New Group and Supergroup Terminals for L Multiplex

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L multiplex terminals provide the several stages of modulation required to translate telephone channels into the broad basebands which can be transmitted on long-haul systems. The group and supergroup equipment has been redesigned incorporating many new features. Pilot-controlled regulators are provided to improve performance. Plug-in modules and automated monitoring facilitate maintenance. The equipment is arranged to reduce office cabling and installation cost. By the use of transistors and other newly developed devices and components, a size reduction of 10 to 1 has been achieved and the required power greatly reduced.

I. INTRODUCTION

The L multiplex terminals are used for Bell System long-haul telephone circuits, including those transmitted over the L1 and L3 coaxial systems, the TD-2, TH, TJ and TL microwave systems. Single-sideband amplitude modulation is used for translating voice channels into the broad frequency bands which can be transmitted by these systems.

Several stages of modulation are required to form the complete baseband. As shown in Fig. 1, these stages are known respectively as the channel bank, group bank, supergroup bank, and mastergroup bank. This paper describes a new design of the group and supergroup equipment.

A companion paper[1] outlines the original development of telephone terminals for coaxial systems, their subsequent use on microwave radio systems, and the increasing need for better performance to accommodate new services such as direct distance dialing and data transmission. The development of channel banks including the new A5 channel bank is described in a recent paper.[2] The original development of the group and supergroup equipment was started more than 20 years ago.[3] Since

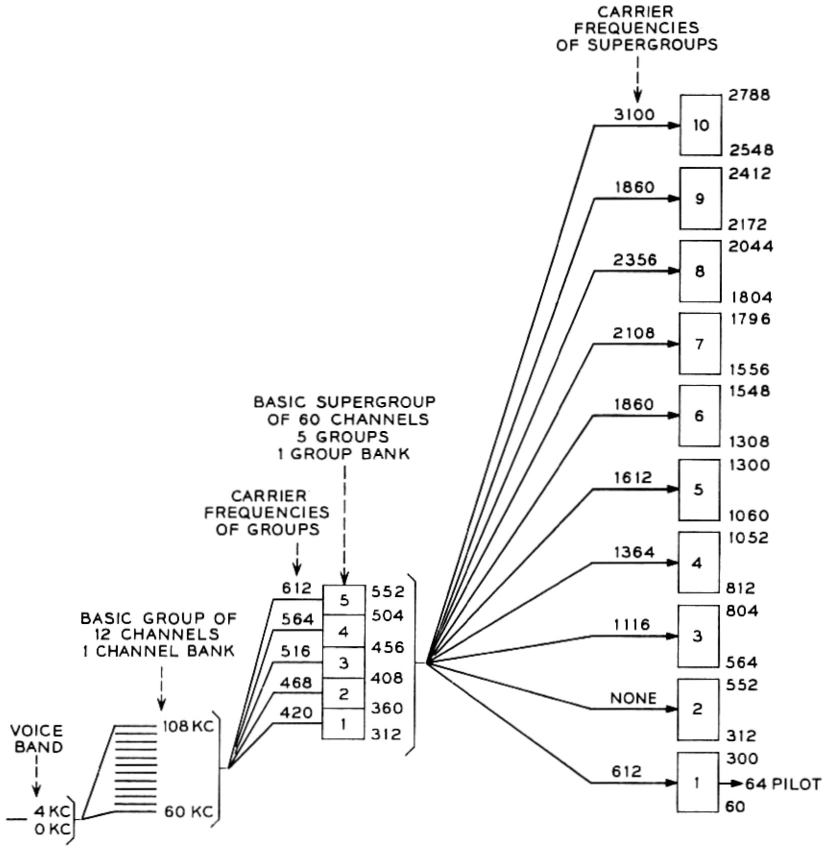


Fig. 1 — Frequency allocation — L600 multiplex.

then, the advent of the transistor and the development of associated components have made it possible to achieve a large reduction in size in the new design, even though several new features have been added.

1.1 *New Features*

Pilot-controlled regulators have been added to the receiving supergroup and group amplifiers. These improve over-all transmission stability by automatically correcting level changes which may occur anywhere along the circuit between the transmitting and receiving terminals.

All amplifiers employ transistors and are mounted in plug-in assemblies, introducing a high degree of flexibility and ease of installation and maintenance. Automatic scanning and alarm circuits have been developed to facilitate maintenance and trouble location.

New group and supergroup carrier supplies for furnishing the required carrier frequencies for modulation, demodulation, and pilots have been developed. These are described in a companion paper.[4]

All equipment for translating the output of 50 channel banks (600 channels) into one mastergroup is arranged in one shop-wired transmitting bay. The corresponding receiving equipment is included in a second bay. This consolidation of equipment which formerly occupied more than 20 bays results in large savings in space and in interbay cabling. The power required has been greatly reduced, and only one supply, 24 volts dc, is required.

A group distribution frame for reassigning channel banks or group connectors has been developed to eliminate the need for recabling when changes are made in circuit layouts.

II. GENERAL DESCRIPTION

Two types of terminals have been developed, the L600 for multiplexing up to 600 voice channels, and the L1860 for multiplexing up to 1860 voice channels. The L600 is used as terminals for TD-2, TJ, and TL microwave radio relay systems and the L1 coaxial cable system. Its frequency allocation is shown in Fig. 1. The L1860 is used for L3 coaxial and TH radio systems. As indicated on Fig. 2, the L1860 employs different supergroup carrier frequencies for certain supergroups and requires the mastergroup stage of modulation. Equipment arrangements for smaller numbers of circuits are also being provided; these are the L60 and L120, for 60 and 120 channels, respectively.

2.1 *Frequency Allocation*

2.11 *L600 Multiplex*

The frequency allocations shown on Fig. 1 agree with those used on the L1 system telephone terminals except for that of Supergroup 1. The band shown, 60–300 kc, is 8 kc lower in frequency than that used in the L1 terminals. The new allocation permits the use of filters for Supergroups 1 and 3 which do not contain quartz crystals, which were previously required. The new Supergroup 1 carrier is the same frequency as the Group 5 carrier, 612 kc, permitting some simplification in carrier supplies. The new allocation agrees with the recommendation of the CCITT.*

* Comité Consulatif International Téléphonique et Télégraphique.

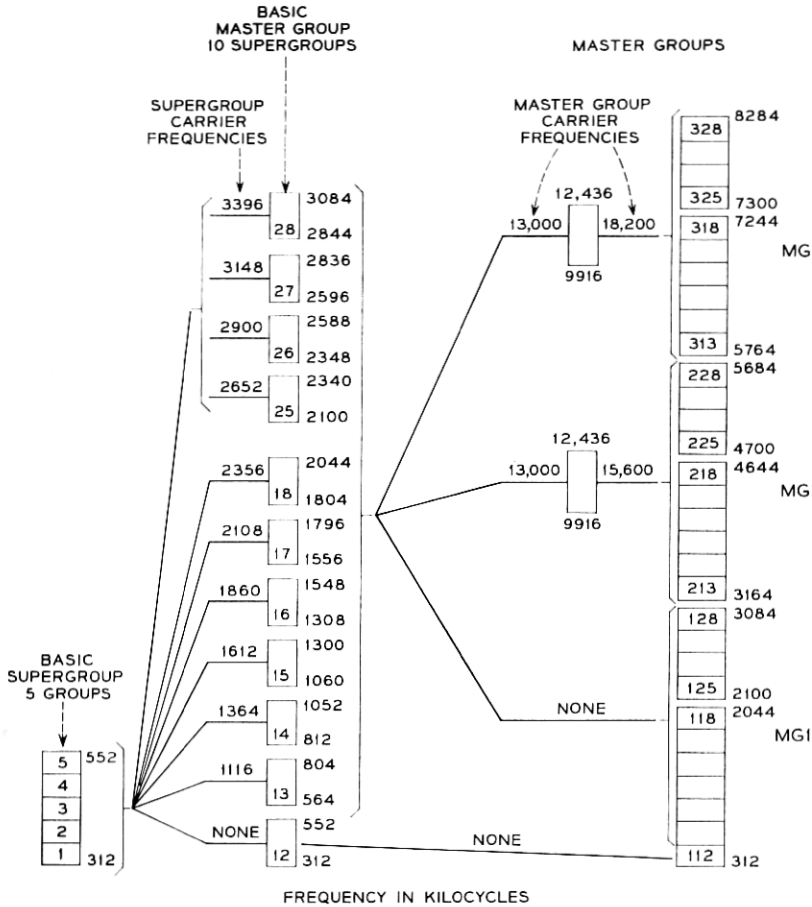


Fig. 2 — Frequency allocation — L1860 multiplex.

The continued use of 64 kc as a pilot frequency for microwave radio systems and for synchronization of carrier supplies makes it necessary to provide a 64-kc band-elimination filter in the transmitting Supergroup 1 to clear a band for the pilot.

2.12 *L1860 Multiplex*

The plan used to obtain the basic mastergroup for the L1860 multiplex, shown on Fig. 2, differs from that used in the L3 system telephone terminals.[4] The four supergroups numbered 25 to 28 are modulated directly to their basic mastergroup allocations instead of using three stages of modulation. The earlier plan required fewer supergroup carrier frequencies and fewer filter designs. However, with the use of the mastergroup terminals for both L3 coaxial system and TH radio system, it becomes economical to supply the additional carriers and filter designs in order to eliminate the sub-mastergroup stages of modulation.

2.2 *Transmitting Circuits*

The block schematic on Fig. 3 shows the group and supergroup circuits. The output of the transmitting portion of the channel bank is connected to terminals on the transmitting group distribution frame, and through the frame to the pilot insertion equipment on the group and supergroup transmitting bay. The 92-kc elimination filter clears a pilot channel between two voice channels. It is required to suppress the carrier leak at 92 kc which would interfere with pilot operation. The 92-kc group pilot* is introduced through a hybrid transformer. The output including the pilot is fed to a second hybrid transformer which provides two equal outputs. One of these is connected through normal contacts on jacks to the transmitting group equipment. The second output is available for monitoring or emergency patching.

If the terminal is retransmitting a group that has been received from an incoming system, the group signal is transmitted through a group connector including a bandpass filter, the group distribution frame and the pilot insertion equipment. If it is desired to operate with a through pilot, a pad is substituted for the pilot elimination filter and pilot hybrid transformer.

In small offices the group distribution frames may be omitted and the connections made directly from channel banks or group connectors to the group equipment.

A transmitting group amplifier is combined with the group modulator in a single plug-in assembly. The lower sideband of the modulator output is selected by a bandpass filter. The filters for the odd-numbered groups have their outputs in parallel. Similarly, the two even-numbered group filters are paralleled. The two sets of outputs are added in a hybrid transformer. The entire band from 312 to 552 kc (5 groups) is amplified in the transmitting intermediate amplifier. A low-pass filter to suppress out-of-band harmonic products follows, and two equal outputs are provided by a hybrid transformer.

Each group bank output is modulated by an appropriate carrier, and

* In order to accommodate wider bands for high-speed data transmission, development work has recently been started to change the group pilot to 104.08 kc and to use the new Group 1 pilot, 315.92 kc, for supergroup regulation.

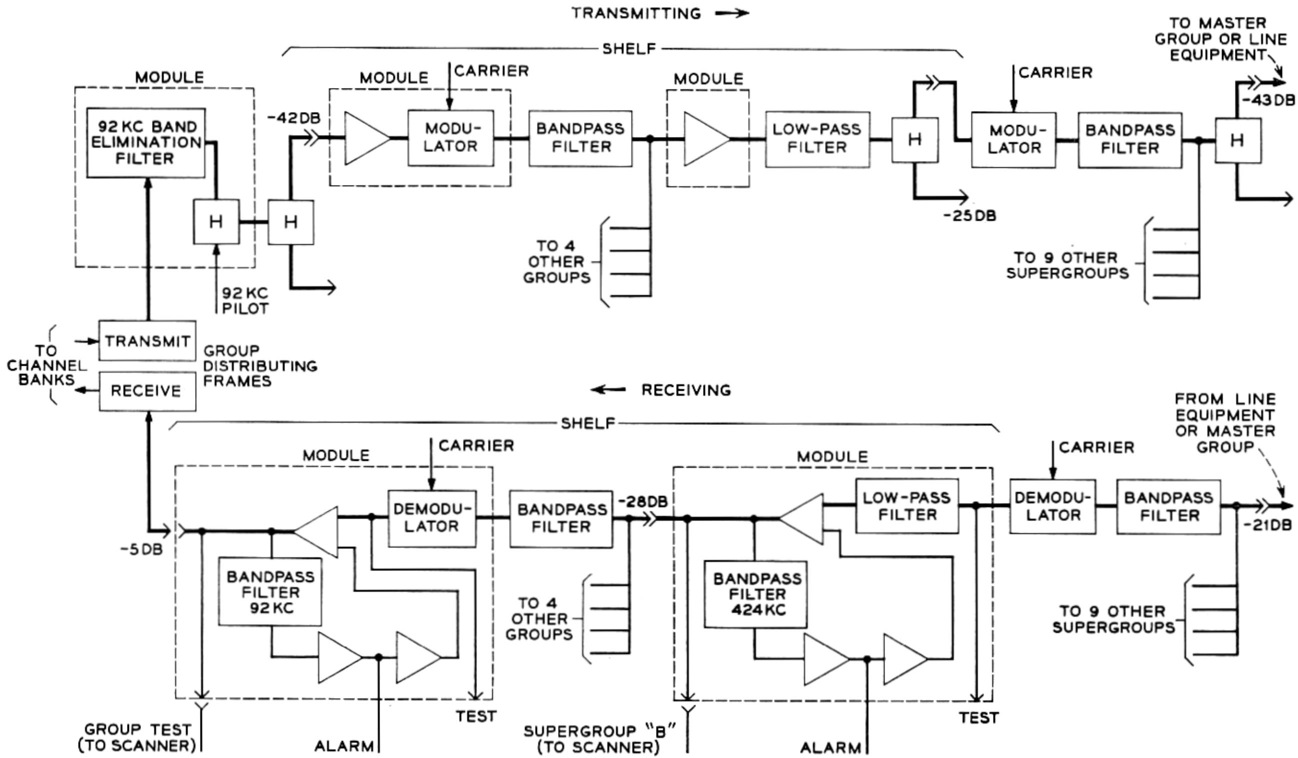


Fig. 3 — Block schematic of group and supergroup circuits. The indicated levels are for one voice channel, referred to zero transmission level.

one sideband is selected by a band-pass filter. An exception is Supergroup 2, which is not modulated, but transmitted directly. As with the group filters, the odd-numbered supergroup filters have their outputs paralleled on one side of a hybrid transformer and the even-numbered on the other side. One output of the hybrid transformer is normally terminated but can be used for monitoring. The second output is patched to a terminal trunk for connection to the transmitting system for the L600 multiplex. When two or three mastergroups are to be combined in an L1860 multiplex, the supergroup bank output is amplified by a transistor feedback amplifier with a gain of 26 db.

2.3 *Receiving Circuits*

At receiving terminals the baseband signal is received from the radio terminals or the mastergroup equipment. It is separated into supergroup bands by filters, and all except Supergroup 2 are demodulated to the basic supergroup band, 312–552 kc. Each supergroup signal is amplified by a regulated amplifier similar to that of the receiving group except that the Group 3 pilot at 424 kc is used to control the regulator.

The receiving group equipment accepts the 312–552-kc band from the supergroup equipment and separates it into group bands by filtering. The output of each group filter is demodulated to the basic group band, 60–108 kc. The lower sideband is selected by a low-pass filter and amplified. The gain of the amplifier is controlled by a regulator operated by the 92-kc pilot. This maintains the pilot at the output of the amplifier at a substantially constant level. Since the gain of the amplifier is constant over the group band, the regulation compensates for any flat level deviation that may occur in the transmission circuit, at either terminal, or in the connecting system.

The main output of the group amplifier is connected through normal contacts on jacks to the receiving group distribution frame and through it to the receiving portion of a channel bank or to a group connector. A second output of the group amplifier is connected to a scanner circuit and a pilot alarm circuit. These circuits will be described in later sections.

III. REGULATORS

In the L1 and L3 terminals, group pilots at 92 kc are added at the transmitting terminals. These are used for circuit monitoring and for periodic manual adjustment of receiving group gain controls. The pilot in Group 3, 424 kc, is used for adjusting the supergroup gain control. With the increased complexity of the toll plant, in which some group circuits may be connected through several different transmission systems and several sets of terminals via group or supergroup connectors before reaching the receiving channel bank, small deviations in level frequently accumulate. With the more stringent requirements of Direct Distance Dialing and data transmission, it has become difficult to achieve satisfactory performance with manual adjustments.

Continuous adjustment of receiving supergroup and group gain by pilot-controlled regulators offers substantial improvement. After considerable field experience with experimental and prototype regulators installed in L1 terminals, it was decided to include both group and supergroup regulators in the new terminals.

3.1 *Design Considerations*

As indicated in Fig. 4, the regulator μ circuit (group and supergroup) consists of a thermistor, transmission amplifier, and portions of a dc amplifier. The regulator β circuit comprises a pilot bandpass filter, a control amplifier, and the remaining portions of the dc amplifier, including the reference. In accordance with fundamental feedback theory,[6] the response of the regulator to variations in input signal is simply:

$$R(\omega) = \frac{1}{1 - \mu\beta}. \tag{1}$$

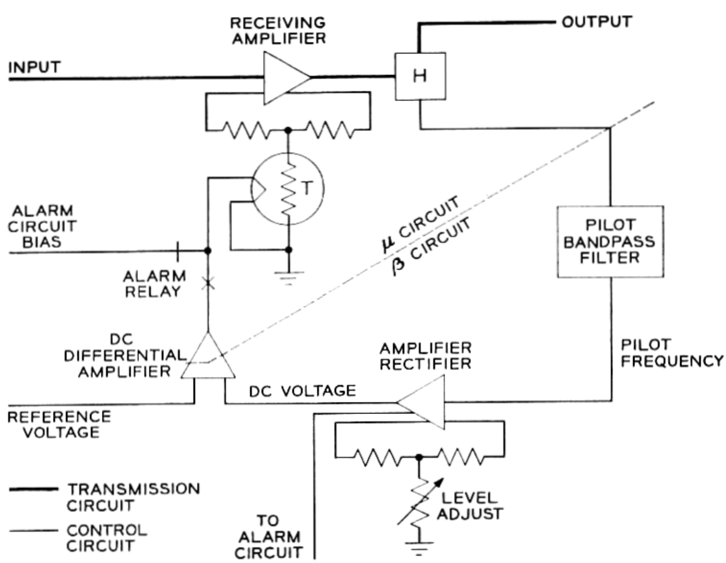


Fig. 4 — Block schematic of pilot-regulated amplifier (group or supergroup).

The value of (1) at dc envelope frequency is the compression of the regulator. A regulation compression of at least twenty to one was a basic design objective. As indicated in (1), such compression requires a comparable β-circuit expansion, or envelope gain. The expansion is provided by the dc amplifier operated against a stabilized diode reference.

System studies indicated that as many as ten regulators in tandem may occur on long routes with the greater proportion being supergroup regulators. In tandem operation, requirements placed upon the individual regulators are quite severe.[7,8,9] Stability is readily analyzed in terms of the envelope frequencies associated with the controlling pilot.

In setting regulator design objectives, the total system envelope gain enhancement is a determining factor. Experience in regulator and servo-control system design had indicated that an over-all envelope gain of 3 db is reasonable for satisfactory transient and frequency response. Thus, for 10 units in tandem, the envelope magnification of each individual regulator should be limited to about 0.3 db to satisfy over-all performance.

A simple and direct method of minimizing gain enhancement is to cut off the $\mu\beta$ loop at 6 db per octave.[7] The 6-db cutoff, to be effective, must be maintained through several octaves of envelope frequency. Thus, the loop gain should be well below zero before other circuit parameters force the cut-off to a more rapid rate. The circuit parameters required to minimize gain enhancement can readily be determined with the aid of a mathematical model.

As indicated in Fig. 5, the model consists of (*i*) a gain controlling element with a low-pass filter characteristic, (*ii*) an amplifier to provide envelope loop gain, and (*iii*) an equivalent envelope low-pass filter simulating the pilot bandpass filter.

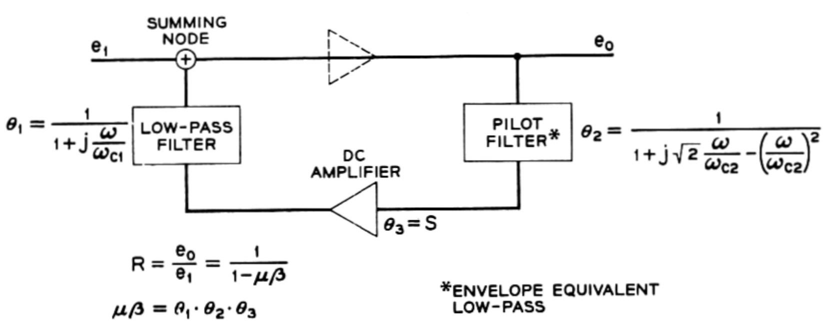


Fig. 5 — Mathematical model of regulator for computing envelope response.

The controlling element is represented as a simple lowpass filter with 6-db per octave attenuation characteristics. The low-pass envelope equivalent of the pilot bandpass filter may be represented as having 12-db per octave attenuation characteristics. The dc amplifier provides a loop gain, the cutoff characteristics of which may be neglected in an envelope analysis. From Fig. 5, it follows that the envelope loop gain is simply:

$$\mu\beta = \frac{S}{\left(1 + j\frac{\omega}{\omega_{c1}}\right)\left[1 + \sqrt{2}j\frac{\omega}{\omega_{c2}} - \left(\frac{\omega}{\omega_{c2}}\right)^2\right]} \tag{2}$$

where S is the envelope loop gain or stiffness, ω_{c1} the (radian) cutoff frequency of the low-pass filter, and ω_{c2} the cutoff frequency of the bandpass filter equivalent.

The regulator closed-loop frequency response follows from (1) and (2):

$$R(\omega) = \frac{1}{1 - \dfrac{S}{\left(1 + j\frac{\omega}{\omega_{c1}}\right)\left[1 + \sqrt{2}j\frac{\omega}{\omega_{c2}} - \left(\frac{\omega}{\omega_{c2}}\right)^2\right]}}. \tag{3}$$

Analyses were made of (3) over a wide range of S and of cutoff frequencies. A convenience in such analyses is the parameter C, defined as the ratio of ω_{c2} to ω_{c1}. The results indicated an approximate relationship for the maximum value of $|R|$ in db, denoted by G, and the parameters S and C. For design, it is useful to consider C the dependent variable:

$$C \cong 11.6\frac{|S|}{G}. \tag{4}$$

The range of values for which (4) is valid is indicated in Fig. 6, which provides a useful regulator design chart.

A loop gain of 35, providing a compression of $\frac{1}{36}$, is a conservative limit for expansion. A desirable limit for gain enhancement is 0.3 db. Thus, referring to Fig. 6, the resulting value of C is 1350.

The computed response of such a regulator over a wide range of envelope frequencies is shown in Figs. 7 and 8. The loop gain ($\mu\beta$) cuts off at 20 db per decade (6 db per octave) until it approaches the cutoff frequency of the pilot filter. Loop phase shift first asymptotically approaches 90°, then later is further shifted by the phase contribution of the pilot filter. The response, R, is a 36 to 1 compression at low frequency, later falling off to 1, a decade before the pilot filter cutoff. At about 0.3 to 0.4 of the pilot filter cutoff, the response experiences a peak of ex-

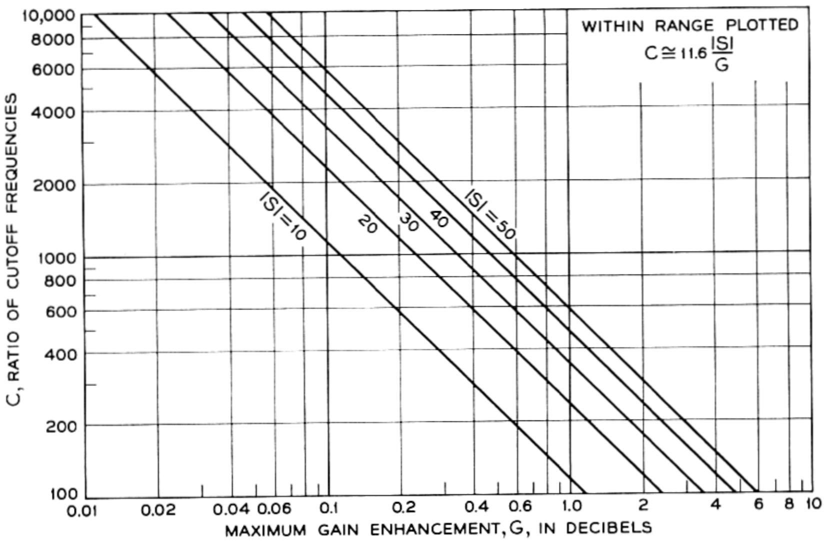


Fig. 6 — Relations among regulator design parameters.

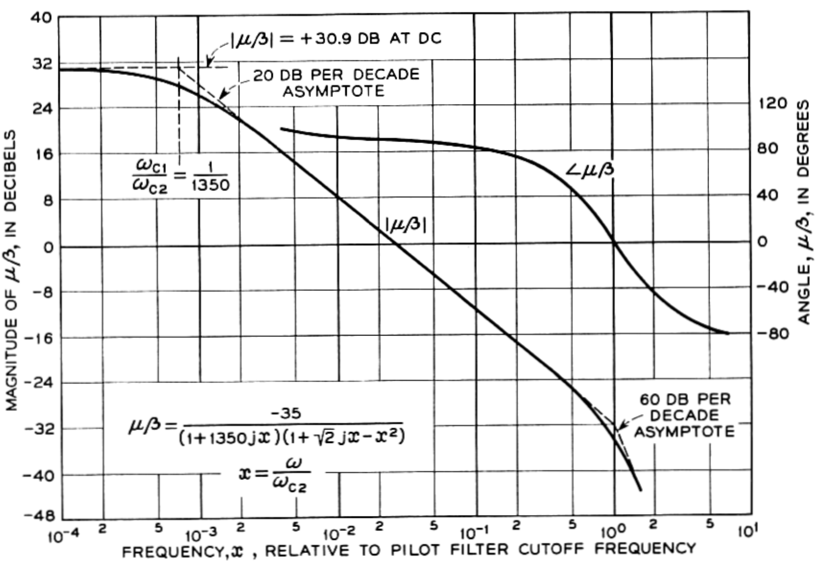


Fig. 7 — Computed loop-gain response of regulator.

pansion, which is shown in Figure 8 in exaggerated scale. As predicted by (4), the peak is about 0.3 db.

The time response of the model is readily determined by analyzing the appropriate Laplace transform, using analog computer techniques. Simplifying (3) and adopting the transform operator p for normalized frequency, the transfer function for the envelope response of each regulator becomes

$$R = \frac{Mp^3 + Np^2 + Qp + 1}{Mp^3 + Np^2 + Qp + (1 - S)} \tag{5}$$

where

$$M = C \qquad p = j\omega/\omega_{c2} \qquad N = \sqrt{2}\,C + 1$$
$$Q = C + \sqrt{2}.$$

The time response of the system to a unit step, $1/p$, at the input of the first regulator is given by the inverse transform

$$R_t = \mathfrak{L}^{-1}\left[\frac{1}{p}\left(\frac{Mp^3 + Np^2 + Qp + 1}{Mp^3 + Np^2 + Qp + (1 - S)}\right)^n\right] \tag{6}$$

where n is the number of units in tandem.

Since the operator p was defined in terms of frequency relative to ω_{c2}, the time scale of R_t is restored by dividing (6) by ω_{c2}.

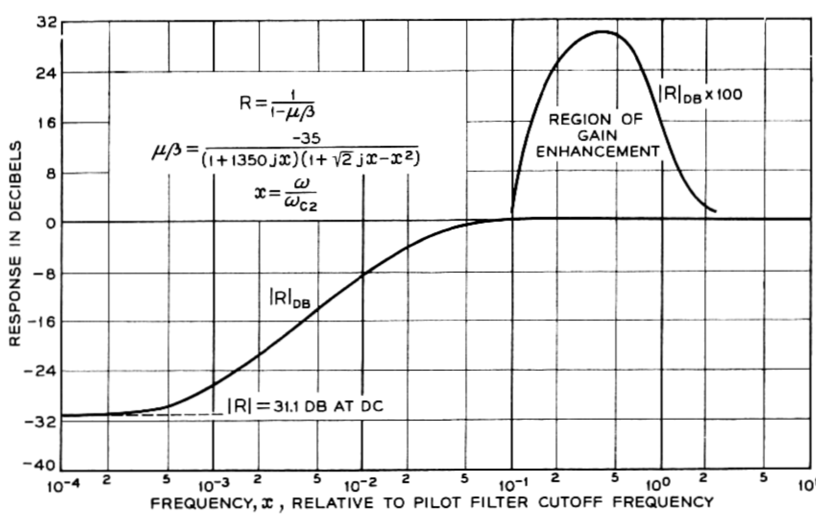


Fig. 8 — Computed through-transmission response of regulator.

Equation (6) is most readily solved using analogue computer techniques. A computed solution for the initial design parameters ($S = -35$, $C = 1350$) is shown in Fig. 9. It will be noted that, for 9 units in tandem, the overshoot is about one-half the amplitude of the initial step.

In evaluating time response, it is convenient to have as a reference the time response of a system with zero gain enhancement. Such a standard may be developed by assuming an infinite-bandwidth filter, i.e., only one source of energy storage in the control loop

$$\mu\beta = \frac{S}{1 + j\,\dfrac{\omega}{\omega_{c1}}} = \frac{S}{Tp + 1}$$

$$R = \frac{1}{1 - \mu\beta} = \frac{\dfrac{T}{1 - S}\,p}{\dfrac{T}{1 - S}\,p + 1} + \frac{1}{1 - S}\left(\frac{1}{\dfrac{T}{1 - S}\,p + 1}\right). \tag{7}$$

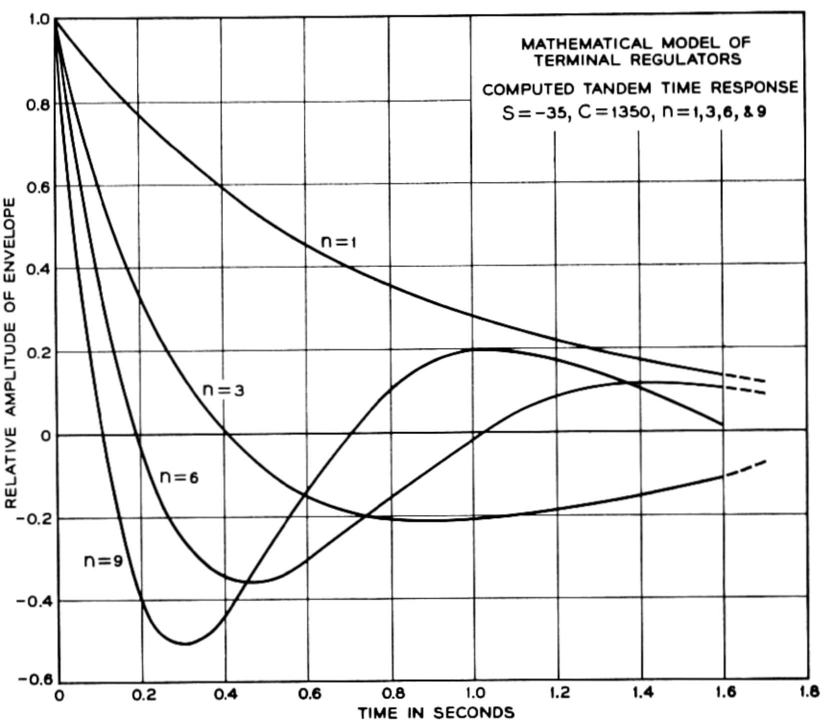


Fig. 9 — Time response of tandem regulators, computed.

If the $1 - S > 20$, the second part of (7) is negligible within the pass-band. In practice $1 - S$ is thirty or more; hence the response of the completely damped system is essentially that of a simple high-pass filter with 20-db per decade slope

$$R \cong \frac{p}{p + \alpha} \tag{8}$$

where $\alpha = (1 - S)/T$.

The time response of a number, n, of such systems in tandem is simply the inverse transform of

$$R_t = \mathfrak{L}^{-1} \frac{1}{p} \left(\frac{p}{p + \alpha} \right)^n. \tag{9}$$

The general solution of (9) may be shown to be

$$R_{t(n)} = \epsilon^{-\alpha t} \sum_{k=0}^{n-1} \frac{C_{n-1,k}(-\alpha t)^k}{k!} \tag{10}$$

where

$$C_{n-1,k} = \frac{(n - 1)!}{(n - 1 - k)!\, k!}.$$

Equation (10) will be recognized as a modified binomial expansion of $(1 - \alpha t)^{n-1}$, a fact that simplifies its numerical evaluation. The time response of completely damped systems was readily obtained by applying digital computer techniques to (10). Relative amplitudes of maximum overshoot — between the completely damped system and the model whose response is shown in Fig. 9 — are compared in Fig. 10. It will be noted that, for 9 units in tandem, the overshoot of the completely damped system is about 33 per cent, whereas that of the model is about 50 per cent.

3.2 *Regulator Features*

The mathematical model described above provided the basis for designing supergroup and group regulators for the L multiplex receiving terminal. However, the group and supergroup regulators differ in pilot frequency, bandwidth, and transmission levels.

The group regulator operates in the group baseband of 60–108 kc; its controlling pilot is 92 kc. The supergroup unit transmits the supergroup baseband, 312 to 552 kc; the pilot is 424 kc, the translation of 92 kc into Group 3. The output transmission level for group circuits is -5 db; for supergroup, -28 db, referred to zero transmission level.

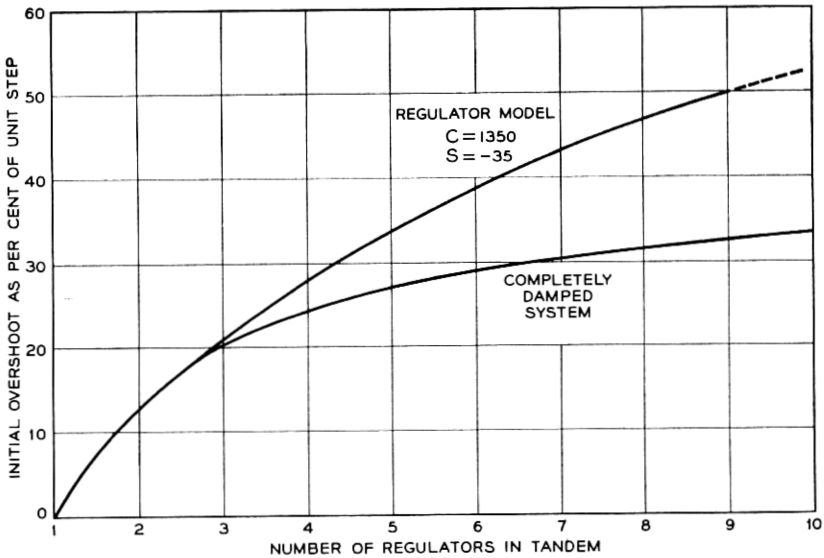


Fig. 10 — Computed overshoot of terminal regulator compared with that of a completely damped regulator.

An indirectly heated thermistor (type 2A) was selected as the element controlling regulator gain in both units. The thermistor, with a time response of 60 seconds, approaches the type of low-frequency cutoff indicated as necessary by the mathematical model.

The thermistor is in the regulator μ circuit, and variations in bead resistance with temperature are regulated out by the control circuit. However, these variations do change the operating range of the thermistor and must be allowed for in control circuit designs. Also, the thermistor operating range affects the over-all expansion or envelope loop gain.

Most of the thermistor thermal inertia is concentrated in the heater. However, the bead does provide a separate, if smaller, source of energy storage. Thus at higher envelope frequencies the thermistor attenuation characteristic exceeds 6 db per octave and phase shift exceeds 90°. Envelope phase shift in excess of 90° contributes to gain enhancement.

In both group and supergroup regulators, the thermistor controls transmission gain by shunting the major loop feedback in the transmission amplifiers. Thus, the control method is the same for both units, i.e., amplifier gain varies directly as thermistor control current. The transmission amplifiers do not contribute appreciable phase shift within the pertinent band of the pilot envelope frequencies.

The proximity of adjacent transmission signals requires that the group and supergroup pilot bandpass filters provide sharp attenuation on both sides of the controlling pilot. The attenuation of both filters exceeds 40 db, two hundred cycles from pilot. The cutoff frequency of the group filter is about 15 cycles from pilot while that of the supergroup filter is approximately 50 cycles. The supergroup filter thus injects considerably less phase shift into the regulator loop within the pertinent band of envelope frequencies.

Amplification of the pilot within group and supergroup control loops is provided by a three-stage amplifier, tuned to the pilot frequency. The tuning is sufficiently broad that envelope phase shift is not appreciably affected. Output of the amplifier is rectified to provide about 4 volts dc across the 6000-ohm input impedance of the dc amplifier. A voltage doubler circuit on the output of the supergroup tuned amplifier provides the same 4-volt output, despite the lower input level available in the supergroup control loop. A gain control potentiometer is provided in the pilot amplifier feedback loop for manually adjusting the output level of the regulator.

The dc amplifier provides the necessary thermistor current by expanding departures in the input signal from the reference voltage. As indicated in Fig. 11, the amplifier consists of two silicon transistors sharing a common emitter resistor, in differential configuration. Satis-

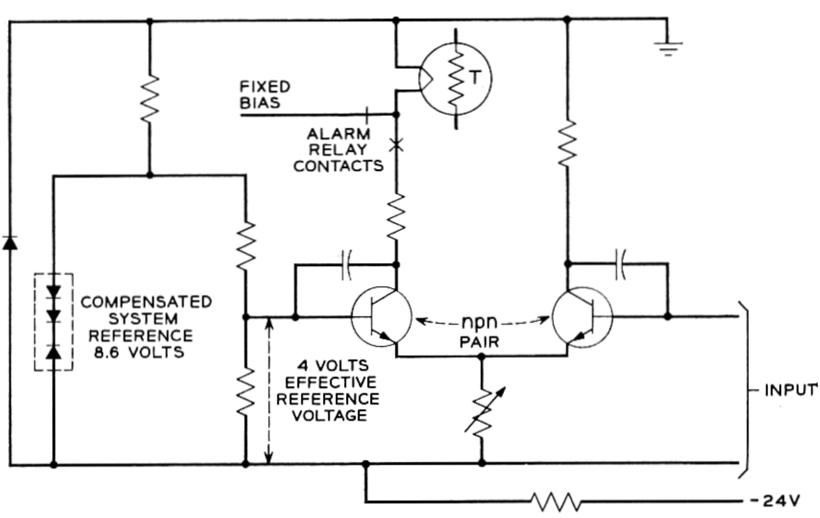


Fig. 11 — Schematic of dc differential amplifier.

factory amplifier stability is provided by paired transistor units in the differential circuit. Since the transistors share a common emitter resistor, collector current is a function of the difference between the input and the reference voltages.

The reference diode (about 8.5 volts) consists of three separate *p-n* silicon junctions, one reverse-biased. Forward-biased junctions are selected to compensate for the thermal characteristics of the reverse-biased junction, providing stability of 0.005 per cent per degree F. The complete dc amplifier contributes about 0.1 db change in regulator level over the range 40°F to 140°F.

The envelope expansion provided by the differential amplifier is a function of the effective reference voltage as well as transistor gain. A reference voltage of about 4 volts provided more than the required 20 to 1 expansion for the gain range of the transistor. The reference voltage was effectively reduced to 4 volts by shunting the reference diode with precision resistors. This reduced the pilot amplifier gain requirements.

Typical operation of the regulator in response to a change in the level of input signal may be summarized as follows. Assume a small step-type decrease occurs in the input signal. This step is transmitted without delay through the transmission amplifier and through the control circuit to the input of the direct current amplifier. The direct-current amplifier immediately responds to the step-type decrease in its input by increasing the current through the thermistor heater. Because of the direct-current amplifier expansion characteristic, the change in thermistor heater current will represent a much greater potential change in the gain of the transmission amplifier. The thermistor begins to change its bead resistance but, because of its thermal inertia, the change cannot be made immediately. As the gain of the transmission amplifier changes, the input to the direct-current amplifier is increased toward its former value. Thus the thermistor current is reduced to a value which represents the change in gain of the transmission amplifier. When equilibrium is reached, a small servo-type error signal remains in the regulator output. This same error signal at the input of the direct-current amplifier causes the required change in amplifier gain that compensates for the original decrease in signal level.

The thermistor provides sufficient delay for a smooth, exponential-type response free from excessive overshoot or hunting. Thermistor time response is, of course, speeded up by the closed-loop expansion. The transient response for small changes is completed in two to three seconds; for large non-linear changes, ten to fifteen seconds. This contrasts with the 60-second open-loop time response of the thermistor.

The intended operating range of the supergroup regulator is ±6 db from normal level; that of the group ±4 db from normal. A typical regulation characteristic is shown in Fig. 12. The lower limit is readily adjustable by the maximum thermistor current delivered by the direct current amplifier. The upper limit reflects zero thermistor heater current or minimum transmission amplifier gain.

3.3 *Tandem Operation*

Tests were conducted on 9 supergroup regulated amplifiers of the final design in tandem. The frequency response was obtained by modulating the pilot at the input to the first regulator and recording the envelope response at the output of the last (ninth) unit. The resulting data is plotted in Fig. 13. It will be noted that a peak gain enhancement, limited to about 3 db, occurs at about two cycles per second. The comparable time response for 9 in tandem to a small step disturbance is shown in Fig. 14. This response is compared, for reference, with that of a completely damped system. Overshoot is about 50 per cent, which is approximately that predicted by the model (Fig. 10).

Five group regulators in tandem measured about 3.5 db of gain enhancement, with time response producing overshoot 50 per cent of the original step. The additional gain enhancement of the group circuit is due to the sharper cutoff characteristics of the group pilot bandpass filter.

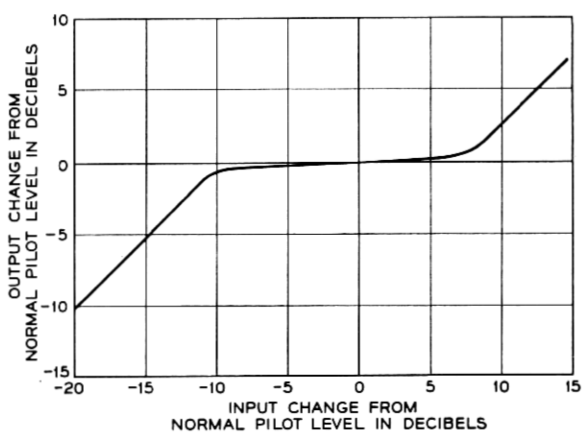


Fig. 12 — Supergroup regulator — measured regulation characteristic.

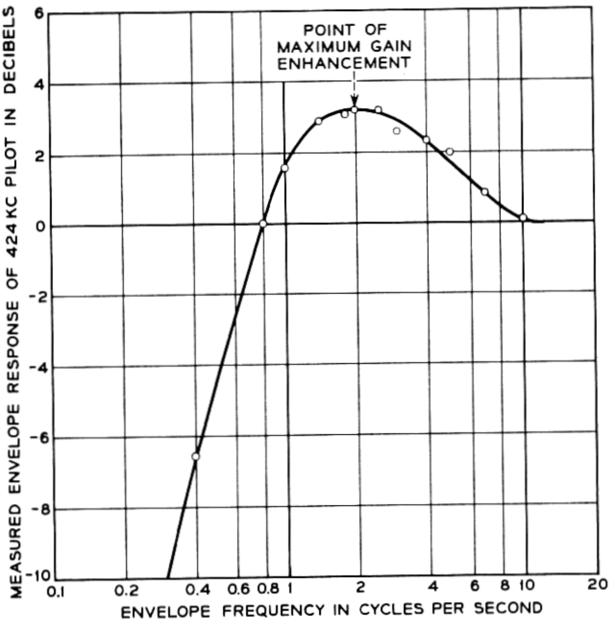


Fig. 13 — Measured frequency response of nine supergroup regulated amplifiers in tandem.

3.4 *Trial Results*

Several experimental regulator circuits were installed in L1 receiving terminals to gain field experience. Later, a more extensive trial was undertaken in which 50 prototype regulators and amplifiers, 20 supergroup and 30 group, were installed in terminals covering a wide geographical area from Chicago to California.

Performance data was obtained over a one-year period using automatic trunk testing equipment which sets up connections and measures voice-channel net loss on an automated basis. The data indicated substantially improved net loss stability, and led to the decision to incorporate regulation in the L600 and L1860 terminals.

IV. OTHER TRANSMISSION CIRCUITS

4.1 *Amplifiers*

Several transistor feedback amplifiers have been developed for use in the new terminals. These fall in two main categories: transmission

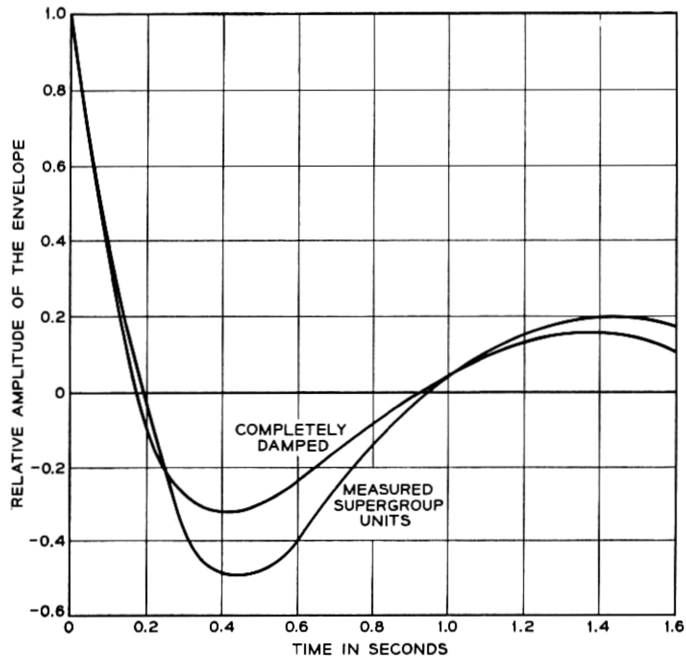


Fig. 14 — Measured time response of nine supergroup regulated amplifiers in tandem vs that of a completely damped system.

amplifiers and pilot amplifiers. The transmission amplifiers are designed for constant gain in the band of interest, resistive input and output impedances to match the external circuit, and power capabilities to handle the expected loading with low nonlinear distortion. The pilot amplifiers are designed for large stable gains at one frequency. Since there is much similarity among the various types in each category, only one of each will be described.

Diffused silicon npn transistors are used in all amplifiers. This type was chosen because of its adequate high frequency performance for this application, the permissible junction temperature which is higher than germanium transistors, and its anticipated low cost in quantity production.

Printed wiring boards are used for all amplifiers to reduce variations in wiring and assembly, insuring good reproducibility. Input and output transformers have manganese-zinc ferrite cores which have been developed to yield the same performance as obtained with earlier designs requiring up to 100 times as much volume. The transformers were designed for mounting directly on printed wiring boards.

4.1.1 *Receiving Group Amplifier*

Each receiving group requires an amplifier with a nominal gain of 38 db. The gain is adjusted by the pilot-controlled regulator over a range of ±4 db from nominal. The transmission level at the output is −5 db, referred to zero transmission level. Good linearity is required at levels up to the peak loading of 12 voice channels.

The schematic is shown on Fig. 15. Hybrid bridge feedback is used at both the input and output to control the impedances. Local emitter feedback is provided on the second and third stage to improve the linearity at high output power, and to control the maximum value of loop gain. A silicon junction voltage-limiter diode is used to stabilize the bias circuit. The supply voltage is nominally 24 volts dc.

Two equal outputs are obtained from the output hybrid transformer. One is the regular output, and the second output is divided between the pilot-controlled regulator, and the group test jack used for monitoring.

As described earlier, the regulator controls the gain of the amplifier by controlling the direct current supplied to the heater of an indirectly heated thermistor. The thermistor element resistance forms the shunt portion of the feedback network.

The output transistor has a collector dissipation of about 0.35 watts. To obtain a junction temperature which would not jeopardize long life, a 23A transistor is used which has a fluted heat radiator attached to the case. A production model of the amplifier is shown in Fig. 16, which also shows the pilot amplifier described in the next section.

The gain characteristics are shown on Fig. 17. The forward gain in the 60–108-kc band is over 75 db, making the minimum feedback about 35 db. Measurement of the loop gain and phase shift characteristics indicate that a phase margin of at least 30° and a gain margin of 10 db was realized.

4.1.2 *Pilot Amplifier*

The schematic of the pilot amplifier for the 92-kc group pilot is shown in Fig. 18. This amplifier provides about 47 db of power gain to raise the pilot signal to the level needed, after rectification, to drive the dc amplifier in the group regulator. A second output is used to supply the pilot alarm circuit. The antiresonant circuit in the feedback path reduces the gain more than 25 db at frequencies more than 30 kc from the pilot.

The gain control has a range of 6 db and is used to adjust the output level of the regulated group amplifier. Since the pilot amplifier is in the control loop of the regulator, gain variations in it would directly affect

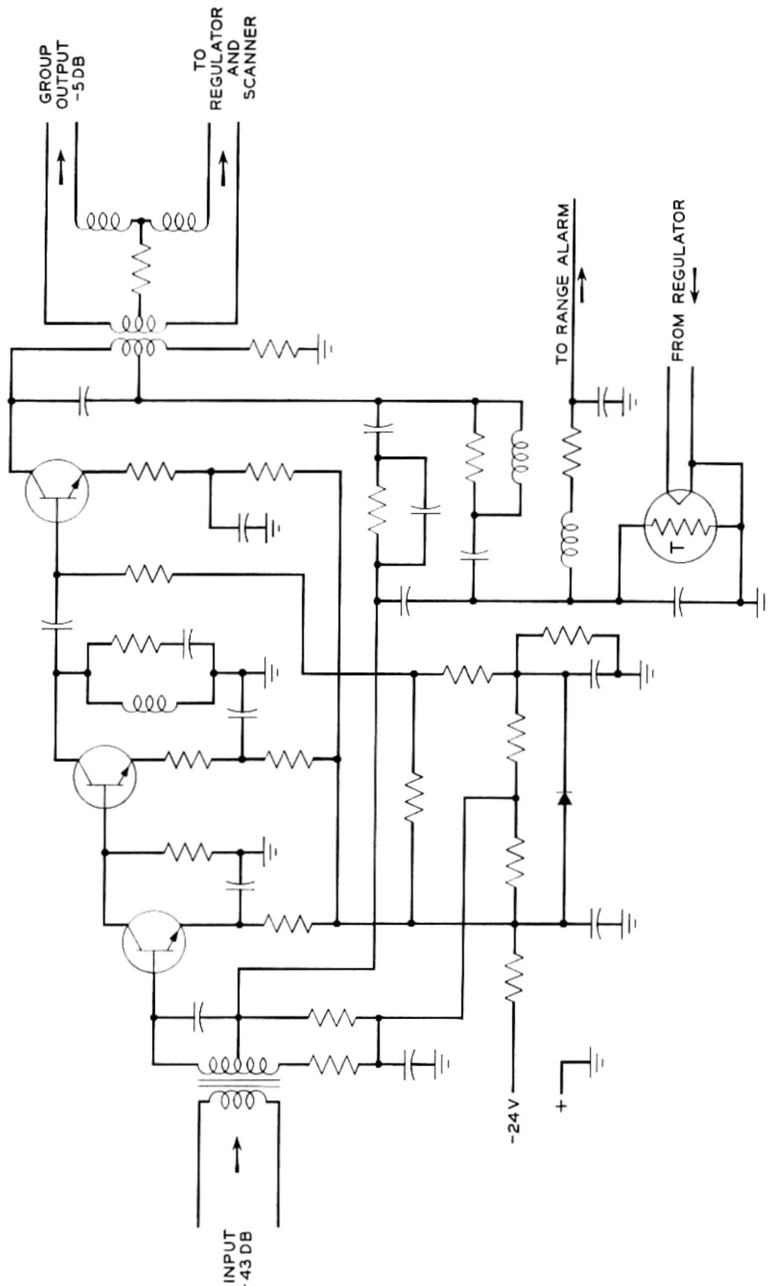


Fig. 15 — Schematic of receiving group amplifier.

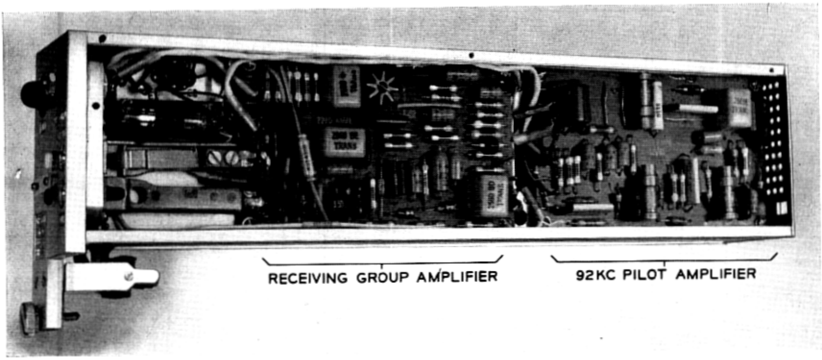


Fig. 16 — Receiving group module with side cover removed: monitoring jacks and thermistor on left, group amplifier in center, and 92-kc pilot amplifier on right.

the output level. Variations are reduced by over 35 db of feedback at the pilot frequency, and by local feedback on the first two transistors. The loop gain and phase shift characteristics are shown on Fig. 19. The feedback circuit from collector to base of the third stage is antiresonant at the pilot frequency, increasing the forward gain at 92 kc, but reducing it at other frequencies at the same rate that the feedback circuit reduces the amplifier gain.

4.1.3 *Computer Program*

A special computer program[10] has been developed for computing the performance of these amplifiers. It serves as an aid to the design and to indicate the effect of variations in parameters on the performance. The program solves up to 23 nodal equations representing the amplifier parameters and schematic. Subsidiary programs are used to convert transistor and transformer measurements to the hybrid parameters used in the program.

4.2 *Modulators*

4.2.1 *Choice of Element*

The modulators and demodulators in the earlier group banks and in the lowest 8 supergroups employed copper-oxide varistors for the modulating devices.[11] These have some obvious disadvantages such as high shunt capacitance, requiring a low-impedance circuit for their use in group and supergroup modulators. This in turn leads to instability with temperature and aging, causing small deviations in loss. However, the

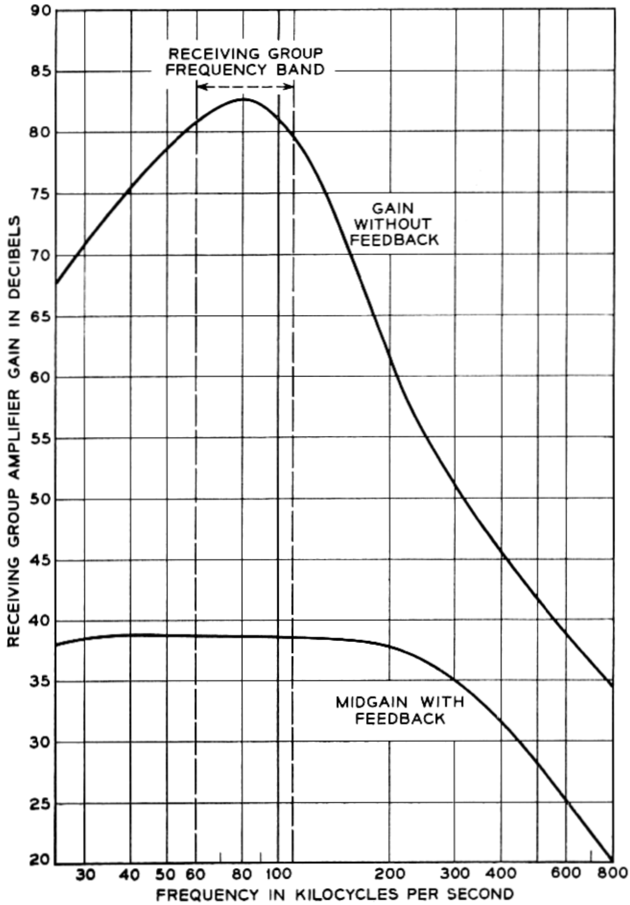


Fig. 17 — Receiving group amplifier gain characteristics.

device has low noise, produces low harmonic distortion, and has performed satisfactorily in general. With the increased use of silicon devices in applications formerly filled by copper oxide, the demand for copper-oxide devices is decreasing and it may not be long before it is uneconomical to provide them for modulators.

With these considerations in mind and after preliminary tests of silicon diodes, it was decided to use silicon diodes in the modulators for the new terminals.

An examination of available types of diffused junction silicon diodes led to the selection of the 432A diode. This diode has less than 4 pf

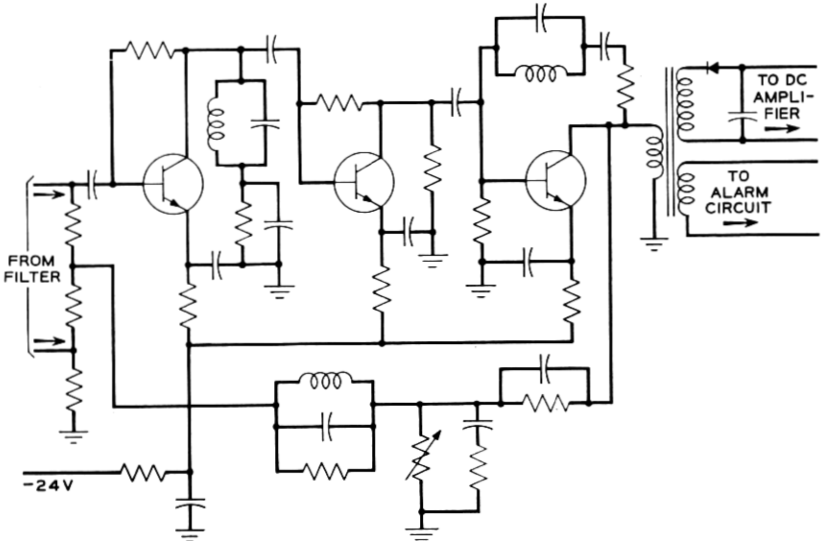


Fig. 18 — Schematic of 92-kc pilot amplifier.

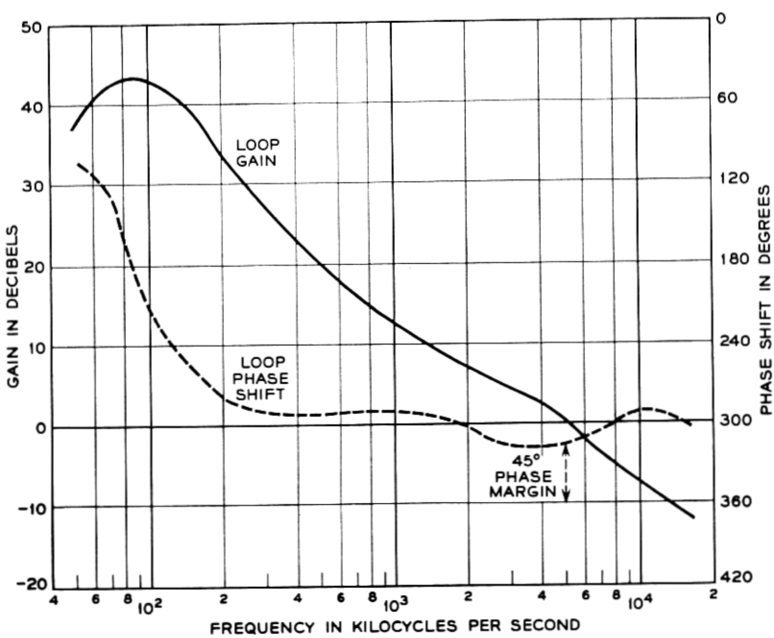


Fig. 19 — Pilot amplifier loop characteristics.

reverse capacitance and a recovery time of less than 4 nanoseconds. With a forward current of 10 milliamperes, the ac resistance is less than 20 ohms. The characteristics are sufficiently uniform so that it is economical to select quads having carrier balances of greater than 35 db.

4.2.2 *Modulator Performance*

When used in the conventional ring modulator circuit shown on Fig. 20, the diode has yielded satisfactory performance for both group and supergroup modulation and demodulation stages. An impedance level of 1,000 ohms is used to terminate the ring section. This makes the insertion loss of the diodes almost negligible when the carrier level is sufficient to produce a forward voltage of 0.8 volt. The carrier is supplied at an impedance level of 40 ohms.

A group carrier level of +15 dbm is standard on existing terminals and this has been continued on the new ones. With the silicon diodes, the level can be decreased to 10 dbm or increased to 22 dbm before the modulator loss to the wanted sideband increases 0.2 db. Reducing the level below +14 dbm increases the harmonic distortion to an undesirable degree. Noise tests have shown the silicon modulators to have a noise figure about 2 db larger than the copper-oxide modulators, but the conversion loss is substantially less.

When the generator and load impedances terminating the ring and its transformers are resistive, the modulator loss is constant with frequency over the group and supergroup bands. When one of these terminations is a bandpass filter, the impedance departs from an ideal resistance, especially due to the effect of the filter impedance at the frequency of

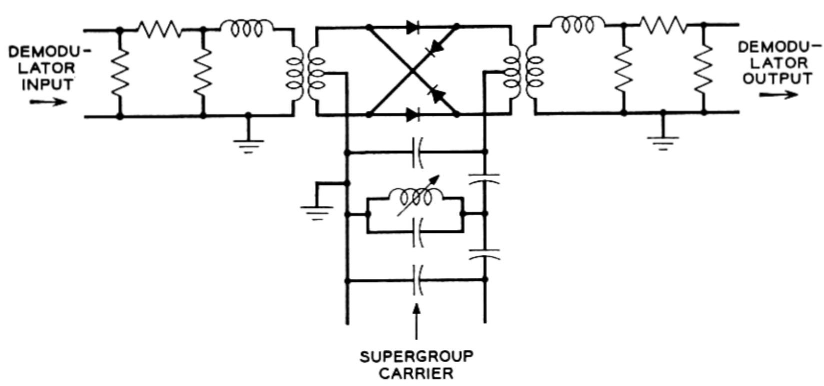


Fig. 20 — Schematic of supergroup modulator or demodulator.

the unwanted sideband. Without impedance correction this introduces loss distortion in the passband of the wanted sideband. The inductors and resistors shown on Fig. 20 perform the necessary impedance matching for the supergroup modulators and demodulators. A similar circuit is used in the group modulators and demodulators.

The final design of modulator circuits and bandpass filters together have passband loss distortion substantially equal to that of the filters alone with resistive terminations.

4.3 *Filters*

A study of the original L-1 multiplex terminal[3] showed that over 50 per cent of the space occupied by the terminal was required for filters to separate the frequency spectrum, select carriers and pilot frequencies. Therefore, to achieve a new equipment arrangement it was essential that development work on the filters be undertaken to substantially reduce the size, and if possible, the cost. However, a reduction in the quality of the system to achieve a size and cost reduction could not be tolerated; that is, the same discrimination and distortion requirements were imposed on the new filters.

In the original filters, for example, slug-tuned air core inductors with large molded silver mica capacitors were used. Also, a method of double shielding in the series arm of the filters was incorporated which placed the parasitic capacities to ground across specific shunt branches of the structure. These large air core inductors with sufficient space about them to give a good stable low value of capacitance to ground made the filters quite large. These filters proved to be very stable with temperature and aging and produced practically no modulation in the system.

To obtain a substantial size reduction it became evident at the start that all component apparatus had to be miniaturized, particularly the large air core inductors. Also, the use of double shielding should be eliminated, if possible.

Of the many types of filters required in the terminals only a few typical ones are described in the following sections to illustrate the trend in components, method of assembly and shielding.

4.3.1 *Components*

An investigation of available component apparatus with satisfactory tolerance and size revealed that only capacitors and resistors were available in production for miniaturization of filters. A development program had to be undertaken on crystal units, inductors and transformers to realize size reductions that would be comparable with capacitors and resistors.

Several types of small ferrite core adjustable inductors have been developed which have good temperature coefficient characteristics, low dissipation factors and have an adjustment range of several per cent. The ferrite core inductors do introduce measurable modulation in the system but it has a negligible effect on the over-all performance. Several small-size ferrite transformers have been developed for use in amplifiers, modulators and filters in the system.

Several types of small size shielded crystal units were developed for use in filters. The units were required to have a low dissipation (high-Q) and good temperature coefficients. A method was developed for encapsulating the quartz crystal plate in an evacuated cold welded container, eliminating the use of glass containers and additional shielding.

A comparison of the old and new style components used in the fabrication of typical filters is shown in Fig. 21. One can readily see that with such a size reduction in component apparatus with substantially the same electrical characteristics, the filter designer had an excellent chance to make sizable reductions in volume.

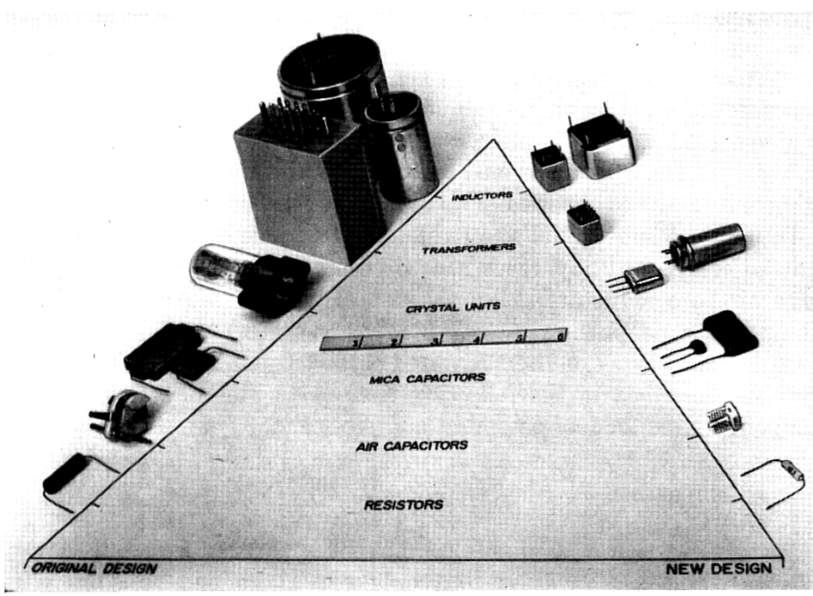


Fig. 21 — Comparison of old and new style components.

4.3.2 *Group Bandpass Filters*

With component apparatus available that can be mounted by its leads, it was decided after investigating various methods of assembly and wiring to use printed wiring techniques. Printed wiring provides good uniformity and consistent capacitance between leads and to ground, from components in production. Also, with printed wiring it was found possible to obtain low ground resistance paths and satisfactory shielding between various portions of a filter using shielded inductors. To provide adequate shielding from the filters to various other parts of the terminal the filters were inserted in drawn metal containers with soldered covers.

In packaging filters for the system the number of different sizes was kept at a minimum. Also, an arrangement was made to provide some of the filters with a moisture-resistant seal where necessary.

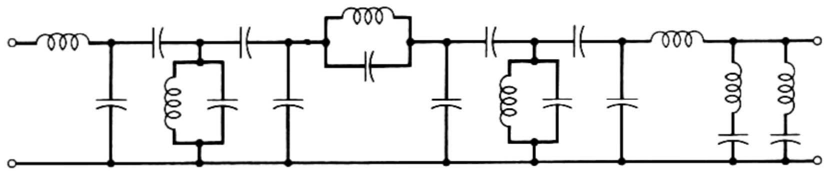
The five group bandpass filters were designed to operate in a 75-ohm unbalanced circuit with alternate filters paralleled, i.e., numbers 1, 3 and 5 in one group and numbers 2 and 4 in the other. Each group at its paralleled side was connected to the opposite port of a hybrid coil with an impedance compensating network shunted across each group to improve the impedance at the line and modem side of the filter. Each filter passes a 48-kc band, the five bands extending from 312 kc to 552 kc.

The schematic of the filter, together with the insertion loss characteristic of a typical group filter, is shown in Fig. 22. This characteristic is adjusted in a visual test set by tuning the slugs in the inductors of the filter under test until it is identical to a reference filter. The volume reduction of this filter over the old design was 30 to 1 and the cost reduction about 3 to 1. Each of the filters and the compensating networks plus hybrid coils were assembled in a metal container $1\frac{11}{32} \times 2\frac{11}{16} \times 4\frac{11}{16}$, exclusive of terminals and studs. These six units were assembled on the rear of the group bank equipment shelf and wired together with small coaxial cables. Fig. 23 shows the internal arrangement and external appearance of the filter.

The performance of this new miniature filter was similar to the original larger filter except for modulation, which was poorer but entirely satisfactory for system performance.

4.3.3 *Supergroup Bandpass Filters*

The new supergroup bandpass filters with the exception of Supergroups 1 and 3 are identical in size and schematic to the group band filters. All supergroup band filters have a band width of 240 kc. The



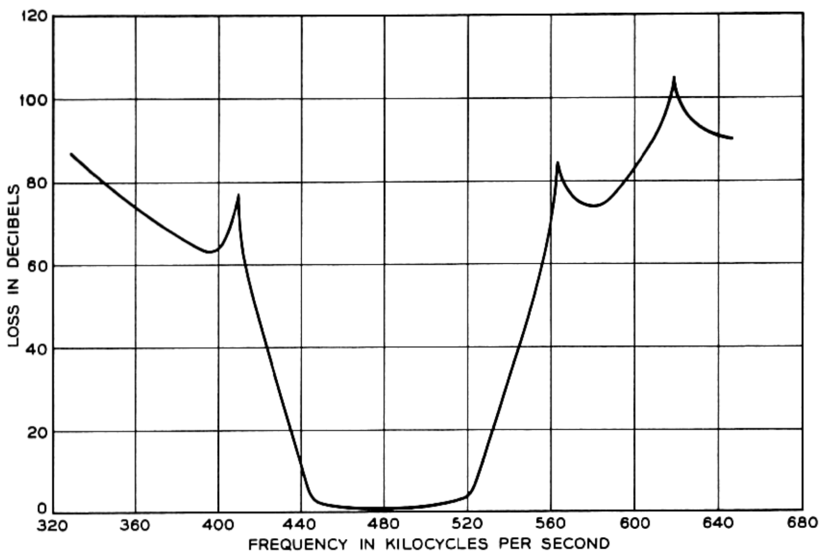


Fig. 22 — Schematic and insertion loss of a typical group band filter.

ten supergroup bandpass filters were designed to operate between 75-ohm impedances with alternate filters paralleled, numbers 1, 3, 5, 7 and 9 in one group and 2, 4, 6, 8 and 10 in the other. Each group at their paralleled side is connected to opposite ports of a hybrid coil with a compensating network shunted across each group for impedance and distortion improvement. In order to meet the discrimination requirements for the high-frequency filters it was necessary to use a special grounding arrangement. Also, to meet the crosstalk requirement between the upper supergroup filters it was necessary to use small coaxial jacks instead of terminals on the filters with all connections made with coaxial cabling. Fig. 24 shows a typical schematic and insertion loss characteristic of a supergroup filter except 1 and 3, connected in parallel with other supergroup filters.

In the frequency range above 2 mc it has not been possible to obtain as good a distortion characteristic across the useful band of 240 kc with

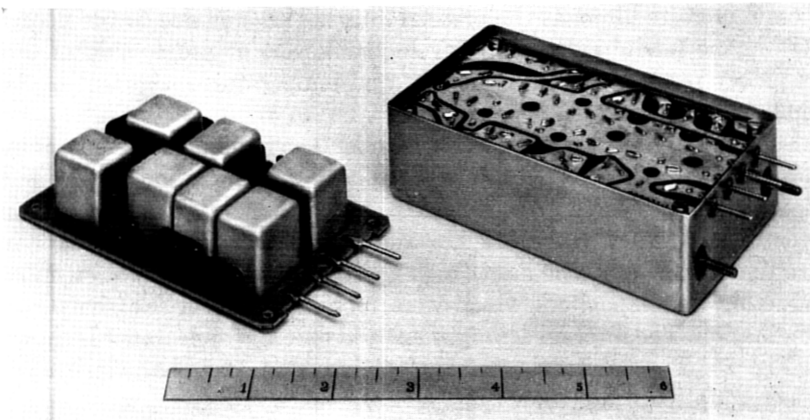


Fig. 23 — Mechanical contruction of group band filter, right; component side of board, left.

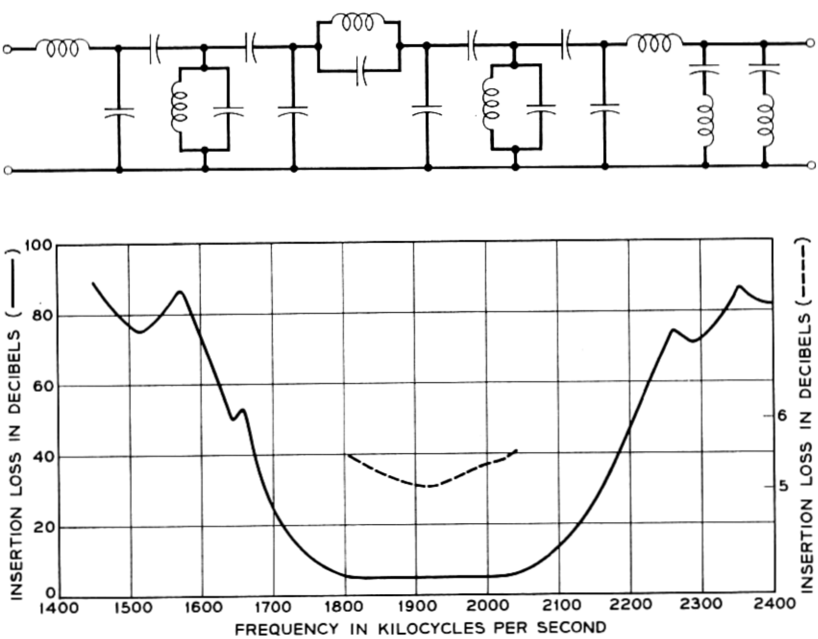


Fig. 24 — Schematic and insertion loss of typical supergroup band filter.

these miniature filters as the original filters. This was due to the poorer "Q" in the ferrite inductors. Development work is progressing in this frequency range to improve the "Q" and temperature coefficient of the small ferrite inductors.

Supergroup filters number 1 and number 3 were designed as minimum inductor asymmetrical LC filters with sharp discrimination on one side of each of the filters. This was necessary to attain a high discrimination over the frequency range 312 kc to 552 kc. These filters are larger in size to accommodate the larger high-Q ferrite inductors and a few more inductors and capacitors which were required to meet the sharp discrimination. The internal arrangement and external appearance is shown in Fig. 25. The schematic and typical insertion loss characteristic of Supergroup No. 3 are shown in Fig. 26.

To equalize the distortion across supergroup bands 1 and 3 to less than 0.5 db, equalizers are provided which insert the correction at corresponding frequencies in the basic supergroup band, 312–552 kc.

4.3.4 *Crystal Filters*

In practically every communication system, extremely narrow band elimination and bandpass filters are needed to remove extraneous noise or frequencies from a spectrum so that pilot frequencies may be inserted and picked-off further along in the system to control gain or shaping. In this system crystal filters were used for this purpose because of their extremely high Q, good temperature characteristics and stability.

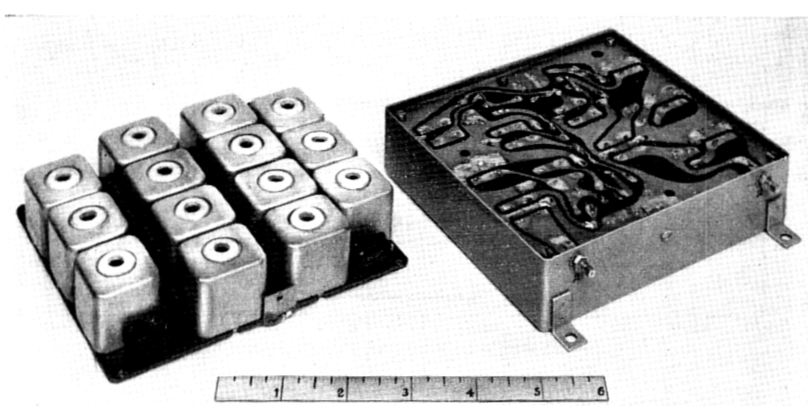


Fig. 25 — Mechanical construction of supergroup filter no. 3: right, printed wiring side; left, component side.

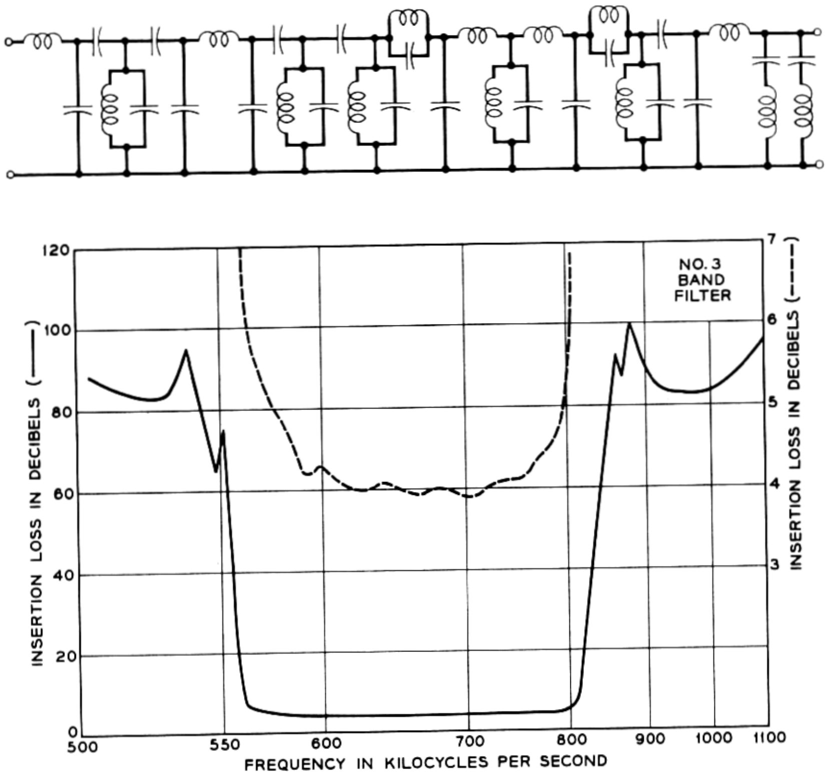


Fig. 26 — Schematic and insertion loss characteristic of supergroup filter no. 3.

Two such typical crystal filters are the 92-kc band elimination and bandpass filter. The 92-kc band elimination had to suppress a narrow band about 92 kc, pass the voice-frequency channels either side of 92 kc with practically no distortion, have a good return loss over the 60 to 108-kc band and operate over the central office temperature range. The schematic of filter which was found to be most economical for this job together with its insertion loss characteristic is shown in Fig. 27.

The schematic of the crystal bandpass filter which selects this 92-kc pilot frequency is shown in Fig. 28 with its typical insertion loss. It was designed as a lattice section to operate from a 135-ohm balanced impedance to a 1,000-ohm unbalanced impedance.

The internal arrangement and external appearance of these filters are shown in Fig. 29.

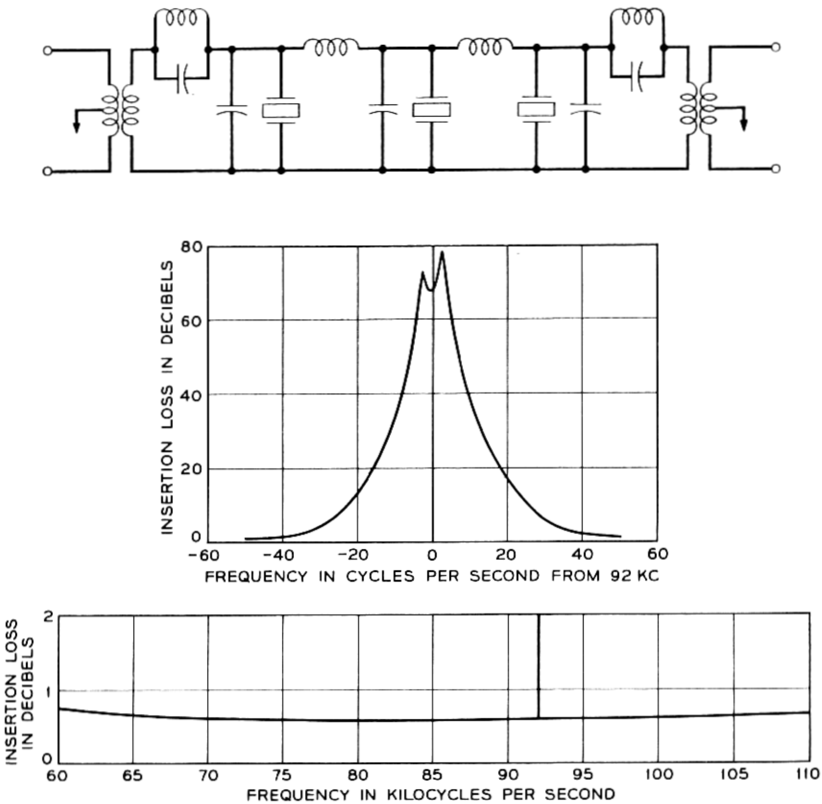


Fig. 27 — Schematic and insertion loss of the 92-kc band elimination filter.

4.3.5 *Carrier Supply Filters*

In the carrier supply portion of the terminals only "LC" filters are used because of the load carrying requirements and the availability of high-Q ferrite inductors for those moderately narrow band filters. Also, from cost consideration it proved to be more economical to use LC rather than crystal filters.

The channel carrier supply filter has to operate in parallel at the output of the harmonic generator and provide 45-db and 75-db discrimination 4 kc and 8 kc respectively, either side of the selective harmonic. The schematic of the filter used to meet this requirement with a typical loss characteristic is shown in Fig. 30.

The group carrier supply filters connected to the output of a 12-kc harmonic generator have to meet requirements similar to the channel

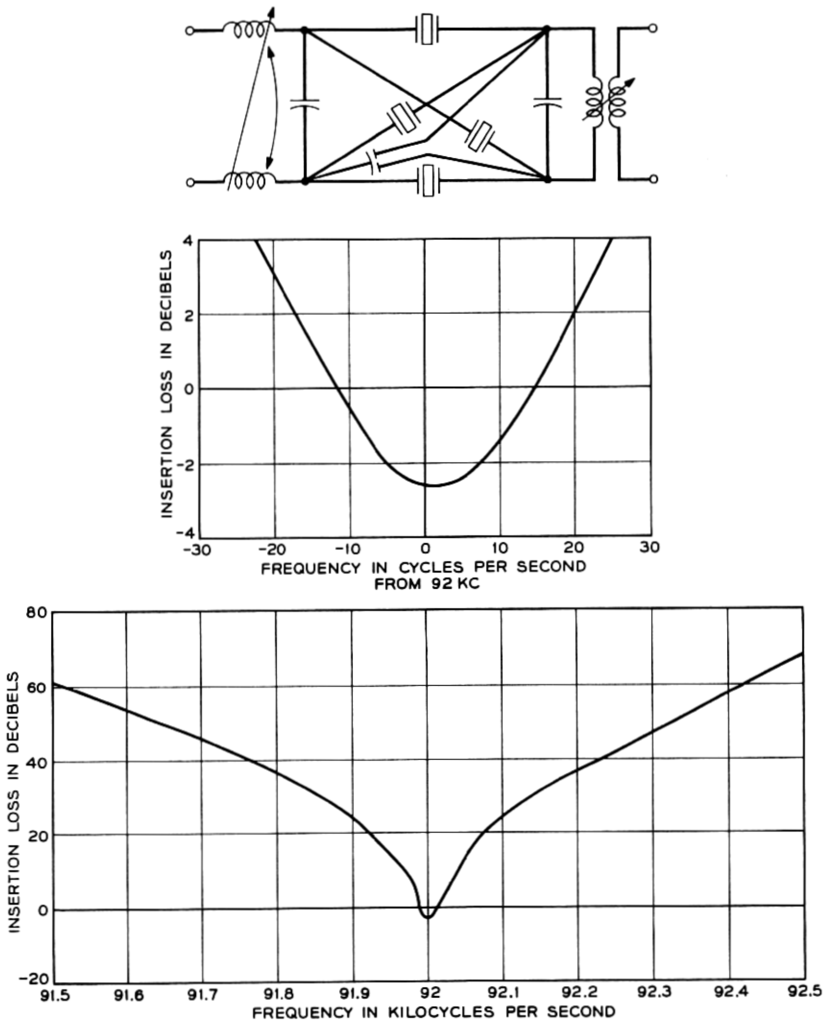


Fig. 28 — Schematic and insertion loss characteristic of the 92-kc crystal bandpass filter.

carrier supply filters in a higher frequency range. The schematic of these filters together with a typical loss characteristic is shown in Fig. 31.

The filters for the supergroup carrier circuit were constructed as two identical individual filters with a transistor amplifier between them.

All of these filters were constructed with the same type of components in the same manner as the other filters of this system.

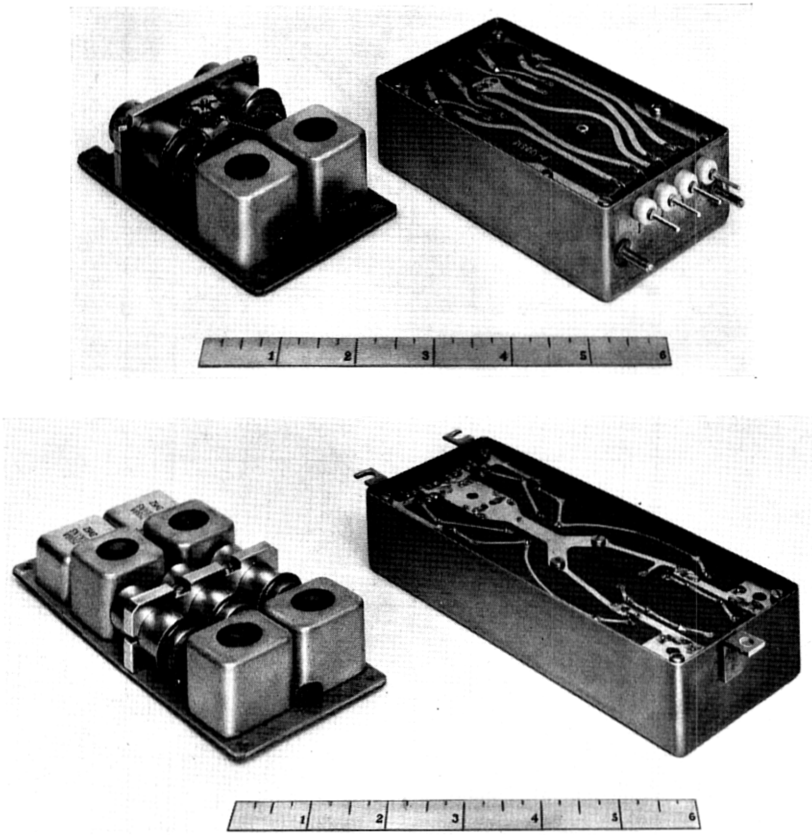


Fig. 29 — Mechanical construction of the 92-kc bandpass filter (upper photo) and elimination filter (lower photo). Component side of board at left, printed wiring side at right.

4.3.6 *Group Connectors*

At branching points it is frequently required to transfer a group of 12 channels from a receiving terminal to another transmitting terminal. This can be done at the basic group frequency, 60–108 kc, by the use of a bandpass filter. This filter must furnish the discrimination needed to suppress portions of adjacent groups which are not suppressed by the group bandpass filters.

A new group connector, the B-2, has been developed with less attenuation distortion than that of the earlier design, now known as the B-1. Discrimination of more than 70 db is provided at frequencies below 59.7 kc and above 108.6 kc. A typical passband and discrimination frequency

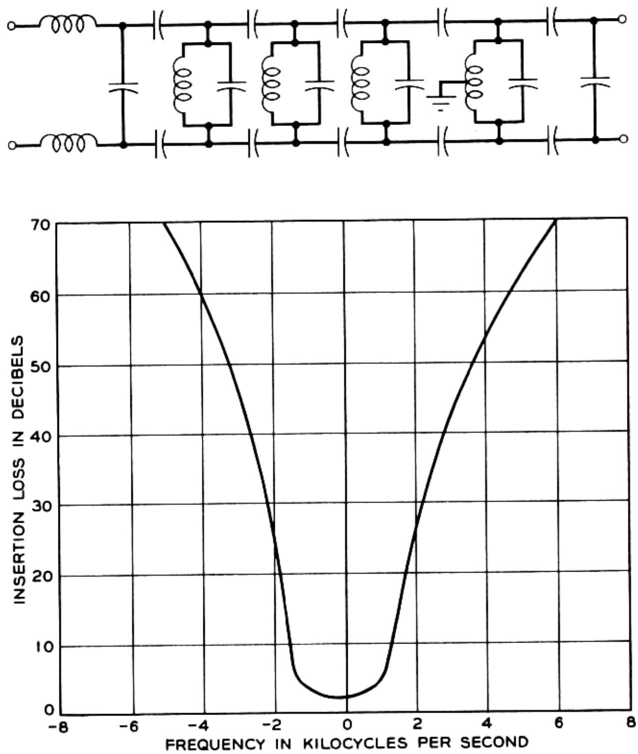


Fig. 30 — Schematic and insertion loss of channel carrier supply filter.

characteristic is shown on Fig. 32. The envelope delay distortion in the band, 64–104 kc, is about 100 microseconds. For applications such as data transmission requiring constant delay, a delay equalizer can be provided.

The filter used in the connector employs special wide crystal filter sections which give a high degree of selectivity at the band edge. The schematic of this filter is shown in Fig. 33.

A model of the new connector is shown on Fig. 34. In addition to the filter, an attenuator is supplied to adjust the loss of the connecting circuit, and space is available for adding a delay equalizer.

4.4 *Supergroup Connector*

When it is desired to transfer an entire supergroup from a receiving terminal to another transmitting terminal, this can be done at the basic

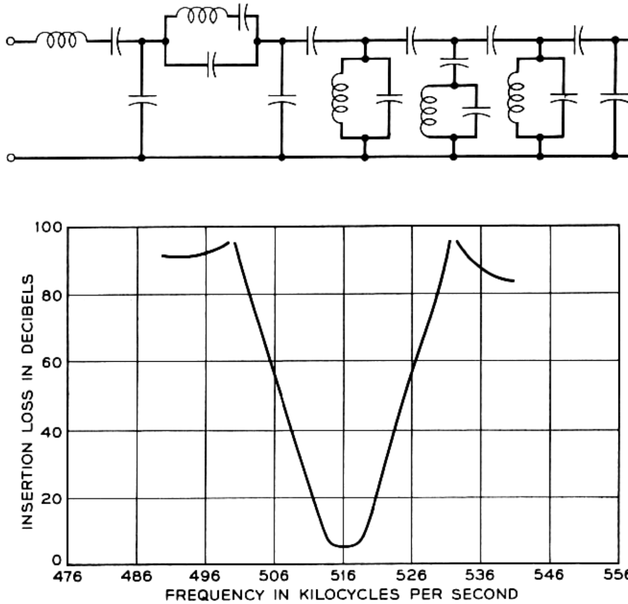


Fig. 31 — Schematic and insertion loss of group carrier supply filter.

supergroup band, 312–552 kc, with the use of filters and an amplifier. This equipment is known as the C-2 supergroup connector, replacing the earlier C-1 version. A block schematic is shown on Fig. 35.

The bandpass filter has been designed as a minimum inductor structure using high-Q ferrite inductors and has over 80-db discrimination at frequencies below 304 kc and above 560 kc. The passband distortion is less than ± 0.2 db. A delay equalizer is being developed to equalize the delay distortion of this filter for data transmission. When this is not required it can be replaced by a pad.

Two pilots at 308 and 556 kc, respectively, occur in certain supergroups on certain systems. To prevent interference, these are suppressed by a crystal band elimination filter. Crystal units are used because of the high degree of selectivity required and are mounted in a temperature controlled oven.

A transistor amplifier provides the gain needed to compensate for the loss of the filters and equalizer. The transmitting group intermediate amplifier and associated low-pass filter are used for this purpose.

The filters and equalizer preceding the amplifier have been designed to occupy the space in the receiving bay which is provided for the five re-

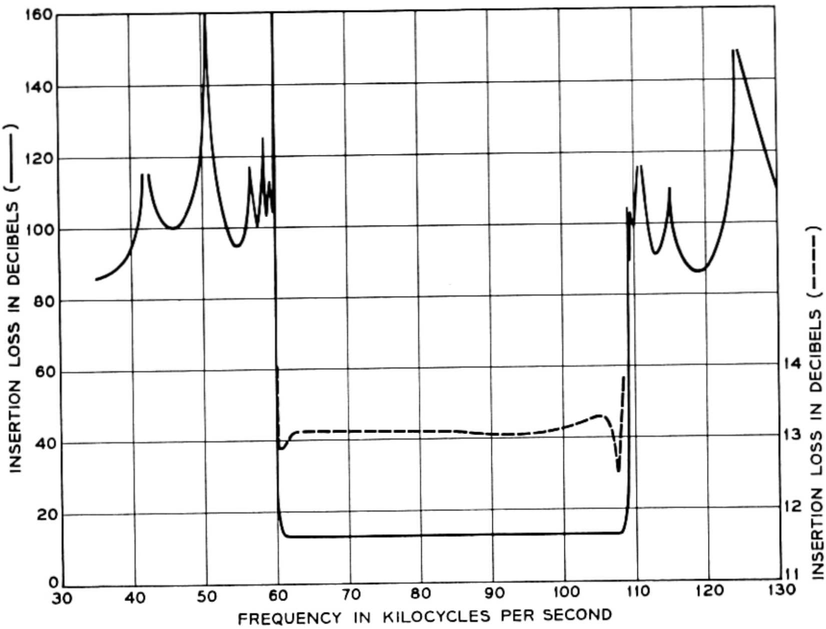


Fig. 32 — Insertion loss of the B-2 group connector filter.

ceiving group amplifiers. When a supergroup connector is used, these are not required, and the supergroup connector filters may be installed as shown on Fig. 36, without modifying the bay wiring.

The amplifier and low-pass filter are located in the transmitting terminal in place of the corresponding equipment for the transmitting group bank.

V. AUXILIARY CIRCUITS

5.1 *Alarm Circuits*

Several types of alarm circuits are provided to alert office personnel to conditions requiring their attention. Three of these indicate a service interruption: fuse failure, carrier supply, and loss-of-pilot. A fourth indicates when a regulator nears the end of its effective range. This may indicate an incipient trouble condition.

The fuse alarm is a standard circuit in which a blown fuse closes the alarm circuit through a bus provided for this purpose. The carrier supply alarms are described in a companion paper.[4]

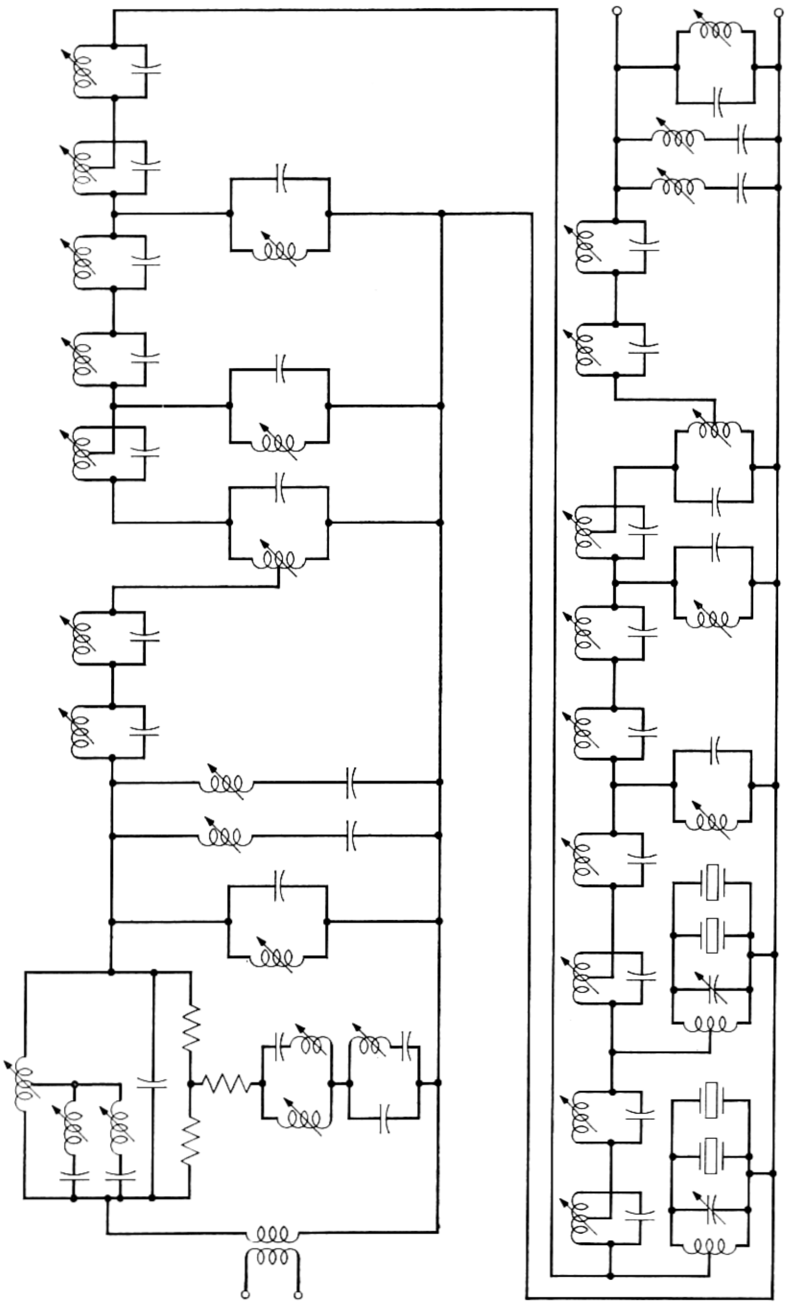


Fig. 33 — Schematic of the group connector filter.

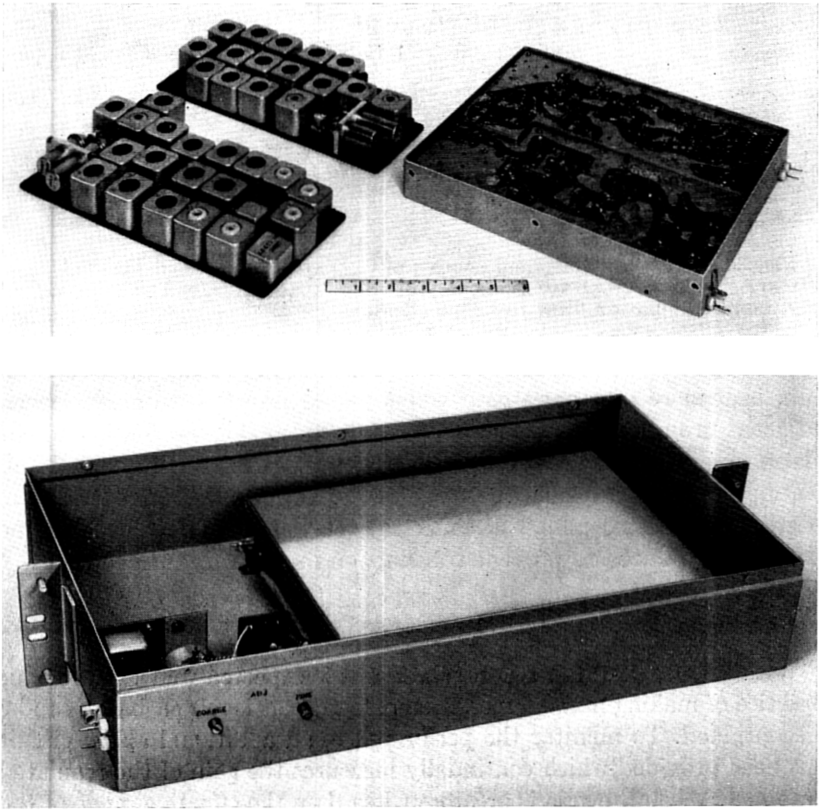


Fig. 34 — B-2 group connector. Upper: internal construction of filter. Lower: assembly with cover removed

5.1.1 *Pilot Alarm*

The loss-of-pilot alarm indicates that the pilot has disappeared, or become too weak for satisfactory regulation. When this occurs, the operation of a miniature relay in the receiving group or supergroup module transfers the thermistor heater winding to a fixed current source instead

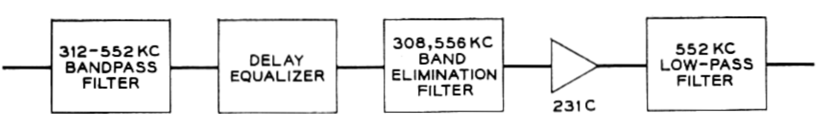


Fig. 35 — Block schematic, C-2 supergroup connector.

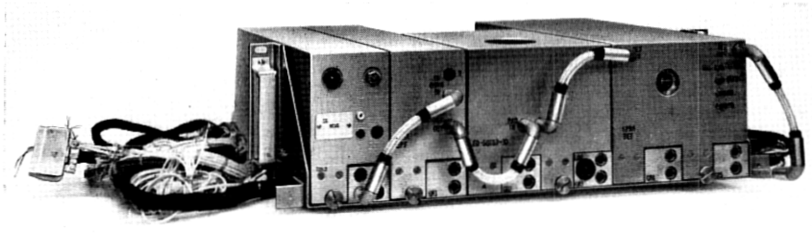


Fig. 36 — Receiving terminal portion of C-2 supergroup connector. Units are, left to right: supergroup receiving amplifier, bandpass filter, pad or delay equalizer, band elimination filter to suppress pilots.

of the regulator. This maintains the amplifier at a mid-range value of gain instead of maximum gain which would interfere with service on adjacent groups or supergroups. The relay also closes a contact to the alarm circuit. A portion of the received pilot current is amplified and rectified and used to hold the relay in the normal, operated condition. A weak pilot or no pilot will cause the relay to transfer. A short time delay is introduced to prevent transfers on momentary interruptions.

5.1.2 *Range Alarm*

With the use of automatic regulation, it is expected that the previous practice of making manual measurements of pilot levels each day can be discontinued. To monitor the performance, an additional alarm circuit has been provided which continually measures the gain of the regulated amplifier. When the gain is greater or less than the effective range of the regulator, an alarm is actuated.

This condition could be caused by malfunction of terminal equipment or by an out-of-limit pilot being received from the transmission system. A sudden loss of pilot will actuate the pilot alarm and prevent the range alarm from occurring. In general, the range alarm indicates an operating condition which is marginal and should be corrected, although service may still be satisfactory.

From its nature, the range alarm lends itself to time-shared operation. It is not essential that the condition be discovered immediately; a delay of several minutes can be tolerated. This makes it feasible to measure the gain of each amplifier in a terminal in turn, repeating the cycle continuously. A scanning circuit, as described in a later section, was developed to facilitate measurements of pilot level. By incorporating means for measuring amplifier gain this scanner has been made to serve both purposes.

The shunt resistance of the amplifier feedback circuit is supplied by the thermistor element. There is a direct correlation between this resistance and the gain of the amplifier. The resistance can be measured conveniently by supplying a small direct current and measuring the voltage. The amplifier portion of the circuit is shown on Fig. 15. Blocking capacitors isolate the measuring circuit. Filtering is also required to prevent noise and crosstalk from entering the amplifier through the measuring circuit.

A differential dc amplifier, the 234B amplifier, has been designed to amplify the dc voltage across the thermistor element. One output of this amplifier drives a meter to display the gain reading. Two additional outputs operate an alarm relay when the gain is outside the effective regulating range.

The connection between the amplifiers and the differential amplifier is by means of the scanner circuit described later. To simplify the scanner, the group amplifier measuring current is transmitted by a simplex system on the group test balanced pair and the shield. At the output of the scanner, the dc signal is separated from the group test voltage by a transformer.

In order to have a means for registering an alarm condition without interrupting the scanning, a magnetic latching relay has been provided for each supergroup shelf. Each shelf accommodates one supergroup amplifier and the associated five group amplifiers. The relay is latched by a pulse from the alarm relay in the 234B amplifier when an end-of-range condition is detected. It remains latched, lighting an alarm lamp on the shelf, until it is reset manually.

5.2 *Pilot Measuring Circuit*

The group pilot at 92 kc and the supergroup pilot at 424 kc are used to control the group and supergroup regulators as described above. They are also used for maintenance, in measuring gains or losses of portions of the equipment, and as an indication of the performance of the transmission system.

A special pilot measuring circuit has been developed to measure these two pilots at the receiving terminal. The operation has been reduced to its simplest form: the signal is patched into the measuring circuit and the deviation from normal level is indicated on a specially calibrated meter.

The group pilot requires a three-stage common-emitter transistor amplifier before rectification. The supergroup pilot is at a lower level and requires an additional two-stage pre-amplifier. All three amplifiers have considerable feedback to stabilize the gain against variations. The pilot bandpass filters are crystal filters designed to have a stable passband loss, as well as a stable frequency characteristic. These precautions are needed to achieved the desired accuracy.

After rectification, the difference between the rectified pilot and a dc reference voltage is used to drive a meter. The meter displays the deviation from normal pilot level and has a range of ± 1 db.

5.3 *Scanner Circuit*

A scanner circuit has been developed to provide easy access to the receiving group test outputs and to the second outputs of the supergroup amplifiers. The equipment has been designed to accommodate all the regular and spare amplifiers on three receiving bays (three L600 multiplex terminals or one L1860 multiplex terminal).

The circuit contains wire spring relays arranged to make the following connections: the test output from any selected supergroup amplifier to a supergroup test jack, the test output from one of the associated five group amplifiers to the group test jack, and the corresponding thermistor terminals to the range alarm circuit. Relay walking circuits are included so that the scanning can be automatic, measuring each amplifier in turn in the three bays and then repeating the cycle. About 15 minutes is required for the complete cycle.

Digital display lamps are included in the meter assembly shown on Fig. 37, to indicate which bay, supergroup, and group are being measured. The meters show the deviations from normal for group and supergroup pilot and for the gain of the two amplifiers.

The control panel for the scanner is shown on Fig. 38. Any group or supergroup can be selected manually and held connected, or scanning can be initiated by depressing the proper key.

The pilot meters indicate the pilot deviations when the test jacks are patched to the pilot measuring circuit. Signals at the other frequencies in the group and supergroup bands can also be measured by connecting a suitable measuring circuit to the test jacks.

VI. PERFORMANCE

Extensive tests have been made on several L600A Multiplex transmitting and receiving bays and performance has been at least equal to the objectives in all respects affecting voice transmission and voice channel data transmission. In the rapidly developing field of wideband data transmission, firm objectives for group and supergroup bands have not yet been established. The performance of L1860A multiplex will be tested when the first installation is completed in early 1963.

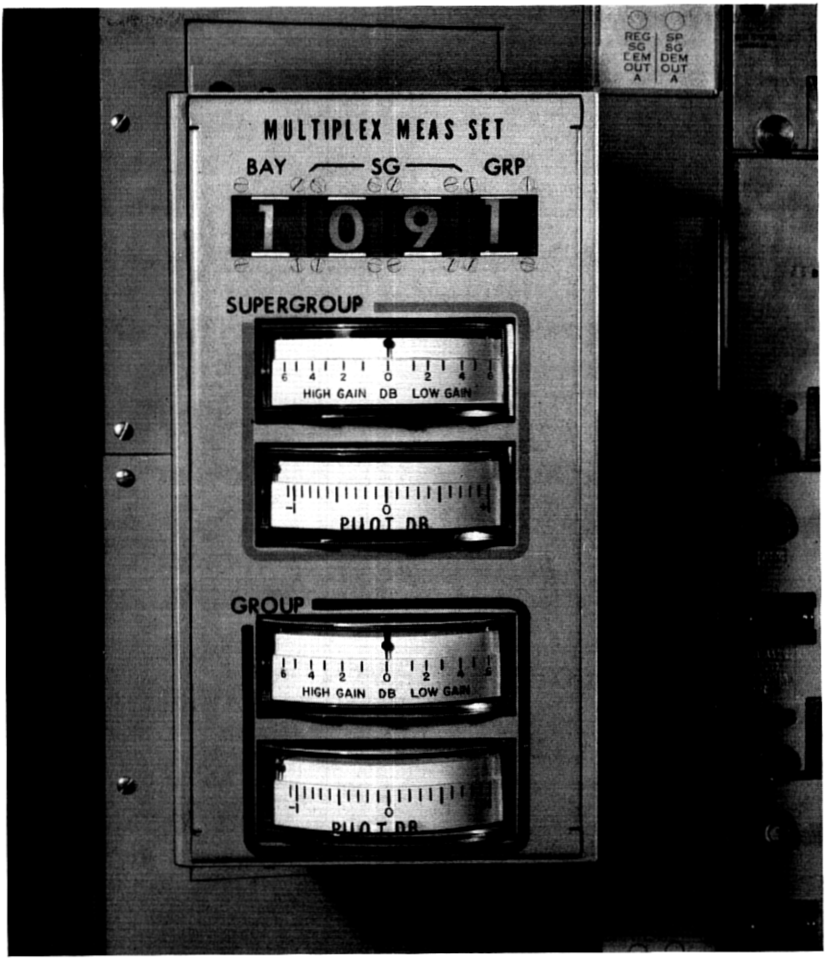


Fig. 37 — Meter display unit for receiving terminal.

The addition of transmitting group amplifiers has resulted in lower noise levels. With a transmitting group bank patched to the receiving bay at the group bank output, and with an A5 channel bank connected to the receiving group output, channel noise, as measured on the 3A Noise Measuring Set,[12] indicated about 15 dbrn at the +7 db level with "C" message weighting (equivalent to 2 dba at zero level). With white noise loading on all channels in the supergroup except three adjoining channels, the noise level in the center quiet channel increased to about 16.5 dbrn when the loading was −15 dbm per channel at zero transmission level.

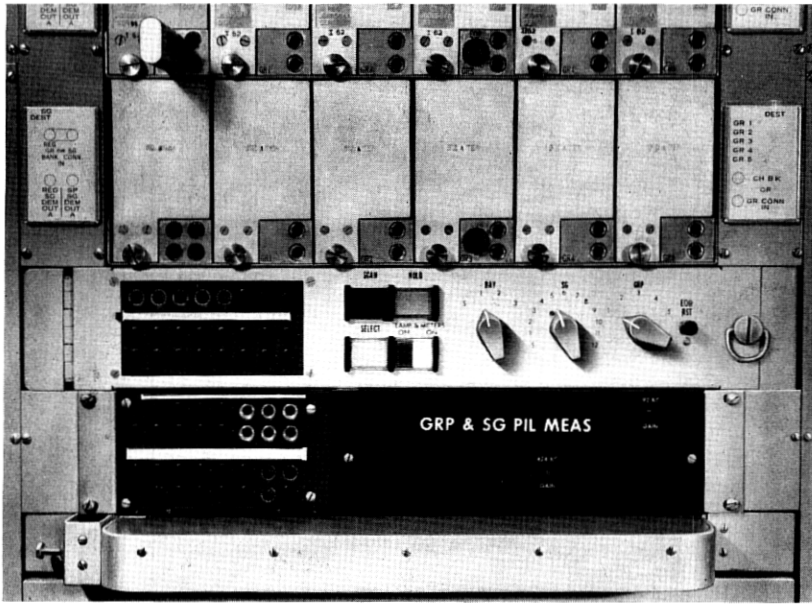


Fig. 38 — Central portion of receiving bay showing unequipped Supergroup No. 1 shelf, scanner control panel, pilot measuring unit, and writing shelf.

Temperature tests on 26 receiving groups equipped with regulators showed that with constant input pilots, the variation in output pilot levels averaged less than ±0.2 db from 40° to 120°F. Similar tests on 8 supergroup receiving amplifiers showed about twice as much variation. When the input pilot levels were varied ±4 db for the groups, the outputs remained within ±0.25 db. For ±6 db variation in supergroup input levels, the outputs changed less than ±0.35 db.

All equipment on both the transmitting and receiving bays was designed to operate from 24 volts dc. Tests showed satisfactory operation with supply voltages from 22 to 26 volts, and marginal operation from 20 to 28 volts. At higher voltages, some parts of the circuit overheat and reliability will be decreased. Below 20 volts, some of the relays in the scanner and alarm circuits did not operate.

VII. EQUIPMENT FEATURES

One of the major problems that has been created by the large use of the L1 and L3 carrier telephone terminals is that of interbay cabling. In many offices, the available overhead cable racks have become overloaded, forcing the addition of more racks where possible. Some of the congestion has been caused by changes in circuit assignment of the equipment. Generally this reassignment required new cabling and when the new cables were run, the old cables were quite often left in the racks rather than risk disturbing working circuits by attempting removal.

Several steps have been taken to relieve this problem: new and smaller cables have been developed for use in the system, a group distributing frame has been developed to reduce recabling requirements, the equipment arrangements have been designed to combine many functions in one bay thus reducing interbay cabling, the floor plan layouts have been changed to provide arrangements which will keep interbay cabling runs within reasonable lengths.

7.1 *Cables*

Previously a large number of cables were required between the various bays in an L multiplex terminal. Not only were these large in number but also relatively large in size. The shielded pair cables connecting the channel banks to groups have been reduced to one-half the diameter by the use of the new 761A cable rather than 720 cable, as shown on Fig. 39. A significant reduction in size was achieved by the use of miniature coaxial cable, 0.1 inch in diameter. The miniature cable is one-fourth the diameter of the 724 cable previously used. With the smaller size comes a much smaller bending radius which has made it possible to

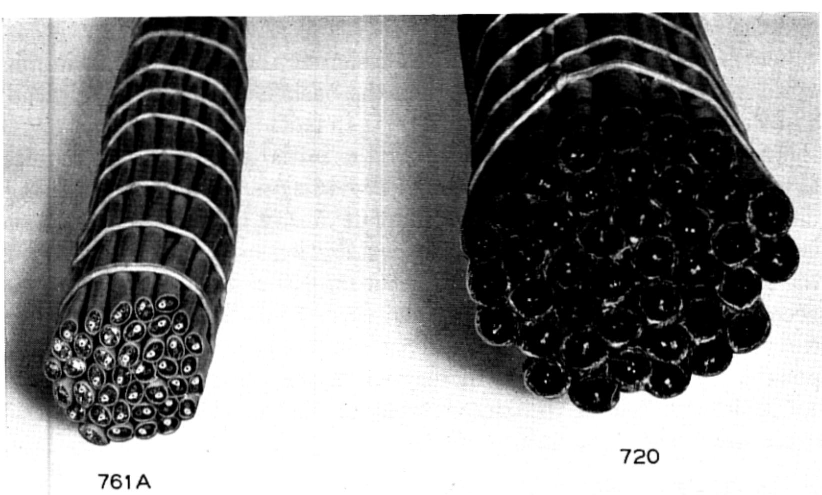


Fig. 39 — Size comparison of 40 shielded pairs of 761A vs 720 cable.

place this cable into tight areas. However, the transmission loss of the miniature coaxial cable limits its use to runs of less than 100 feet.

7.2 *Bay Layouts*

The earlier terminals required one bay for each supergroup bank and one bay for each two group banks. The group carrier supply required one bay to supply each 10 group banks. In conjunction with the active equipment units an additional bay containing jacks was required to provide a means for testing and emergency patching. This bay was located in a central test area, and all the input and output leads of the equipment were cabled to this location.

In planning the new design it became apparent that large savings in cabling could be realized by combining many functions in one bay. With the use of transistors, ferrites, and other new devices, the necessary reduction in size of the apparatus and equipment units has been realized.

One bay, 11 feet 6 inches high, 19 inches wide, is required for each direction of transmission for the group and supergroup equipment for 600 channels. All of the needed carrier supplies are also accommodated on the same bays. In the earlier designs this much equipment required more than 20 bays.

In addition to providing the standard features, these same two bays contain all of the automatic gain regulators and the testing, maintenance, and alarm circuitry, most of which was not available in the earlier equipment. The transmitting bay for the L600 multiplex is shown on Fig. 40 and the receiving bay on Fig. 41.

One of the major considerations in designing the bays was to minimize options and include as many units in the basic bay as was economically and functionally feasible. This means that units such as the group bank shelves are usually provided whether the initial circuit layout requires all of them or not. This technique of providing a complete bay package makes it possible to have the greatest flexibility of circuit changes and additions with the shortest possible installation intervals. By providing the framework and hardware for an entire 600 channels in the bay the necessary plug-in units can be added as growth dictates. The cost for carrying the initially unused shelves can be justified by the savings possible by having the units factory-wired and the savings in time and convenience in having the equipment available when needed. The plug-in equipment is omitted until needed.

7.3 *Plug-in Unit and Bay Hardware*

The active circuits, which affect transmission, are contained in modular plug-in units mounted in the same shelves with the patching jacks.

The necessary gain adjustments are contained in these plug-in units, are accessible from the front of the bay, and can be adjusted on an in-service basis. The active spare transmission units, scanner, carrier supply, carrier distribution equipment, and alarm units mount in the bay or bays of transmission equipment they serve.

7.3.1 *Receiving Modules*

The group and supergroup receiving modules each consist of amplifiers, networks, filters, and miscellaneous apparatus assembled in a drawer-like metal chassis of the plug-in type. The physical appearance of the two units is quite similar except for the front face plate. The group module with one side cover removed is shown on Fig. 42. This is the reverse side from that shown on Fig. 16. The metal chassis, which houses the apparatus, consists of an I-shaped aluminum extrusion for the basic shell, a die cast front plate, a rear plate perforated for ventilation and two removable side plates. The apparatus units contained in the shell are mounted to the web of the extrusion by screws. The units are then interconnected by soldered wires. Any unit, however, can be removed independently by disconnecting the wires and removing the mounting screws.

The front plate contains jacks for testing, a potentiometer for adjusting the regulated output power and an alarm lamp which indicates loss of pilot. The connector plug is attached to the front plate and is cabled up through the shell to the individual apparatus units.

The module is locked in place on the equipment shelf by means of a captive screw located on the face plate and a tang located at the rear of the shelf which engages the rear plate. No other guides are required on the chassis or shelf for alignment purposes. This entire package, with all its circuitry, is only 5 inches high, by $2\frac{3}{4}$ wide and 15 inches long. Each shelf contains one supergroup module and the associated 5 group modules. The receiving bay contains 11 shelves, one of which holds the spare group bank equipment.

7.3.2 *Transmitting Modules*

The transmitting group assemblies consist of an amplifier and a modulator housed in a single apparatus can which connects to the equipment shelf through a multiple-contact plug. Five group amplifiers and one intermediate amplifier are mounted on one shelf as shown on Fig. 43. The amplifiers can be extracted by using a special tool which inserts in the slot on the front face. The associated group bandpass filters are mounted in the rear.

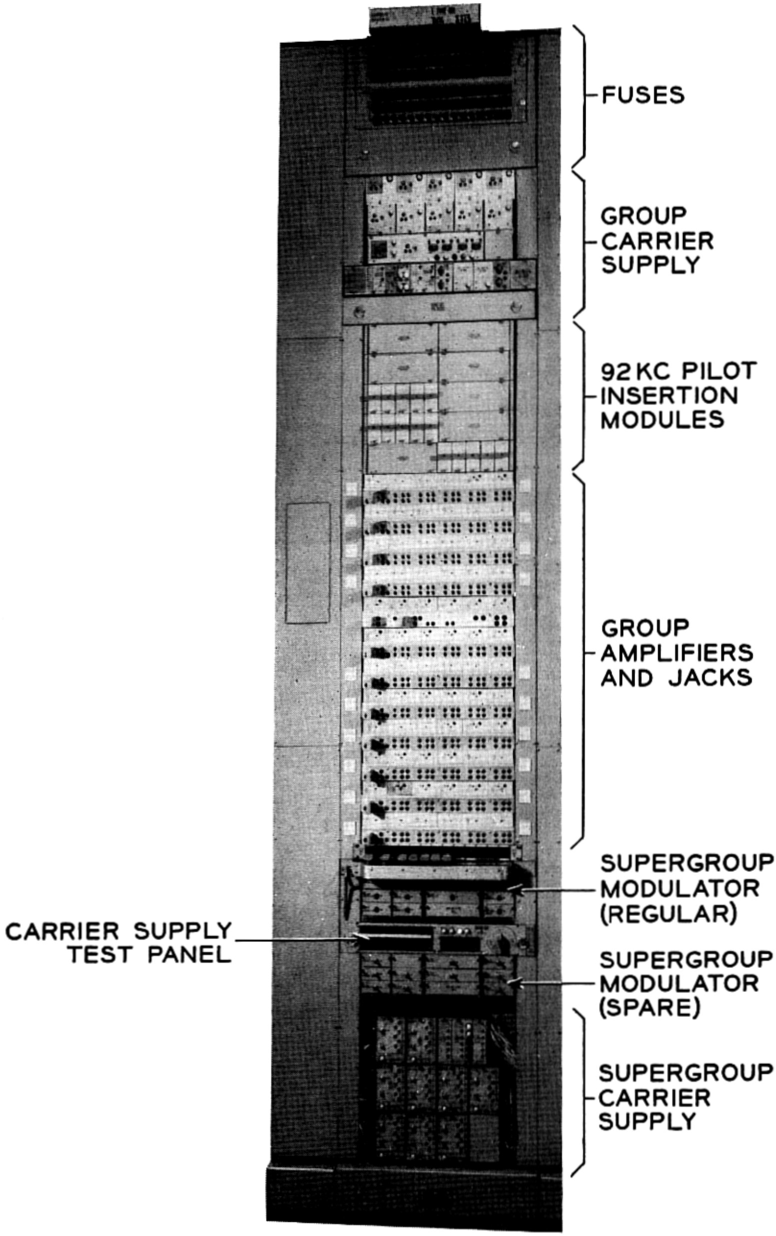


Fig. 40 — Transmitting bay, L600 multiplex.

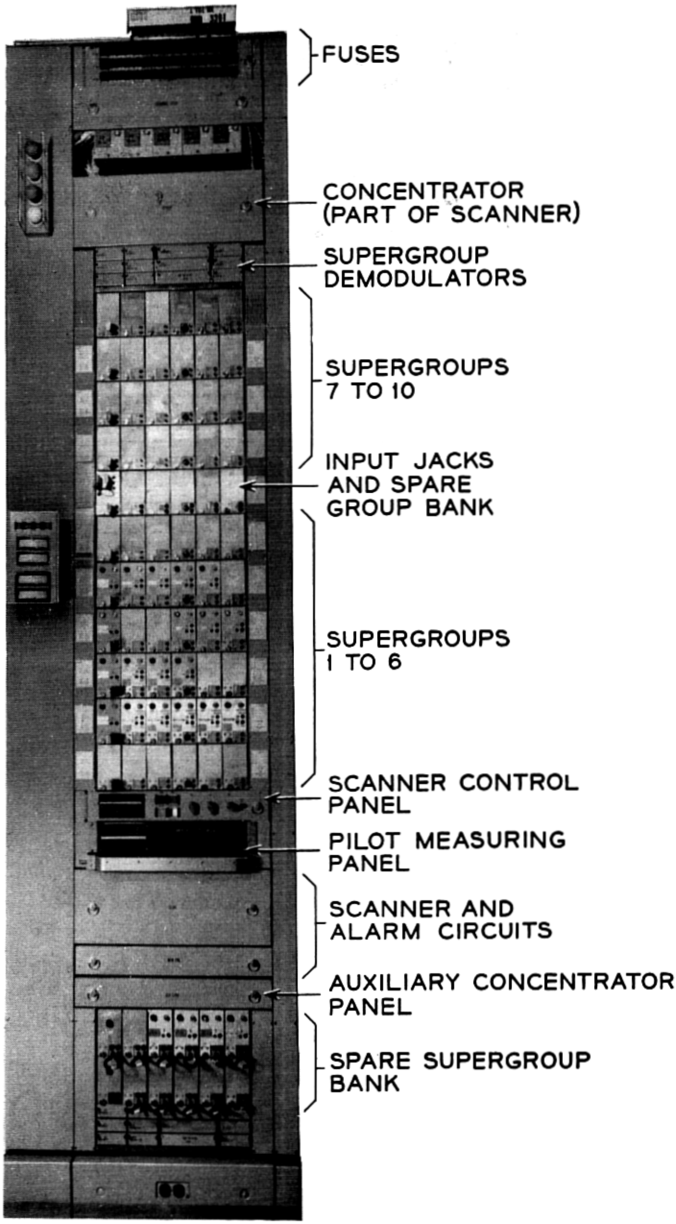


Fig. 41 — Receiving bay, L600 multiplex.

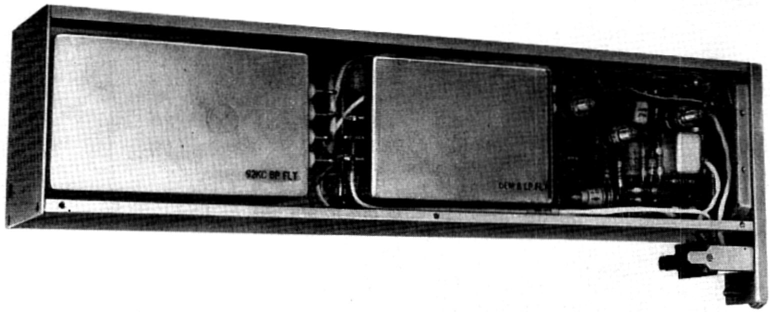


Fig. 42 — Receiving group module with cover removed (reverse side from that shown on Fig. 16). Differential dc amplifier and alarm circuit on right.

The supergroup modulator, demodulator, and bandpass filter units are mounted on flat plates which slide into a shelf framework shown on Fig. 44. The same basic design is used for both the transmitting and receiving bays. Interconnections between these units are made by the use of miniature coaxial cable equipped with jacks.

7.3.3 *Other Equipment*

The remaining equipment units located in the bays are primarily flat-panel construction packaged to utilize the 15 inches depth. These units are the fuse, concentrator, pilot measuring circuit, scanner and control panel, the alarm and auxiliary concentrator panels.

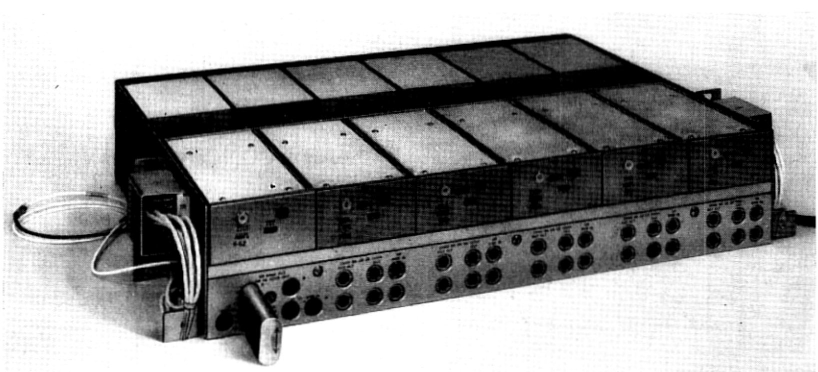


Fig. 43 — Transmitting group bank. Plug-in unit on left is group intermediate amplifier. Others are 5 group amplifiers and modulators. Group bandpass filters are in rear.

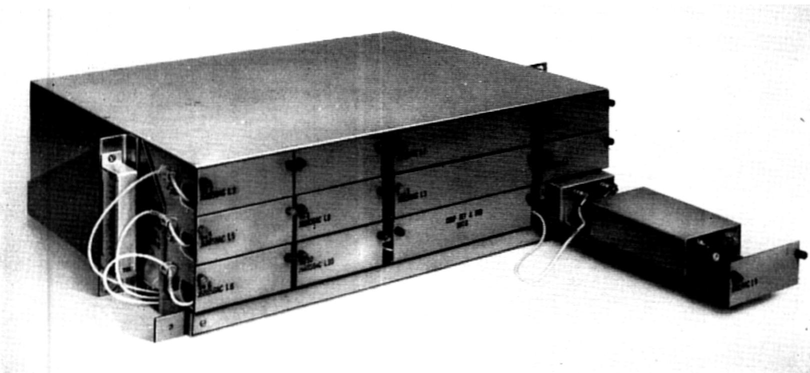


Fig. 44 — Supergroup modulators and bandpass filters.

7.4 *Group Distribution Frame*

With the continuous growth in the toll plant it frequently becomes desirable to transfer groups of circuits from one system to another. For example, when a new microwave or cable system is completed, some circuits are transferred to it from existing systems. This provides capacity for growth on the existing systems as well as on the new system.

Most toll offices now have a main distribution frame where all individual voice circuits in the office are connected to the voice frequency patch bays and through them to the channel banks. The individual circuits can be transferred by changing the connections on this frame. When whole groups of twelve voice channels were to be transferred it has been the practice to make the transfer by changing the cables between the channel banks and the group equipment, rather than transferring twelve pairs in the main distribution frame. When the reassignments involved group connectors, no alternative existed except to recable the connection from the connectors to the group equipment.

A study of the history of circuit reassignments indicated that each channel bank or group connector was reassigned on the average of once in three years although there are wide variations. Several possible methods of providing a convenient means for making these transfers were studied. All involved running all channel bank and group connector cables to a common location in the office and fanning out from there to all the group equipment. At the common location, some form of cross-connection must be provided.

Providing distribution frames for the group connections permits installation of channel banks and group connector filters without pre-

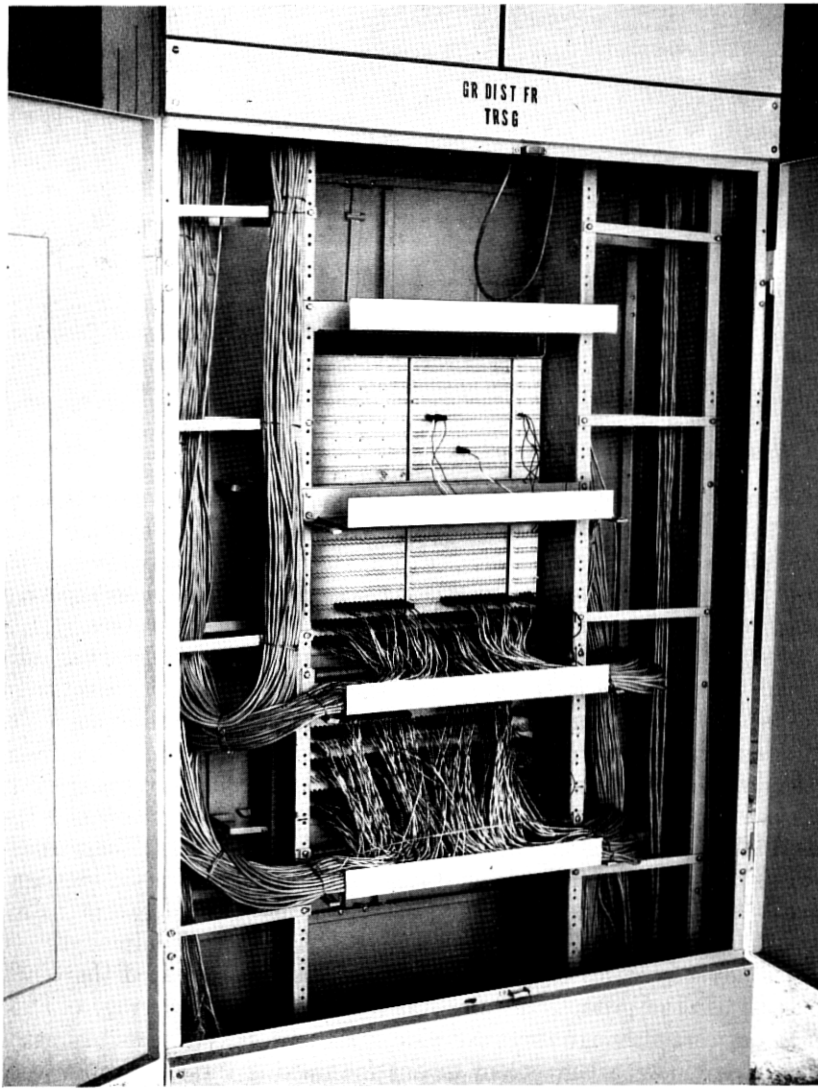


Fig. 45 — Group distributing frame for cross-connecting up to 1200 groups, cabling side.

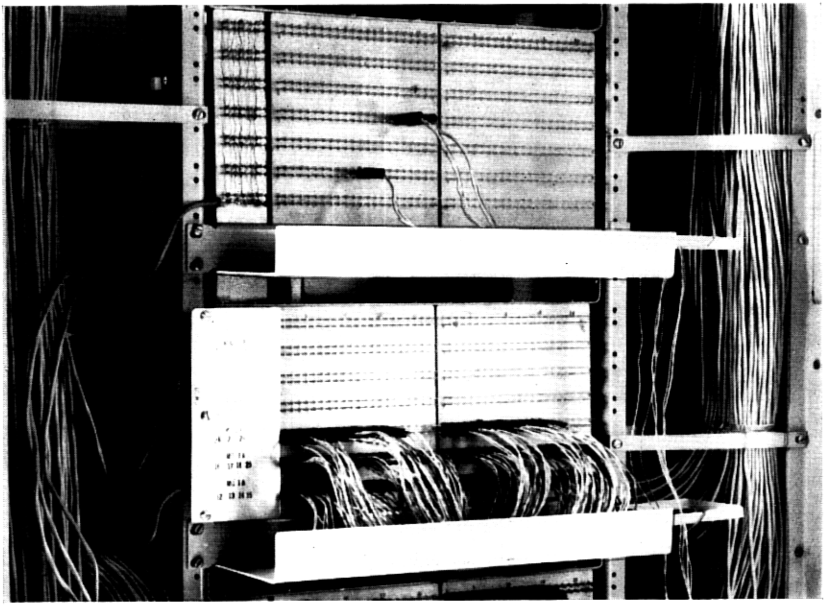


Fig. 46 — Group distributing frame, cross-connection side.

determining to what group equipment each will be connected, simplifying engineering and installation planning.

Tests of crosstalk indicated that unshielded pairs could be used for the cross-connections provided the whole frame was shielded from external disturbances. Wire-wrapped connections to terminals were used instead of pin-type connectors to conserve space and shorten the length of the cross-connections.

The frame shown on Fig. 45 can accommodate up to 1200 channel bank connections for one direction of transmission. The other direction is accommodated on a second bay. The cabling is run on both sides of the terminal strips and terminates on the reverse side of the terminal strips. All cross-connections are made on the front of the terminal strips. A close-up of one terminal strip is shown on Fig. 46. The insulated tubing over each pair facilitates locating a desired pair and reduces the risk of interfering with adjacent pairs when changes are made. Wire-wrapping and unwrapping tools are used.

The installation of group distribution frames involves recabling every channel bank or group connector in the office, but once this is done, further reassignment can be made with a minimum of effort.

7.5 *Office Layout*

To capitalize on the features discussed, new floor plan layout arrangements are desirable. These layouts are designed to keep cabling runs to a minimum and combine certain functions by grouping the bays. The grouping is significant especially when certain units are shared by two or more bays. The scanner and pilot measuring equipment, spare supergroup equipment, and alarm equipment will serve up to three receiving bays while the carrier supplies will serve three transmitting bays and three receiving bays. The method of locating the bays in this manner will keep the cable runs, between the shared equipment, within the 100-foot loss limitation of the miniature coaxial cable. These bays are designed for front-side maintenance, making it possible to mount them back-to-back or next to a wall.

VIII. CONCLUSION

New group and supergroup terminals for long-haul telephone circuits have been developed which incorporate many new features to improve performance. The use of transistors and associated modern components, together with new materials, has permitted a great reduction in size and the promise of increased reliability. The equipment has been designed to reduce installation effort and minimize office cabling. The addition of group and supergroup regulation in the receiving terminals will make possible new high standards of transmission stability.

The improved performance and lower installed cost of the new terminals should assure a wide use for several years.

IX. ACKNOWLEDGMENTS

As in any project of this size, many individuals have contributed. In addition to the members of the authors' groups and the authors of the companion papers, significant contributions have been made by D. S. Williams, J. L. Garrison, D. W. Grant, S. G. Hale, and members of their groups.

REFERENCES

1. Hallenbeck, F. J. and Mahoney, J. J., B.S.T.J., this issue, p. 207.
2. Blecher, F. H. and Hallenbeck, F. J., B.S.T.J., **41**, Jan., 1962, p. 321.
3. Crane, R. E., Dixon, J. T., and Huber, G. H., Trans. A.I.E.E., **66**, 1947, p. 1451.
4. Albert, W. G., Evans, J. B., Jr., Ginty, J. J., and Harley, J. B., B.S.T.J., this issue, p. 279.
5. Elmendorf, C. H., Ehrbar, R. D., Klie, R. H., and Grossman, A. J., B.S.T.J., **32**, July, 1953, p. 781.
6. Bode, H. W., *Network Analysis and Feedback Amplifier Design*, New York, D. Van Nostrand Co., 1945.
7. Oliver, B. M., Proc. I.R.E., **36**, 1948, p. 466.
8. Kinzer, J. P., Trans. A.I.E.E., **68**, 1949, p. 1181.
9. Ketchledge, R. W. and Finch, T. R., B.S.T.J., **32**, July, 1953, p. 833.
10. Clark, O. P., I.R.E. Convention Record, 1962.
11. Caruthers, R. S., Trans. A.I.E.E., **58**, 1939, p. 253.
12. Aikens, A. J., and Lewinski, D., B.S.T.J., **39**, July, 1960, p. 879.