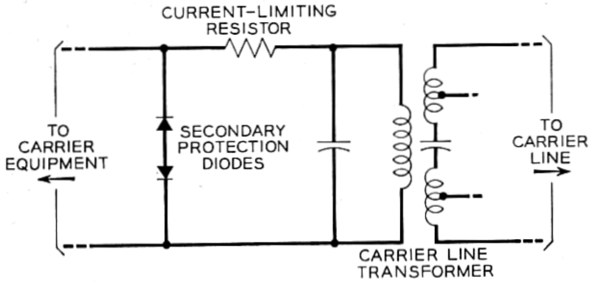

Fig. 4 — Secondary protection circuit in carrier portion of P1 carrier terminal.

The +4 dbm output level coupled with noise and crosstalk considerations indicated that 30-db bare carrier line loss between terminals would be possible. A survey of existing and planned Bell System rural telephone lines indicated that substantial amounts of entrance cable and open wire would be encountered in potential carrier layouts. Calculations of carrier frequency loss of those facilities showed that 30-db loss would not be sufficient to care for all of the necessary rural applications, which confirmed the need for carrier repeaters.

3.5 *Compandors*

Compandors were incorporated in the P1 system because their several advantages more than offset their added cost. The crosstalk and noise advantage provided by their use reduced the need for expensive line treatment to reduce crosstalk. In addition, the compandor noise advantage permitted lower received carrier levels to be used, thus increasing the permissible carrier line loss. Compandors also eased the requirements on terminal and repeater filters, thus reducing filter cost.

The compandor in the P1 system is a simplified version of the syllabic compandor used in Type N1 and O carrier systems, but its performance is comparable to those units. The new problem of matching the compressor and expandor characteristics in P1 terminals operating in different ambient temperatures has been simplified by the use of silicon-aluminum junction diodes in the compandor variolossers and control circuits.

3.6 *Channel Regulation*

Channel regulation was necessary to provide satisfactory transmission performance and keep maintenance adjustments to a minimum. The regulation was designed to compensate for daily and seasonal carrier circuit net loss variations caused by changes in line attenuation with temperature. It would be desirable to have the terminal regulation range equal to 30 db, the maximum line loss that can be spanned between the terminals, to ease engineering layout considerations. However, cost considerations led to a 15-db range, with span pads used where required by system layout to adjust the received carrier power to the center of the range of the regulator.

The regulation in the receiving amplifier is of the backward-acting type. A reference control signal, derived from the receiving amplifier output, is used to vary the loss of the balanced diode variolosser at the amplifier input. The regulator "stiffness" of 1.6-db change in channel voice frequency output for 15-db variation in carrier input is obtained

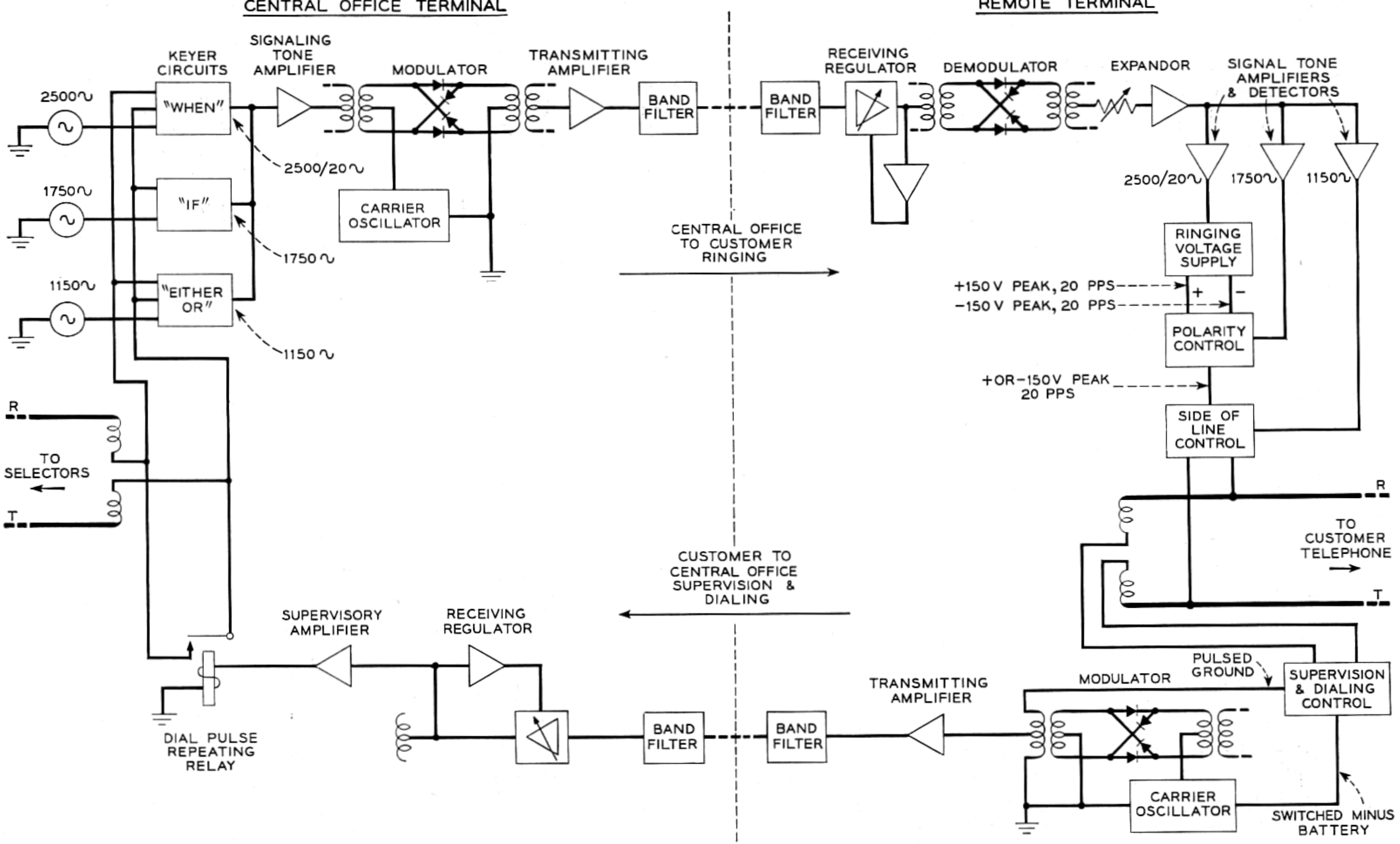

Fig. 5 — P1 signaling block schematic.

by the combination of the rectified control signal voltage exceeding the reference voltage of a silicon-aluminum junction diode and by the expansion characteristic of the variolosser. The variolosser uses a specially coded set of the silicon diodes which are matched for both ac and dc characteristics. Modulation products introduced by the variolosser have been kept below those produced in the associated receiving demodulator.

3.7 *Signaling*

The need to transmit customer signaling information over a carrier channel required the development of means of passing dialing and supervision signals toward the central office. It also required passing ringing information to the remote terminal for the types of multiparty ringing generally used in the Bell System, including four-party selective service, eight-party semi-selective service and divided code ringing.

These requirements were met in such a way that the carrier system can be inserted into a normal voice frequency circuit and function without requiring any change in the existing signaling equipment in the central office or in the customer's telephone. The central office terminal is activated by 20-cycle ringing signals which are reproduced at the remote terminal. The remote terminal is activated by switchhook signals and dial pulses which are reproduced at the central office terminals. Thus, the two directions of signaling require completely different circuits. A block schematic of the arrangement used is shown in Fig. 5.

3.7.1 *Ringing*

The customer signaling originating in Bell System central offices consists of 20 cycles superimposed on plus or minus battery and applied between either tip or ring and ground. These signals control the transmission over the P1 carrier system of three in-band frequency tones, the proper combination of two of them serving to select the party to be rung from the far end. The third tone (2,500 cycles), modulated at a 20-cycle rate, carries the information as to whether 20-cycle ringing is present or absent. In-band frequencies were chosen to encode ringing information for transmission over the carrier channel because of the substantially lower cost of in-band filters as compared to those required for out-of-band transmission.

The three signaling tones are generated by three transistor tone oscillators incorporated in a P1 central office terminal. One set of three oscillators can be arranged to supply four central office channel terminals.

The transmission of the tones is controlled by three diode-operated

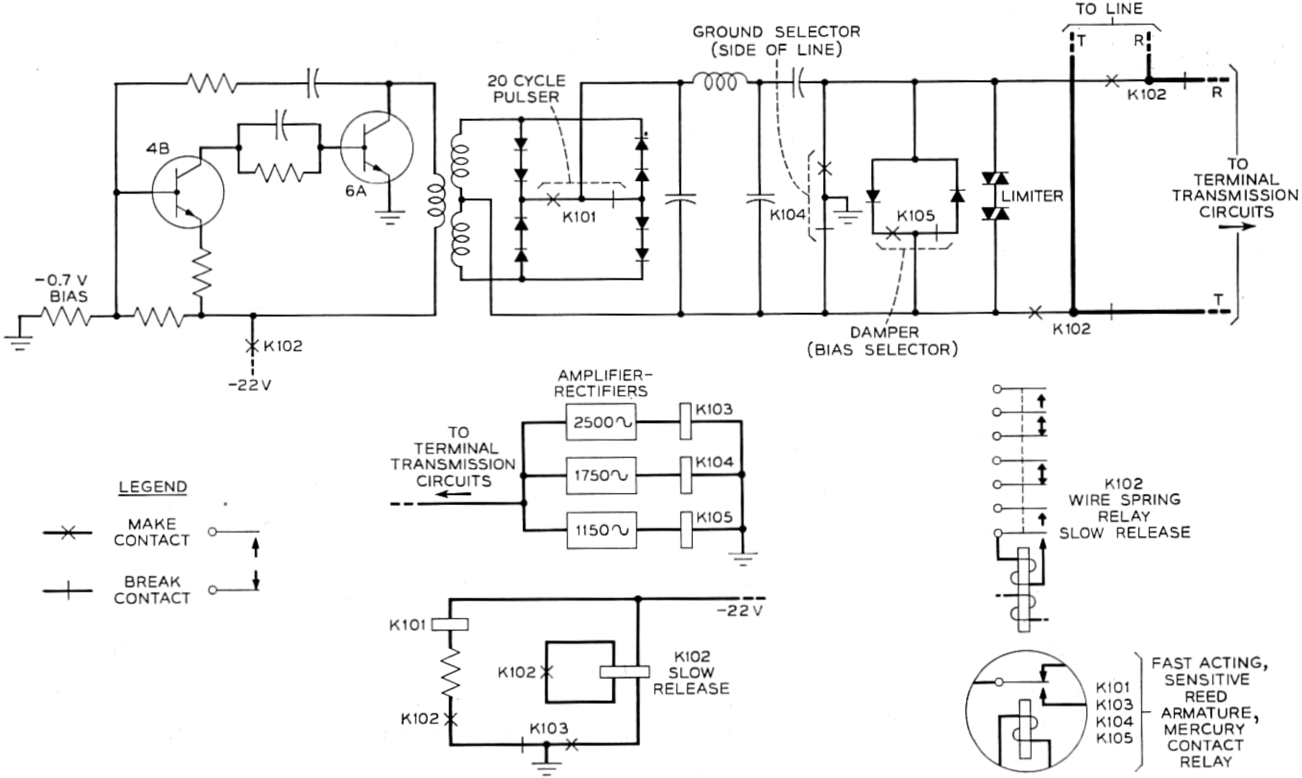

Fig. 6 — Remote terminal 20-cycle ringing generator.

keyers which function independently, depending on the nature of the ringing signal. The 2,500-cycle keyer responds to 20 cycles applied to either the tip or ring conductors. The gating diode is back biased about 3 volts to prevent random noise peaks from operating it. The 1,750-cycle keyer responds to any ringing signal applied to the tip circuit. A diode oppositely poled to the gating diode has a high breakdown so that any reverse voltage peaks leaking through to it will not open the gate. The 1,150-cycle keyer responds to 20-cycle ringing voltage superimposed with either plus bias voltage applied to the tip or with minus bias voltage applied to the ring conductor.

At the remote terminal the signaling tones are each selected at the output of the expandor by tuned circuits, amplified by a transistor and rectified to activate relays controlling the customer ringing. The 2,500-cycle tone interrupted at a 20-cycle rate controls the remote ringing generator, the 1,750-cycle tone determines whether ringing is to be on the tip or ring side of the line, and the 1,150-cycle tone whether the bias applied to the line is positive or negative.

The ringing power at the remote terminal is provided by a 3,000-cycle transistor oscillator which uses a 2-watt 6A transistor in the second of its two stages, as shown in Fig. 6. The rectified output of the oscillator is pulsed at a 20-cycle rate by a relay controlled by the 2,500-cycle in-band tone and applied to the line through a low-pass filter to reduce the harmonic content of the ringing signal. Positive or negative bias is provided from one of two clamper diodes. In order to obtain sufficient power from the ringing generator, two electrolytic capacitors are used in a voltage doubler configuration. The ringing generator draws nearly 500 mils of battery current which, by P1 standards, is a heavy power drain. In order to keep this drain to a minimum, the ringing generator is activated only during the ringing period. Also the generator is connected to the customer's line only during the ringing period to remove its shunting effect on the talking circuit.

3.7.2 *Supervision and Dialing*

Carrier on-off signaling was chosen to transmit supervision and dialing signals from the customer to the central office. This method was used because of the ease of implementing it and because of savings in dc power drain at the remote terminal achieved by transmitting the carrier from that terminal to the central office only during the off-hook condition.

An off-hook signal on the voice frequency extension of the remote terminal, caused by the customer lifting his handset, is used at the remote terminal to activate the transmitting amplifier and to remove a short-circuit from its input. This results in carrier being transmitted to the central office terminal, where it causes relays in the terminal to recreate the customer's line short across the line connecting the central office carrier terminal and the central office switching equipment.

Dialing at the customer's instrument alternately opens and shorts the voice frequency extension at each dial pulse. Opening of the line operates a relay in the remote terminal which short-circuits the transmitting amplifier input and causes the relays in the central office to follow the pulsing of the received carrier, recreate the dial pulses there, and operate the central office switching equipment.

3.8 *Repeater*

Repeaters are used in the P1 system whenever the line transmission loss exceeds the maximum that the terminals can accommodate. The repeaters use transistors for gain instead of electron tubes, but otherwise are schematically very much like previous repeaters as shown in Fig. 7. The two directions of transmission have similar functions differing only in the frequency band that is amplified and the options that are used in the gain regulating circuits.

Identical high-low pass directional filters at each end of the repeater separate the directions of transmission into the high and low frequency groups. Optional phase correction sections for these directional filters are used along a line to improve the phase characteristics in the cut-apart region. The directional filters are connected to the line through the same line matching coils and secondary protection circuits used in the terminals. Repeater input span pads are used to build out the line loss to its

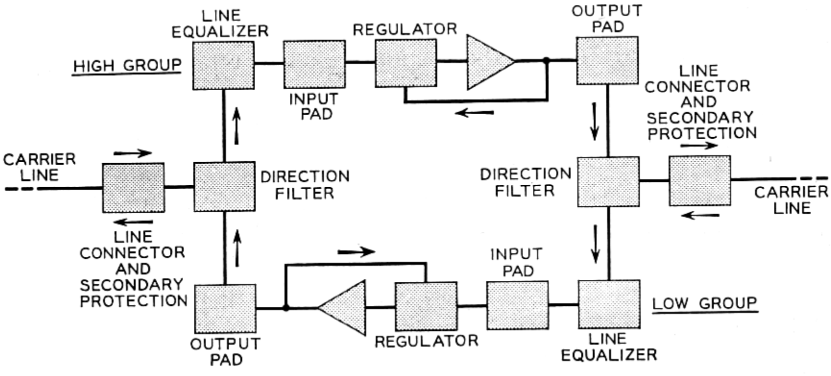

Fig. 7 — P1 repeater block schematic.

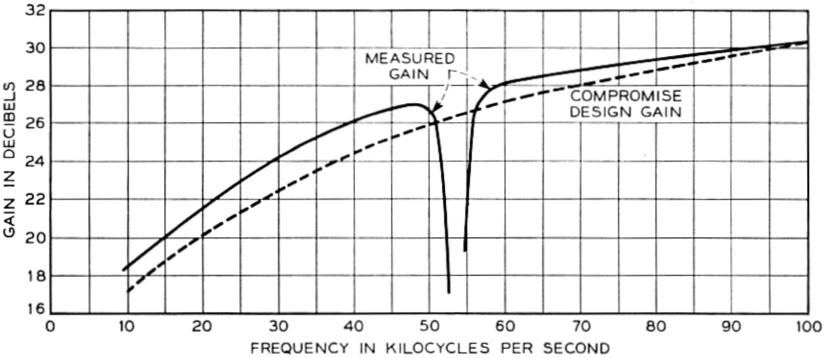

Fig. 8 — P1 repeater gain-frequency characteristic.

proper value for the nonregulated repeater and to adjust the power of the received carriers to the center of the regulator range for a regulated repeater. The output span pads are used where it is necessary to adjust the repeater output power in order to equalize levels between a P1 system and other P1 systems or other types of carrier systems operating on the same open wire line. These pads provide attenuation in 2 db steps up to 30 db.

The repeater amplifiers were designed to have a wide enough frequency band to cover both high and low groups of frequencies, so that each repeater contains two identical amplifiers. Each amplifier has three transistors with each stage connected as a common emitter. Western Electric Company PNP 7B and 6B transistors are used in the first and last stages, respectively, and a NPN type 4C transistor is used in the second stage. Local feedback is required around each transistor to reduce the gain spread and phase variations among units. Overall feedback is obtained around the three transistors with hybrid coils at input and output.

The repeater equalizer characteristic represents a compromise for several types of transmission facilities generally encountered in the rural plant. The equalizer design also covers both the high and low frequency groups so that identical equalizers are used for both the high group and low group sides of the repeater.

A preliminary characteristic for the overall repeater gain is shown in Fig. 8 plotted against the design objective. There is a significant departure in shape only at the cut-apart frequencies. This will be corrected sufficiently to permit as many as four repeaters to be used in tandem. As the design objective is a compromise of the loss of several types of lines that may be encountered in the use of this system, the departures

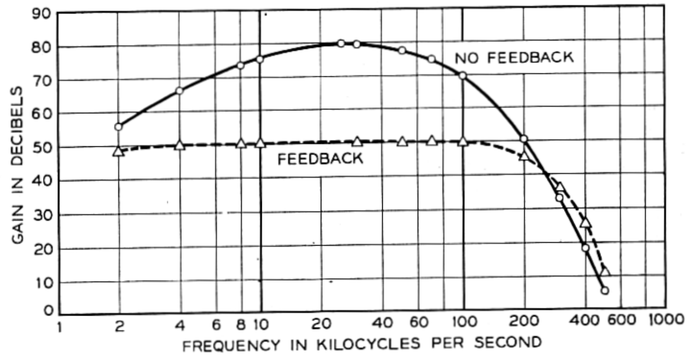

Fig. 9 — P1 Repeater amplifier gain-frequency characteristic.

in system performance may vary considerably from that shown. The repeater amplifier gain frequency characteristic, plotted in Fig. 9, shows a non-regenerative peak gain of the three-stage transistor amplifier of 80 db and a feedback gain characteristic of 50 db. This provides 20 db or more of feedback over the transmitted band to produce the necessary operating stability with temperature and power supply variations, and a working value of modulation suppression.

3.9 *Repeater Regulation*

Repeater regulation will be furnished as an option where variations in line loss exceed the terminal regulating range. It will usually be necessary on systems employing more than one repeater in order to control noise performance. Repeater regulation in the direction of transmission from central office to remote terminal is controlled by the total carrier power of the channels working on one system. In the opposite direction, the repeaters will regulate on a low level carrier frequency pilot because the channel carriers are not always present in that direction of transmission due to their signaling function. The pilot frequencies are shown in Fig. 1.

The repeater regulator, shown in schematic form in Fig. 10, functions in much the same manner as the terminal regulator. The principal differences between the two regulators arise from the requirement that interchannel modulation must be appreciably less than 1 per cent in the repeater. To limit the contribution of the repeater regulator to a small value, the variolosser operates into a lower impedance and at a higher control current than used in the channel regulator.

The input section to the control amplifier is either a flat bridging pad for the case where all carriers are always present on the line or a pilot pick-off filter and its associated single transistor amplifier where carriers are turned on and off for supervision. The latter extra amplifier is necessary because the pilot power is 20 db below the power in each normal carrier.

The regulator stiffness provided by the repeater regulator results in a variation of 1 db in output carrier power for a 10-db variation in received total carrier or pilot power.

4. COMPONENTS

Development of the passive components of the P1 carrier system, including the various filters and other networks, were influenced by three major considerations. The manufacturing cost had to be as low as possible consistent with the traditional standards of Bell System service life. The components had to lend themselves to maximum utilization of the printed wiring techniques to be used as the basic equipment method. And lastly, advantage wherever possible was to be taken of the fact that transistors are low power devices.

4.1 *Filters*

Component-wise, filters are the most important single assembly determining the first cost of a carrier system employing frequency division multiplexing and frequency separation for obtaining equivalent four-wire

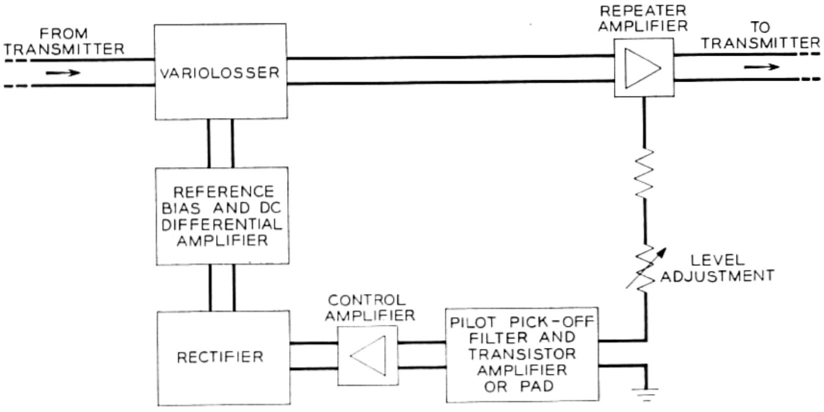

Fig. 10 — P1 Repeater regulator block schematic.

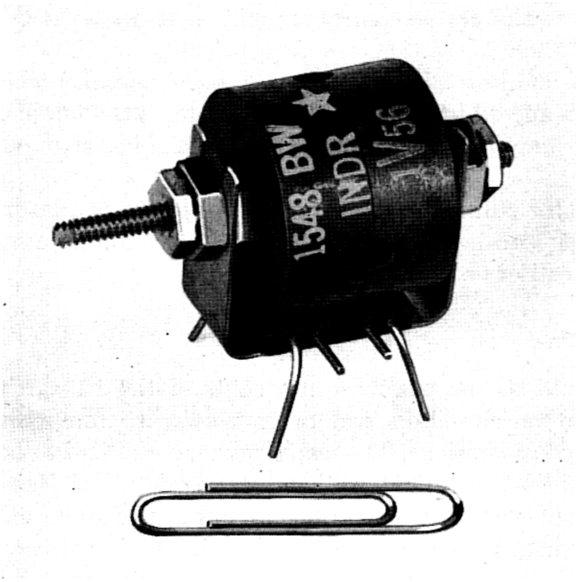

Fig. 11 — Miniaturized inductor for P1 carrier.

operation on the line. Past experience has shown that one-quarter or more of the first cost is often chargeable to the various filter. The decision to employ double sideband modulation was largely based on the knowledge that when frequency space is available the double sideband channel filters are generally the least expensive.

With this decision made, every effort was directed toward the achievement of channel filter designs of maximum efficiency in element utilization. Inexpensive wide-limit capacitors were used, and the desired performance achieved through the use of an adjustable ferrite inductor expressly developed for the P1 system. The filters are rapidly adjusted in the manufacturing process using visual display testing circuits.

4.2 *Inductors*

The inductor which makes this possible is shown in Fig. 11. It is designed for printed wiring use and provides a wide range of inductance while maintaining excellent "Q" performance in the carrier and voice range. This is accomplished in a single basic design by so selecting the winding for particular nominal inductances that the air-gap adjustment remains at or near its most efficient setting. Inductors of this type were used not only in all the channel, demodulator, and signaling filters in the terminal and in the directional filters at the repeater, but also in the channel oscillators and other parts of the circuitry where an inexpensive, adjustable element offered manufacturing or service advantages.

4.3 *Capacitors*

Most of the wide-limit capacitors used in the filters are of the commercially available molded mica type. Where the capacitance values would require large and expensive mica units both in filters and other parts of the circuit, newly available foil-Mylar capacitors were used. These take the form of very small pigtail units in a range of physical sizes similar to those of the solid tantalum capacitors described below. The Mylar capacitors have low working voltages in these miniature sizes and can

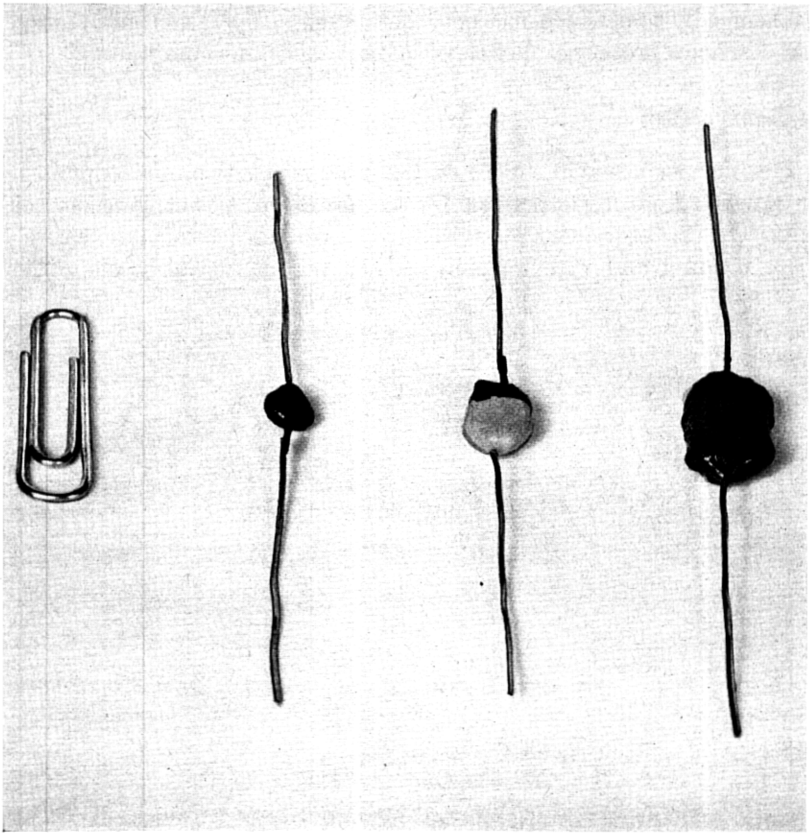

Fig. 12 — Prototype solid tantalum capacitors for P1 carrier.

be employed because of the low voltage protection provided for the transistorized circuits. Both cost and space savings are realized in these capacitors since no cans or potting are required due to the stability of the Mylar dielectric under moisture exposure.

Another new type of capacitor has found widespread use in the P1 system. This is a solid tantalum electrolytic capacitor used in place of the usual paste or liquid electrolytic capacitor. The solid electrolyte is manganese dioxide deposited upon the capacitor surfaces. The anode is made from tantalum metal and upon its surfaces is deposited the tantalum oxide which forms the dielectric. The cathode is an enveloping metal completing the capacitor structure. This new design of capacitor is now available in values up to 100 microfarads in a very small volume. It is expected to be less expensive than other electrolytic capacitors while at the same time providing a rugged structure which is relatively inert electrochemically and which has better stability in operation and storage. Fig. 12 shows prototype models of typical solid tantalum units.

4.4 *Transformers*

Transformer needs in the P1 system are met by two miniature structures which were made possible by the use of low power transistor circuits. The carrier frequency units employ a manganese zinc ferrite core, a spool winding and wire terminals which permit assembly on printed

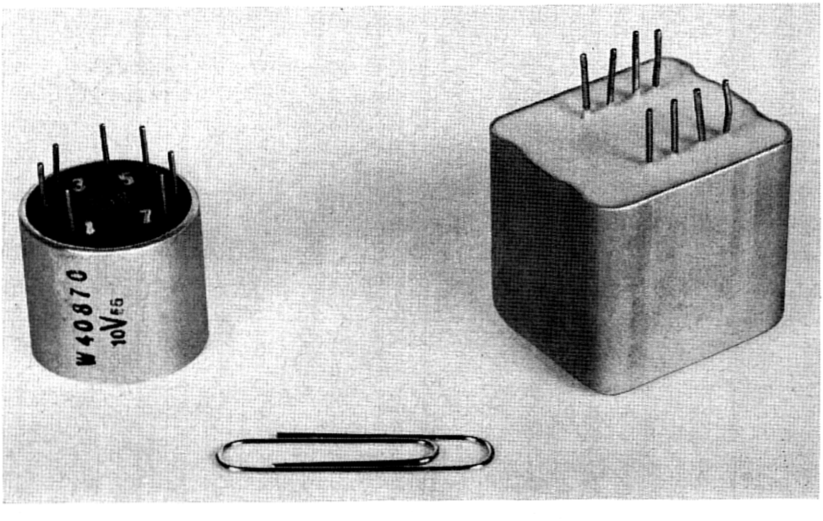

Fig. 13 — Carrier and voice frequency transformers for P1 carrier.

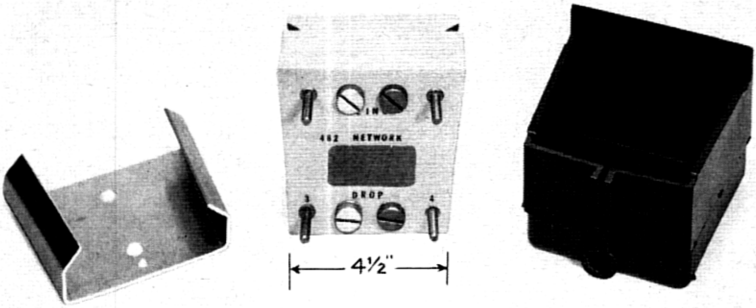

Fig. 14 — Example of P1 carrier line network.

wiring boards. They are potted with an asphalt compound in a cylindrical aluminum can. The voice frequency transformers are wound on laminated core structures of permalloy. The units are potted in an epoxy resin in rectangular aluminum cans. The terminal plate carrying the wire terminals for mounting is a cast unit of a styrene polyester. Both types of transformer are shown in Fig. 13.

4.5 *Line Networks and Filters*

Also deserving mention is a new series of line networks and filters (which do not form part of either the terminal or repeater equipment) with specific functions described in Section 7. All of the networks have been designed with the same type mounting arrangement shown in Fig. 14 with two sizes used depending on the number of components housed. The networks are cast in a styrene polyester. High voltage protection is self-contained and sturdy terminals are provided for bridle wire connection. By means of side slots in the casting the network is mounted on a wedge-shaped holder which is fastened to the crossarm or pole. A flexible rubber cover is snapped over the face of the network to protect against weather effects.

5. EQUIPMENT ARRANGEMENTS

The emphasis placed on economy in this development project made it necessary to consider a number of different approaches before deciding on the physical arrangement provided for both central office and pole mounted equipment. At both locations the terminals for each channel

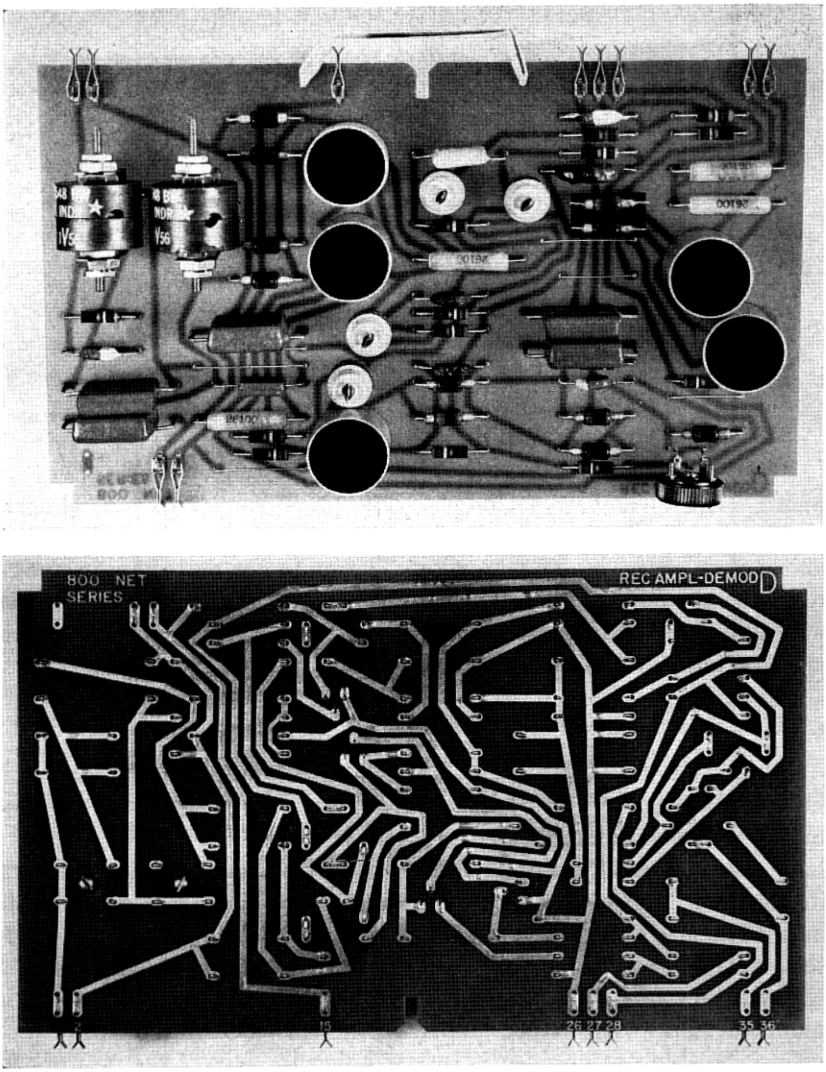

Fig. 15 — Front and back of typical printed wiring board.

were treated on an independent basis, thus providing maximum flexibility in application. While the use of transistors made it possible to take advantage of miniaturized components, the major emphasis in design has not been on miniaturization; instead it has been to achieve low manufacturing costs, simplicity of engineering and installation, and a minimum of maintenance effort. The recent trend toward automation in manufacture of electronic equipment has also influenced the design to a great extent.

5.1 *Printed Wiring Boards*

To best meet these objectives, use has been made of plug-in units which have proved successful in other carrier systems, such as the N1 and O. The assembly technique used here, however, is an entirely new approach for carrier equipment in that the plug-in unit consists of a printed wiring board on which all components are mounted. Printed wiring, which is a comparatively new engineering technique, was selected because of its applicability to automatic assembly, including mass soldering of connections. In addition, the use of printed wiring greatly simplifies testing and inspection and assures a more uniform product. The two sides of a typical printed wiring board are shown in Fig. 15.

5.2 *Interconnection of Boards*

The interconnection of the various plug-in units or printed wiring boards, required to make up a complete P1 terminal or repeater, is accomplished by means of a wire connector specifically developed for this project. Basically, the connector consists of a number of accurately spaced bare wires running parallel to each other and imbedded in cross member strips of insulating plastic material. At fixed intervals the wires are exposed, and this is where contact is made to terminal connectors mounted on the printed wiring boards. These terminal connectors, shown in Fig. 16, are made of spring tempered phosphor bronze

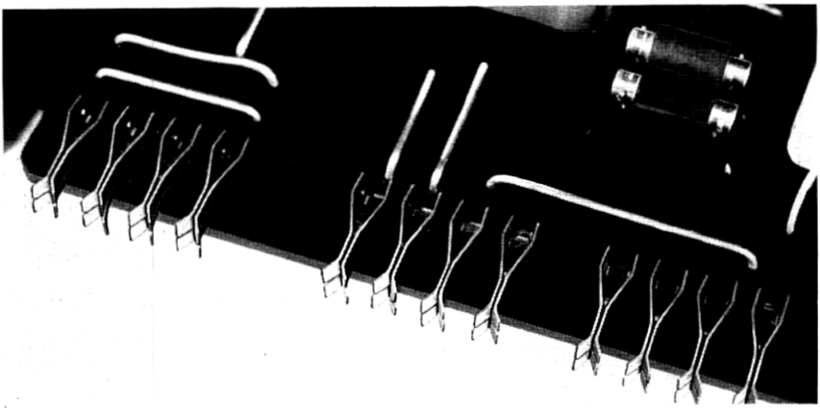

Fig. 16. — Closeup of terminal connectors.

and consist of bifurcated cantilever springs, providing a total of four contacts for each connection.

As can be seen in Fig. 17, the wire connector is actually a molded phenolic box into which are inserted all of the printed wiring boards that make up a complete terminal or repeater. The terminal connectors on the boards thus engage the wires that are imbedded in the back of the connector. To insure contact reliability, a finish of precious metal is provided on both the wires of the connector and the terminal connectors on the board. Additional flexibility in the interconnection of the boards is

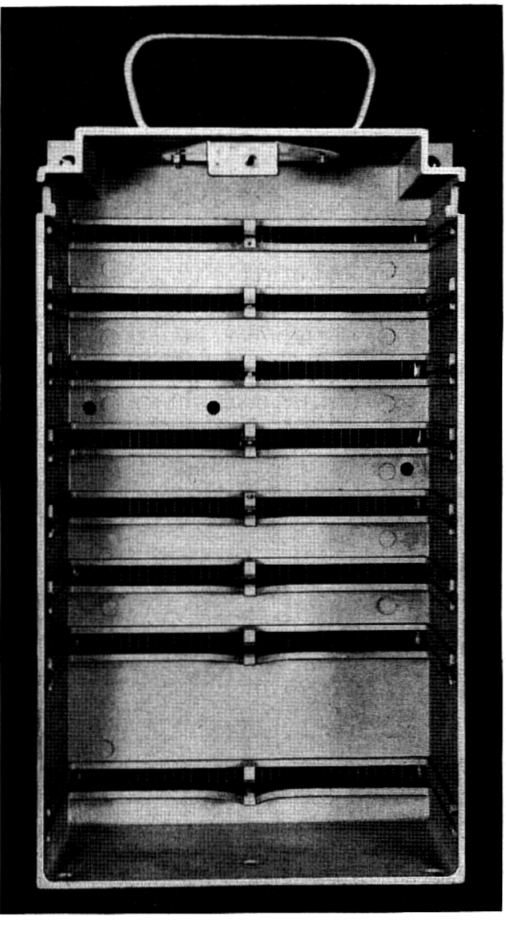

Fig. 17 — Prototype model of connector box unequipped showing grid wires.

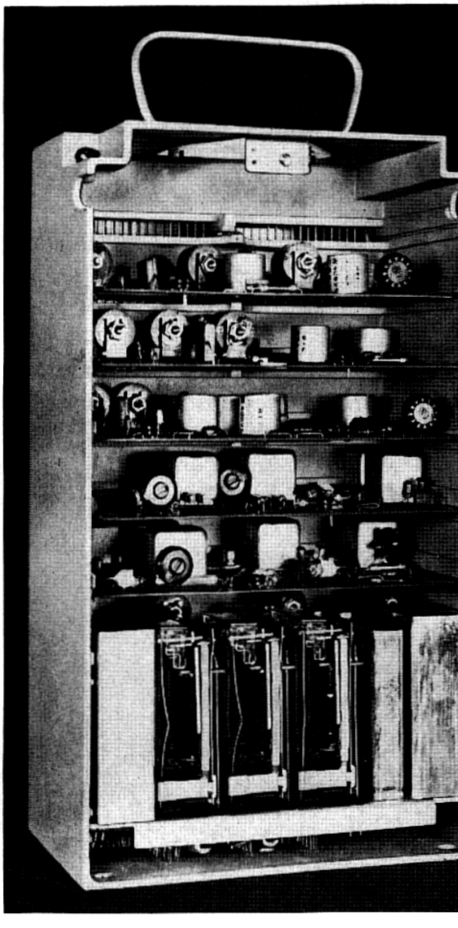

Fig. 18 — Typical terminal networ mounted in a prototype connector box

obtained by cutting the wires at various points by simply drilling holes in the phenol structure supporting the wire.

5.3 *Terminal and Repeater Mounting*

A complete terminal ready for installation at a remote location is shown in Fig. 18. The top position in the connector is shown vacant. This is where the connections to line and power supply are made by means of another plug-in printed wiring board with attached flexible wiring for the external connections.

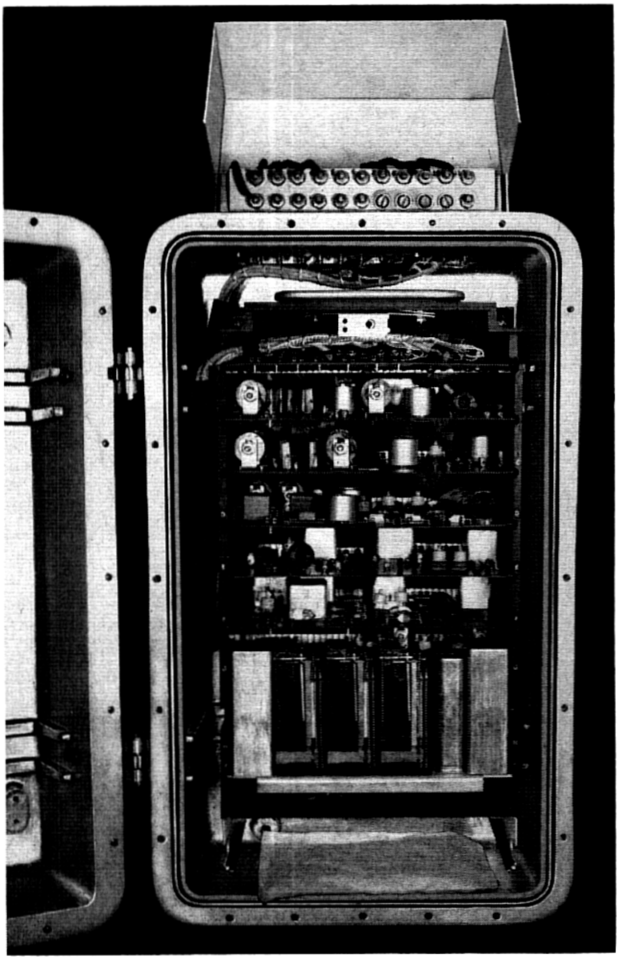

Fig. 19 — P1 carrier remote terminal in pole mounted cabinet.

The equipment described here is equally adaptable to central office mounting and pole mounting at remote locations. At the remote locations, however, it is necessary to provide the equipment with an outer housing which gives protection from all kinds of weather and even from moisture condensation. The opened housing is shown in Fig. 19. Fig. 20 shows a typical remote mounting of the housing on the left. In previous electron tube carrier systems the amount of heat generated by the equipment itself was sufficient to prevent moisture condensation. In the case

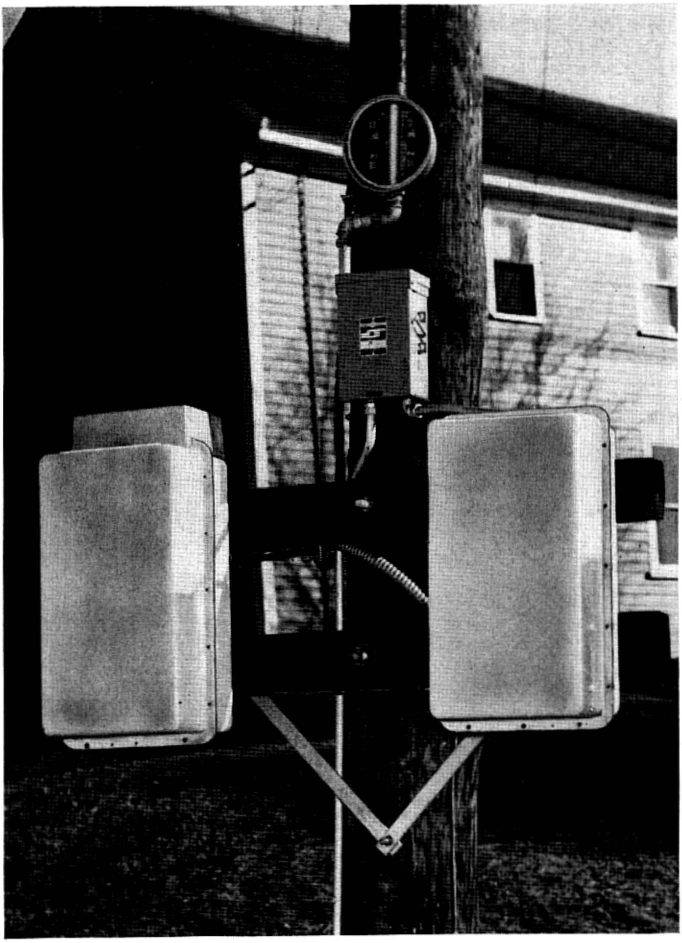

Fig. 20 — Example of remote mounting of P1 terminal and ac power supply.

of the P1 carrier, however, the heat dissipation during the idle period is less than 1 watt for the entire terminal. To prevent condensation, the housing or apparatus case is sealed by means of a neoprene gasket. To further reduce the moisture content of the trapped air, the use of a desiccant is specified. The apparatus case is made of die-cast aluminum with the outside walls finished in white enamel to keep heat absorption to a minimum. The system was designed to operate between temperature extremes of −40°F and +140°F. This limitation might necessitate the additional installation of sun shields in a few cases where extreme temperatures prevail.

The terminal equipment at the central office makes use of the same type of printed wiring boards plugged into a connector as used at the remote location. In the central office, however, the outer housing is dispensed with and the connector is mounted on mounting brackets on standard relay racks. The relay rack layouts can be arranged in a number of ways to suit the particular installation, since no shop wired bays are used. A typical 11′6″ relay rack layout will provide for 10 terminals. No line jacks or alarm features are provided and fusing may be obtained from existing fuse boards in the office. The equipment also lends itself to wall mounting in locations where relay rack space is not available.

5.4 *Testing and Maintenance Features*

One great advantage of the equipment design used in the P1 carrier system is the ease with which an entire terminal or repeater can be transported to, and installed at, a remote location. In case of trouble, the entire equipment unit, be it a terminal or a repeater, can be readily replaced. It is not expected that the maintenance man will attempt to replace an individual printed board at a remote location; however, this procedure is perfectly feasible in a central office. To facilitate the location of trouble in a unit, the various boards are provided with test points located at the outer end of the boards so as to be easily accessible to the maintenance man.

Certain precautions will have to be taken at central repair centers in replacing defective individual components in order not to damage the printed wiring. Too much heat applied by a large soldering iron will destroy the adhesive bond between the copper conductor and the phenolic board, but repair can be made under certain controlled conditions. A limited amount of wiring modifications can also be made to the printed wiring by inserting strap wires in place of components.

6. POWER SUPPLIES

The design of a carrier system with low power drain made possible the development of a low-cost, reliable dc power supply for the carrier equipment. Because the central office carrier terminal was designed to utilize standard central office voltages (24 or 48 volts), only the power supply for the remote equipment will be described here.

Early exploratory studies showed that conventional power supply designs would miss the first and annual cost objective by an uncomfortable margin. A number of unconventional approaches were studied:

(a) Storage batteries charged over the carrier line.

(b) Storage batteries placed in service with full charge and removed to a central point for recharging.

(c) Solar power plants.

(d) Wind power plants.

(e) Thermoelectric power plants.

(f) Dry cells.

In all of the above cases the power plant was either too costly, too large, or technically unfeasible, and none could prove in over the conventional conversion of ac to dc where commercial power is available. This was true despite need for a storage battery to operate the system during ac power failure intervals and to provide peak ringing power.

6.1 *AC Rectifiier-Storage Battery Plant*

The basic elements of the power plant circuit, as shown in Fig. 21, are the conversion section represented by the step-down transformer T1 and

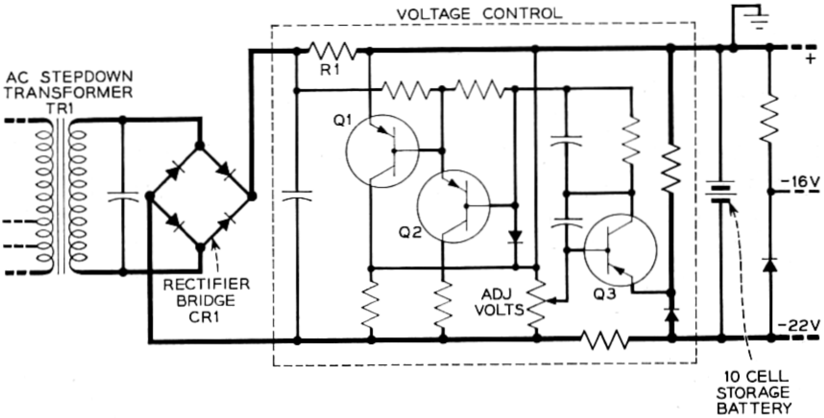

Fig. 21 — Schematic of ac rectifier-battery power supply.

the semiconductor rectifier bridge CR1, the voltage control circuit represented by that part of Fig. 21 enclosed in dashed lines, and the energy storage circuit represented by the battery.

Rectification is obtained with germanium rectifiers that are very efficient, have long life with negligible aging, and are very compact physically. The output of this rectifier is not constant, because the output voltage will vary with the ac input voltage and the dc load current drawn by the carrier terminal. Thus a regulating circuit must be provided.

The regulating network senses the voltage across the battery and compares this voltage to a reference obtained from a silicon junction diode biased in the reverse dirction.[3] Any error in the output voltage is converted to a current signal in the first amplifier stage and amplified by the second stage transistor Q2. The amplified error current is then used to control the impedance of transistor Q1 which acts as a current shunt around the battery.

The fundamentals of the operation of this regulating system are shown in Fig. 22. If the load voltage is too high, the network adjusts the resistance of transistor Q1 so that some of the rectifier output current is shunted around the load. The load voltage will then return very quickly to the regulated value. Because the rectifier circuit must not be overloaded by a discharged battery, some form of current limiting must be provided; this is automatically taken care of by resistor R1. The rectifier is capable of supplying indefinitely the current that would be drawn to charge a battery after a very long power failure.

The storage battery is shown in Fig. 23 near the bottom of the power plant housing. It is a new design with a high specific gravity sulphuric

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[3] D. H. Smith, Silicon Alloy Junction Diode as a Reference Standard, A.I.E.E., Communication and Electronics, No. 16, pp. 645–651, Jan. 1955.

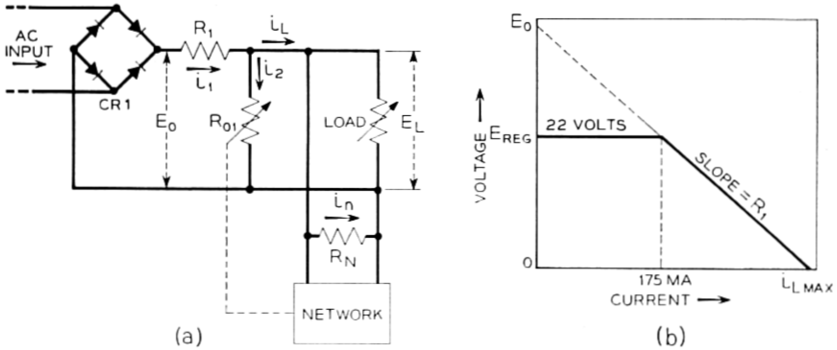

Fig. 22 — Simplified schematic and regulation characteristic of ac power supply.

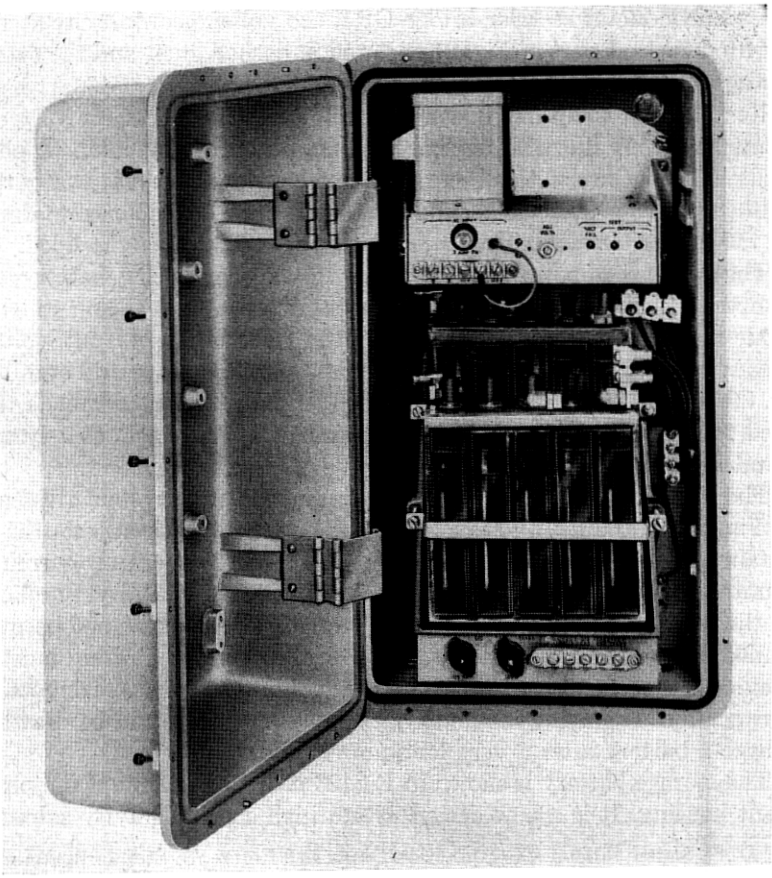

Fig. 23 — P1 carrier ac power plant in cabinet for pole mounting.

acid electrolyte for good low temperature operation and lead calcium alloy electrodes for long life. The battery has 10 cells housed in two jars of five cells each. It is operated at about 23.5 volts and weighs about ten pounds. It provides about six days' reserve for a remote terminal or about two days for a remote repeater. The battery should not freeze at temperatures as low as 40°F, but the storage capacity may be reduced 90 per cent at this extreme. The battery is mounted on steps so that the electrolyte level can be seen through the transparent plastic battery jars. Fig. 23 also shows the compact packaging of the entire power supply within the same type of aluminum housing as used for the carrier terminal. A typical pole mounted installation is shown in Fig. 20. Fig. 24 is a close-up of the bottom of the rectifier chassis which shows the regulating network mounted on a printed wiring board.

6.2 *Air Cell Primary Battery Plant*

Because ac will not be readily available at all remote locations, an alternate power supply has been developed and this is shown in Fig. 25.

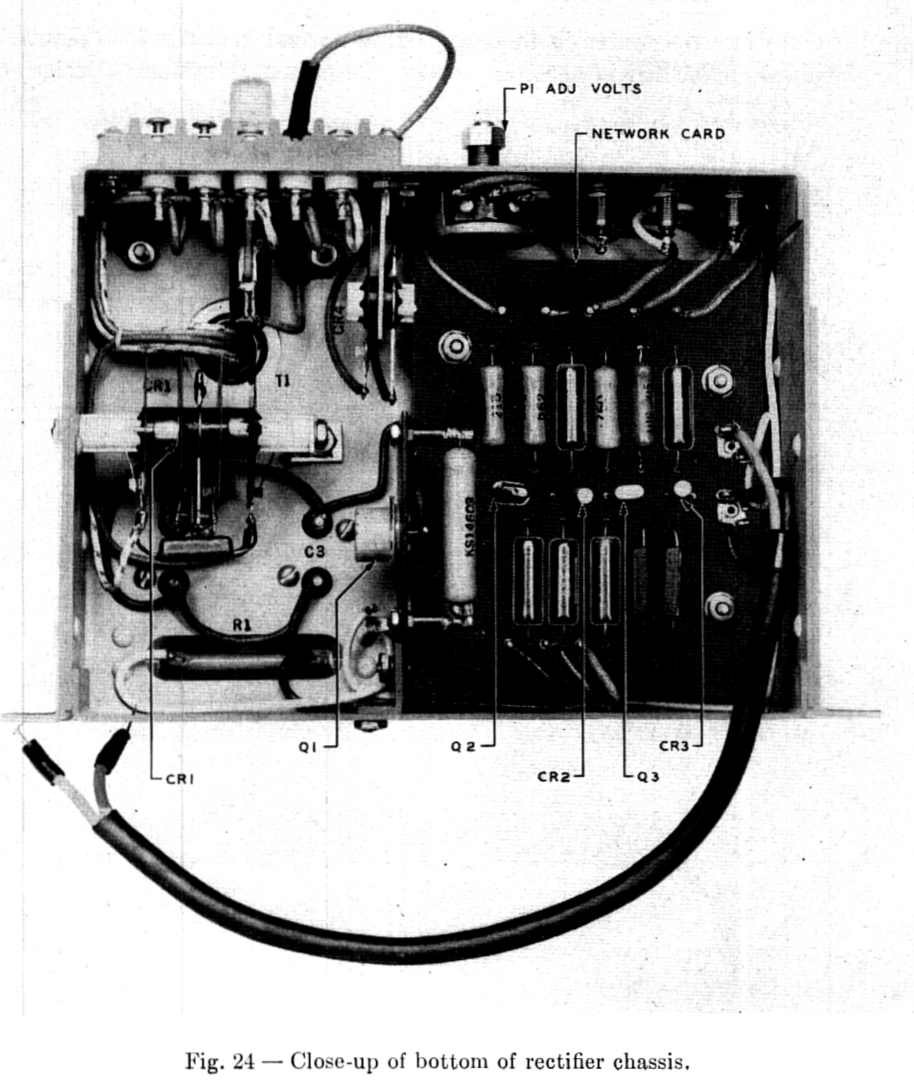

Fig. 24 — Close-up of bottom of rectifier chassis.

The alternative supply uses oxygen-depolarized primary cells having an alkaline electrolyte, and has been used for many years in railway signaling circuits and in the telephone plant. Sixteen battery cells are connected in series to provide enough power for three years of operation of a remote terminal or about one year for a remote repeater. The battery is discarded when fully discharged and is then replaced by a new battery.

7. APPLICATION OF P1 CARRIER TO RURAL TELEPHONE LINES

The P1 carrier system is to be applied to normal exchange loop plant facilities engineered in accordance with the present Resistance Design

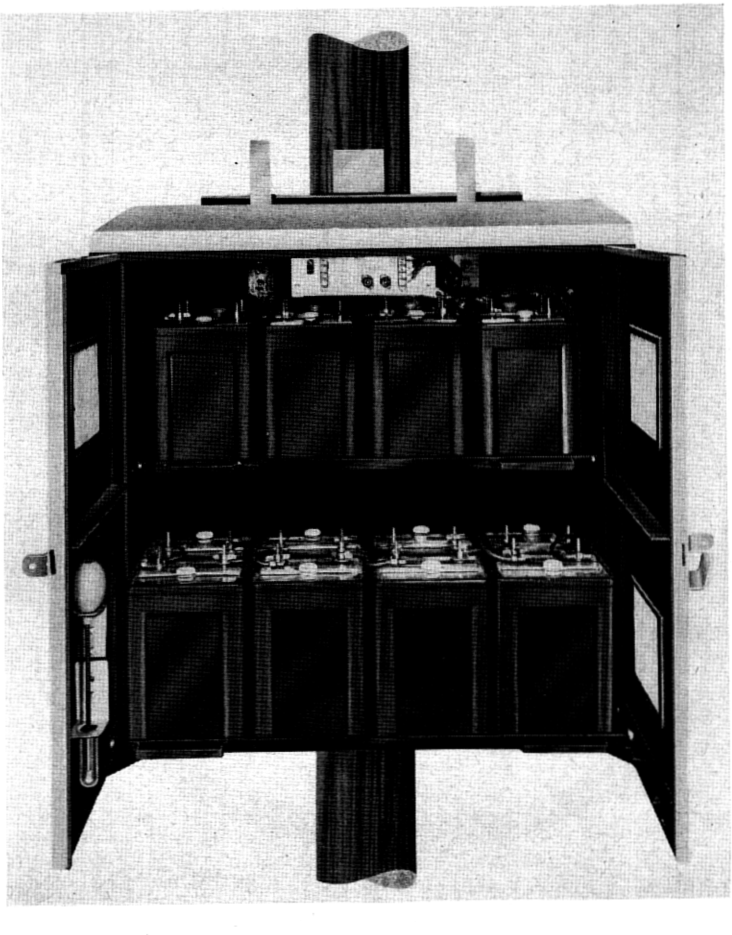

Fig. 25 — Primary battery power plant.

Methods used generally throughout the Bell System.[4] These facilities consist of mixed gauges of high capacitance cable extended at their outer ends by 109-mil steel, 104 mil-copper or copper steel open wire.

In engineering the carrier line design or carrier layout, the Plant Engineer will determine the carrier line layout necessary to meet the over-all requirements for a suitable carrier transmission path on the available physical facilities. To do so he need only be familiar with the general capabilities of the carrier system, its basic "building blocks," and the limitations that must be considered in applying the system to the physical line. The capabilities of the carrier system have been described in earlier sections. From those descriptions it can be seen that the basic "building blocks" for a P1 carrier system are:

1. Central office channel terminals
2. Remote channel terminals
3. Repeaters
4. Ac or dc remote terminal and repeater power supplies
5. Carrier line networks and filters

A carrier application of these "building blocks" is shown in schematic form in Fig. 26.

The low-pass filters or carrier blocking networks shown are placed at the junctions of the carrier line and side leads of customer drops served by physical or derived voice frequency circuits on the base carrier facility. These filters are required to reduce the bridging loss of the side leads at carrier frequencies and to keep carrier frequencies out of the customer drops to prevent annoyance to the customers. High-pass filters are provided to make the carrier line continuous at carrier frequencies, but divide it into isolated sections for voice frequency distribution.

In addition to these blocks, an autotransformer may be required at the junction of the open wire and cable. The autotransformer, either alone or in conjunction with a junction line filter, is required to eliminate reflection losses and reduce crosstalk at carrier frequencies due to impedance mismatch between the cable and open wire. The junction line filter is required to allow the carrier and physical voice frequency circuit to be used on different pairs in the cable and on the same open-wire pair beyond the cable-open-wire junction. This is necessary where the physical circuit is so long that load coils are required on the voice frequency cable pair and non-loaded cable pairs are required for carrier. A pair of junction line filters may also be used to provide a voice frequency by-pass around a repeater. As illustrated in Fig. 26, this may be necessary

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[4] L. B. Bogan and K. D. Young, Simplified Transmission Engineering in Exchange Cable Plant Design, A.I.E.E. Communication and Electronics, No. 15 page 498, Nov. 1954.

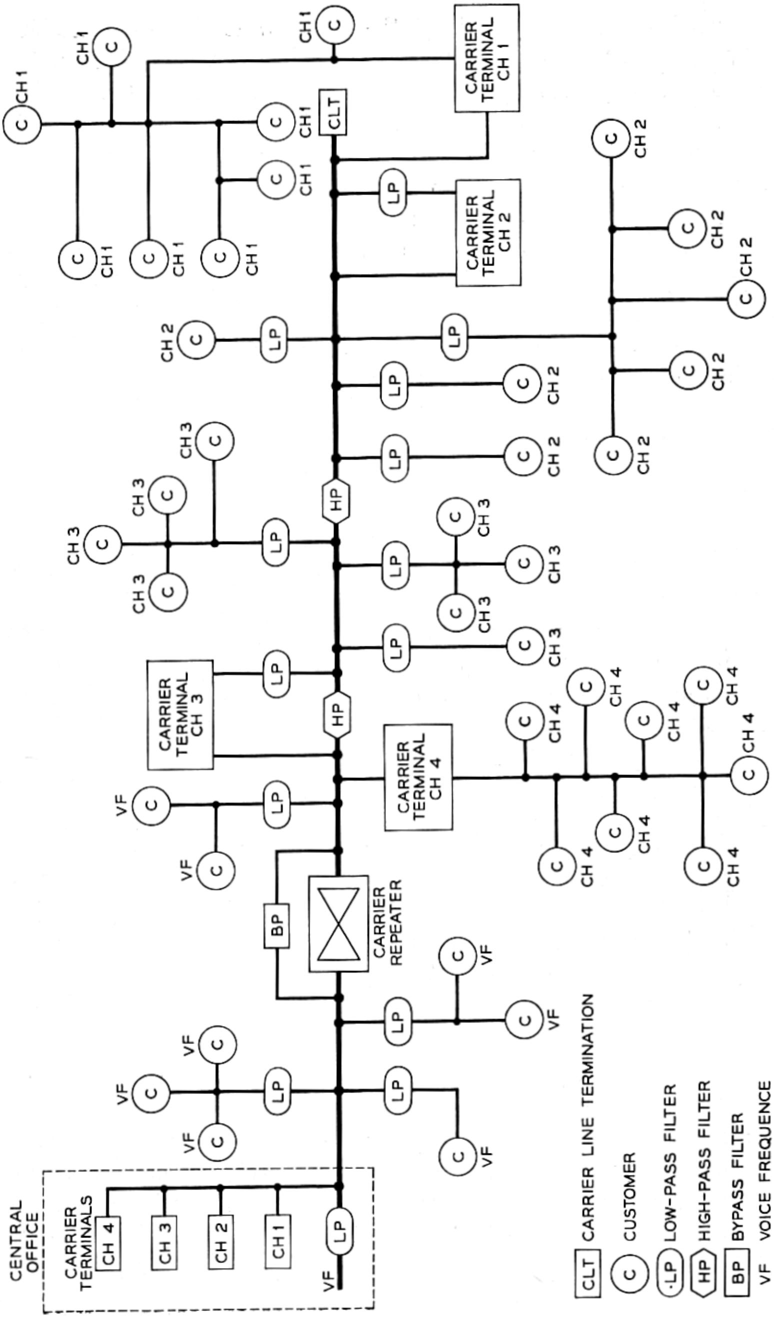


Fig. 26 — Typical P1 carrier application schematic.

to serve customers beyond that point from physical voice frequency circuit.

A carrier line termination network is also provided to terminate the end of the carrier line at all frequencies and thus prevent reflections from interfering with the transmission at remote carrier terminals spaced along the line. This network and all of the other line networks are available in the pole or crossarm mounted arrangement shown in Figure 14 and described in Section 4.5.

Fig. 26 also gives examples of two types of subscriber distribution beyond the remote carrier terminals. One, wire distribution, is indicated by the voice frequency extensions of Channels 1 and 4 and the other, filter distribution, is shown for Channels 2 and 3. Filter distribution permits the carrier line to be used simultaneously for carrier transmission and voice frequency distribution of the derived voice frequency circuit, thus saving the pair of wires required if wire distribution were used.

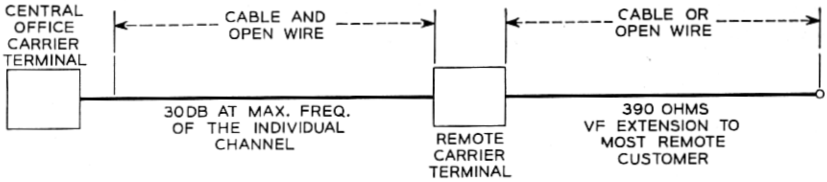
7.1 *Layout Procedure and Ground Rules*

P1 carrier channel layouts for a given rural line will be based on the forecast of commercial requirements for that route. The Plant Engineer must determine the number and arrangements of channels which can be applied within the system limits to meet that forecast. The locations of remote terminals are then chosen based on customer locations, channel frequency arrangements, and the availability of commercial ac power. With the terminal locations fixed, the line losses are determined at appropriate frequencies and repeaters are specified as necessary along with any line networks and filters required for the layout.

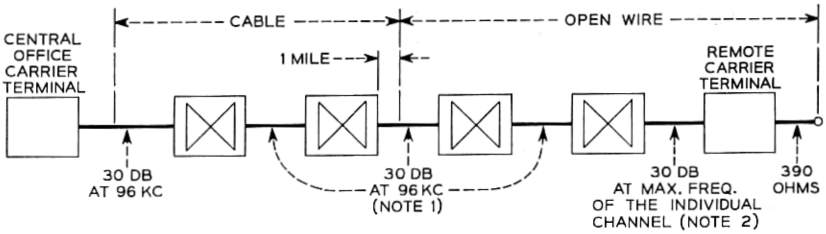
The characteristics and limitations of the P1 system lead to certain simplified ground rules which may be used in laying out the carrier channels. Some of these rules are summarized in Fig. 27. The stackable frequency arrangement is used for non-repeatered operation, and the design of the carrier channels permits the bare line loss of each individual channel to be 30 db at the top frequency between the central office terminal and the remote terminal.

Another limit shown in the figure is that the dc loop resistance of the voice frequency extension beyond the remote terminal can not exceed 390 ohms (5 miles of 109-steel wire). The 390-ohm limit is determined by the talking battery supply requirements of the 500-type customer telephone sets when the battery is supplied from the remote P1 terminal power supply. The P1 carrier system has been designed to operate with the 500-type telephone set. The improved dialing, ringing and transmission features of that set will help to insure satisfactory performance of the over-all carrier derived circuit. In keeping with the system objectives, the over-all transmission of a carrier channel and its voice frequency extension, using the 500-type telephone set, will be as good or better than that obtained on long rural lines using physical plant laid out by the Resistance Design Method mentioned earlier.

As shown in Fig. 27, the normal and staggered grouped frequency arrangements used for repeater operation allow 30-db bare line attenuation at the top frequency (96 kc) between the central office terminal and the first repeater or between repeaters, and about 30 db between the last repeater and each remote channel terminal at the top frequency used for that channel. Directional filter characteristics limit the repeater system can use a maximum of four repeaters for a total line loss of about 150 db at 96 kc. However, noise and crosstalk requirements will permit no more than two of the four repeaters to be used in the open-wire line, with the last cable repeater at least one mile back in the cable from the cable-open-wire junction, as shown in Fig. 27. Spacings must be limited to somewhat less than 30 db on certain line facilities such as B rural wire to insure proper terminal regulation.[5]



(a) STACKABLE FREQUENCY ARRANGEMENT: NON-REPEATED



NOTE 1
CHECK MAXIMUM LOSS AT 30KC AND IF LESS THAN GAIN IN REMOTE TERMINAL TO CENTRAL OFFICE DIRECTION, PLACE INPUT PAD EQUAL TO DIFFERENCE AT INPUT OF REPEATER.

NOTE 2
CHECK MINIMUM LOSS AT MINIMUM FREQUENCY OF EACH CHANNEL FOR THE LAST REPEATER TO REMOTE TERMINAL SECTION AND IF THIS IS LESS THAN THE REPEATER GAIN AT THAT FREQUENCY, PLACE PAD IN OUTPUT OF TERMINAL TO BUILD SECTION OUT TO REPEATER GAIN VALUE.

(b) GROUPED FREQUENCY ARRANGEMENTS: REPEATED

Fig. 27 — P1 carrier application ground rules.

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[5] C. C. Lawson, Rural Distribution Wire, Bell Lab. Record, pp. 167–170, May, 1954.

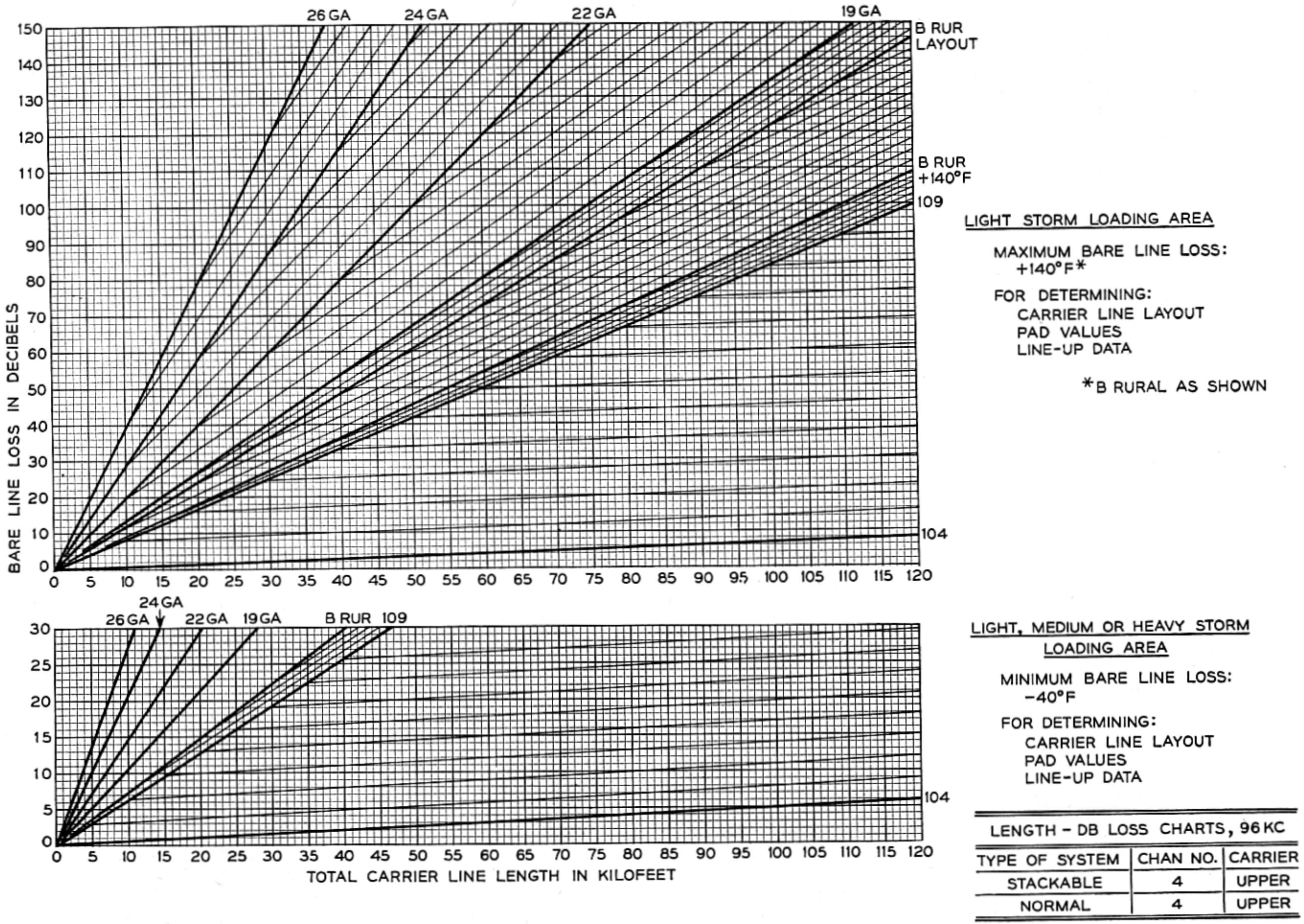
In addition to bare line loss, the ground rules make allowance for approximately 3 db of miscellaneous losses in any normal channel layout, including bridging losses of carrier blocking networks and other terminals on the carrier line, insertion losses of high-pass filters, and losses in the autotransformer and junction line filters used at the cable-open-wire junction. Since these losses do not all add directly, it is simpler to use an average loss factor to cover most conditions rather than make computations to determine a definite loss for each set of conditions that might exist. Thus for channels using a stackable frequency arrangement, a maximum of about 33 db loss, including the bare line loss and miscellaneous losses, may be expected between the points where the terminals connect to the line.

A further loss is experienced because the remote terminals are bridged onto the carrier line. As a result the carrier power transmitted toward the central office terminal is only +0.5 dbm due to a bridging loss of about 3.5 db at that point. Therefore, in the remote-to-central office direction, the minimum power will be −32.5 dbm (0.5 dbm − 33 dbm) at the line terminals of the central office terminal. The minimum carrier power in the central office to remote direction will be −29 dbm (+4 dbm − 33 dbm) at the bridging point of the remote terminal.

7.2 *Terminal and Repeater Location*

In laying out the carrier line design, it is first necessary to determine the possible locations for the remote terminals based on distances to the customers to be served and the availability of commercial ac power, since this is the most economical power source. (When commercial ac power can not readily be made available, the primary air cell batteries can be used.) Having determined the ideal location of the terminals from a physical standpoint, the makeup of the physical circuits back to the central office must be determined and computations made of the carrier frequency attenuation of the facilities. These loss computations are used to determine the number of repeaters required, if any, and their locations, once again modified by availability of commercial power. The Plant Engineer must also check for the necessity of input and output pads at the terminals and repeaters.

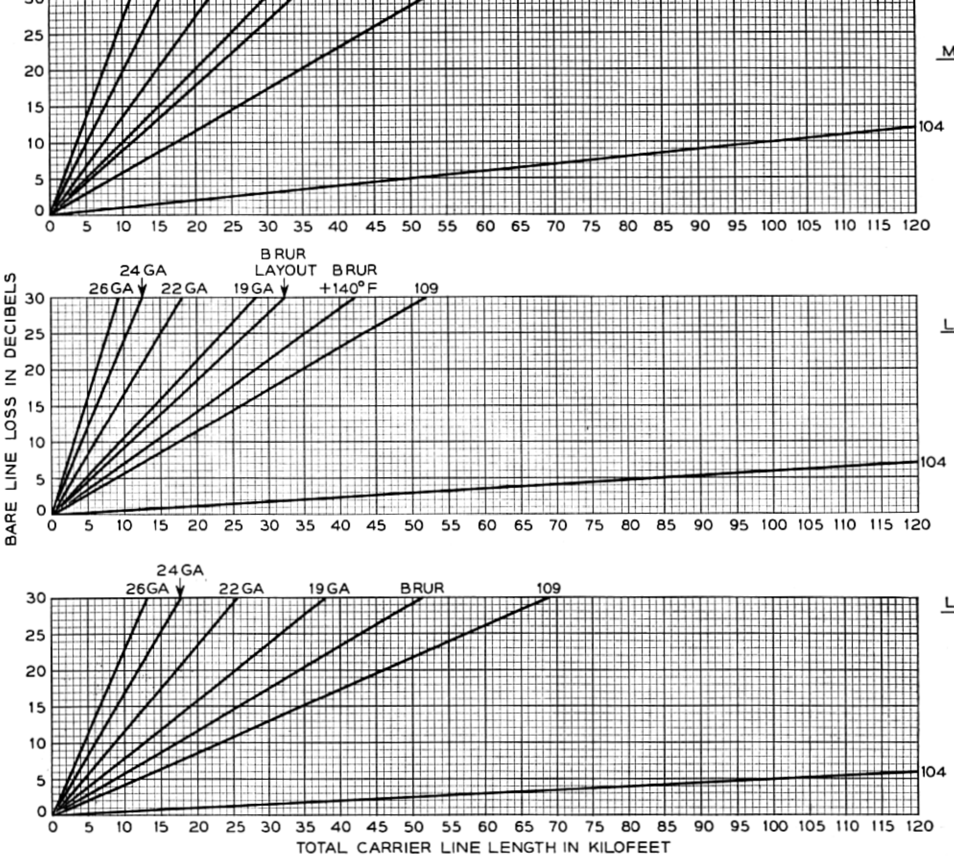
The need for loss computations led to the development of length-loss charts so that a carrier line design could be made in a manner very similar to the loop cable design using the Resistance Design Methods as mentioned earlier.[4] Fig. 28 shows one of the 96-kc length-loss charts used to lay out repeater spacings and Channel 4 over-all circuit design. Fig. 29 shows the 48-kc length-loss charts as an example of the charts that are provided at each carrier frequency other than 96 kc for terminal-to-



LENGTH - DB LOSS CHARTS, 96 KC

TYPE OF SYSTEM	CHAN NO.	CARRIER
STACKABLE	4	UPPER
NORMAL	4	UPPER

Fig. 23 — 96-kc length-loss charts.



MEDIUM OR HEAVY STORM LOADING AREA

MAXIMUM BARE LINE LOSS:
CABLE +30°F WIRE-SLEET

FOR DETERMINING:
CARRIER LINE LAYOUT
PAD VALUES

LIGHT STORM LOADING AREA

MAXIMUM BARE LINE LOSS:
+140°F*

FOR DETERMINING:
CARRIER LINE LAYOUT
PAD VALUES
LINE-UP DATA

*B RURAL AS SHOWN

LIGHT, MEDIUM OR HEAVY STORM LOADING AREA

MINIMUM BARE LINE LOSS:
-40°F

FOR DETERMINING:
CARRIER LINE LAYOUT
PAD VALUES
LINE-UP DATA

LENGTH-DB LOSS CHARTS, 48KC

TYPE OF SYSTEM	CHAN NO.	CARRIER
STACKABLE	2	UPPER
NORMAL	4	LOWER

Fig. 29 — 48-kc length-loss charts.

terminal section layouts of all channels using the stackable frequency arrangement or repeater-to-terminal section layouts for channels using grouped normal or staggered frequency arrangements.

7.3 *Pad Selection*

The Plant Engineer is given general ground rules for determining the values of input and output pads used in the terminals and repeaters. Charts are provided for use in determining the input and output pads, and they are so arranged that the engineer can take values directly from the length-loss charts and enter them into the appropriate slots to calculate the proper pad values.

7.4 *Crosstalk Limitations*

The Plant Engineer must be given information showing how many carrier channels can be applied to each circuit of open wire, cable or B-rural wire on a rural route. Crosstalk studies and tests have indicated that the stackable frequency arrangement or the grouped frequency arrangements used singly or in combination can be used on cable or B rural wire with a full system complement of channels applied to each pair. However, in the case of open wire, the frequency arrangement and number of channels which can be applied is very dependent on the type of transposition system used. The R1 design is the most commonly used transposition design on rural lines of the Bell System, and Fig. 30 gives

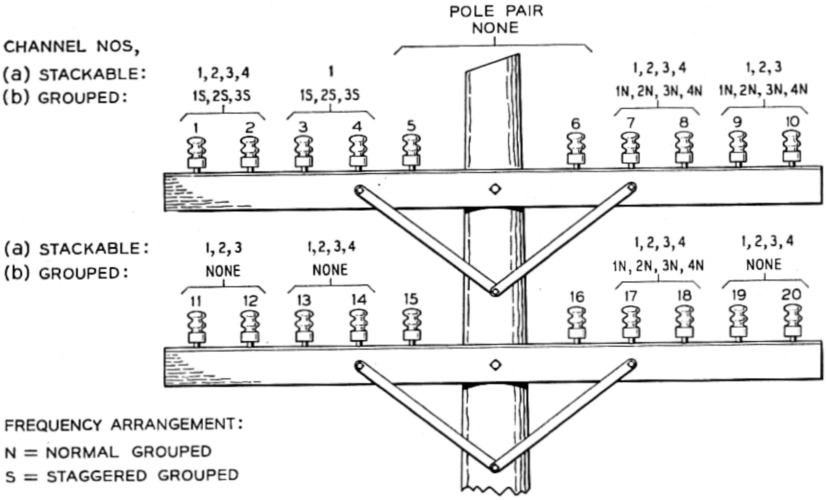


Fig. 30 — Number of P1 carrier channels on an R1 transposed line.

the carrier assignments for the various frequency arrangements on a one and two-crossarm route using the R1 transposition design. Use of a transposition system giving better carrier frequency crosstalk performance than the R1 design is expected to permit the application of a number of additional channels over those shown in Fig. 2.

It will be noted that the grouped arrangement provides four channels less on a two-crossarm basis than the stackable arrangement. From a transmission standpoint, equal numbers of channels would be possible by assigning one or two channels to a pair, but these arrangements will usually be uneconomical for grouped systems because of the high cost per channel of repeaters.

7.5 *Line Networks*

The location of the line networks and filters, which are a permanent part of the carrier layout, will be designated by the Plant Engineer, and the location and type of the remaining networks, which will vary with changes in subscriber service, will be selected by the plant forces. The low-pass filters or carrier blocking networks used on the carrier lines are simple resonant circuits designed to match given ranges of capacitance that will be presented by the drop wire or open-wire side leads. Since this capacitance varies considerably with various lengths of facility, a method will be provided by which the total capacitance of the drop can be determined and the proper network chosen. The other line networks are applied to the line as necessary to achieve their particular functions.

8. INSTALLATION AND MAINTENANCE

A portable field test set has been developed which will simplify the installation and maintenance of the P1 carrier system. The new set, known as the 7F test set, will provide the carrier and audio frequencies and a means of measuring them required to align and troubleshoot units of the system. The set, which is battery operated, contains a carrier oscillator to supply test frequencies from 10 to 100 kc, an audio frequency oscillator having six selected frequencies in the range of 250 to 2,500 cycles, a modulator to modulate the carrier frequency signal with the audio signal, a demodulator for calibrating the modulated signals, and a wide-band amplifier-detector for making level and transmission measurements. The model of the set shown in Fig 31 included a precision dial for signaling testing which was subsequently found unnecessary and eliminated. An ac operated set providing the same desired facilities is now under development.

The carrier channel installation and lineup procedure is set up on the basis of using the test set and a generally available volt-ohmmeter to make a series of measurements in a specified order. This will permit potentiometers to be adjusted as necessary until the specified meter readings are obtained at built-in test points. Lineup of the terminals and repeaters done first in the central office to insure proper operation and then at the in-plant locations to check system performance.

Maintenance will be handled on a complete terminal replacement basis and will consist of making a series of checks with the test set to determine whether the terminal is functioning satisfactorily. If it is not and it cannot be adjusted to restore satisfactory operation, a replacement terminal will be used to restore service. All repairs and isolation of trouble within the terminal unit or on the individual boards will be handled at a centralized testing or repair point so as to require a minimum of personnel with electronic experience. The test set has been designed to handle all tests for a P1 carrier system, when used with the volt-ohmmeter, and when used by trained personnel will permit trouble to be isolated to a given printed wiring board in the P1 carrier equipment.

9. ACKNOWLEDGMENTS

The authors wish to thank all their colleagues for their important and necessary contributions to this paper. Particular appreciation should be expressed to E. H. Perkins for his contribution to the first half of the paper and to D. H. Smith for Section 6 on power supplies.

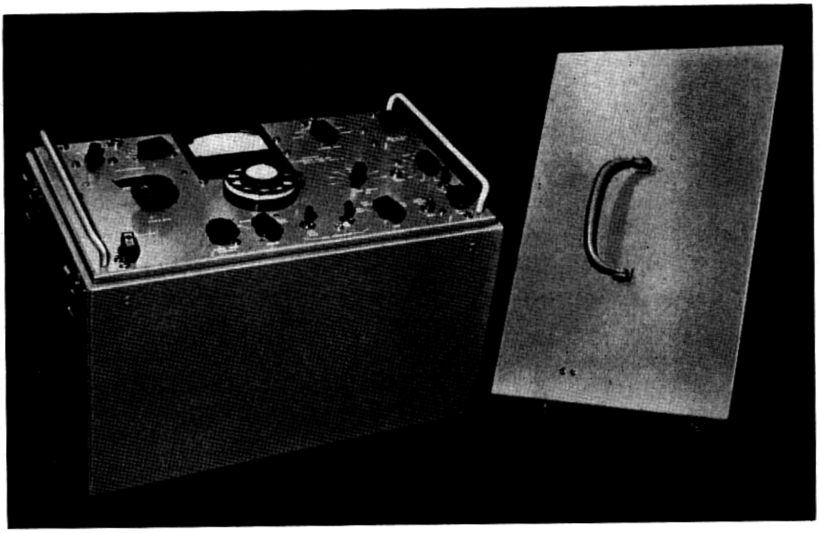


Fig. 31 — P1 carrier 7F test set.