Carrier Supplies for L-Type Multiplex

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This article describes the carrier and pilot supply equipment of the L-type multiplex. Also discussed is the modernized carrier supply for the A-type channel banks described in an earlier paper.

A short review of previous carrier equipment and recent developments in carrier application is followed by a general discussion of the design approach. Finally, specific circuits and equipment units are described.

I. INTRODUCTION

The L-type multiplex operates by frequency-division and thus requires a source of carrier power for each channel or group of channels transposed from one frequency band to another. Specifically, this means a carrier source for each channel, group, and supergroup modulator. These carrier frequencies must be resupplied at the receiving terminal also; and since the system is single-sideband with carrier suppressed, they must be resupplied with extreme frequency accuracy to prevent undue frequency shift in the channels. This is accomplished by accurately synchronizing these carriers to a received pilot which is derived from the carrier supply at the transmitting end.

II. REVIEW

2.1 *Old Carrier Supply*

Since a synchronized carrier supply tends to be expensive, it has been designed conventionally as centralized equipment so as to spread the cost over a great many channels. This was appropriate when the emphasis was placed on large installations. The old equipment (hereafter called "electron tube" equipment) was designed before large-scale application of carrier techniques to short-haul trunks. The new equipment recognizes this use of carrier and is designed to be economical for small-density installations without unduly penalizing the large.

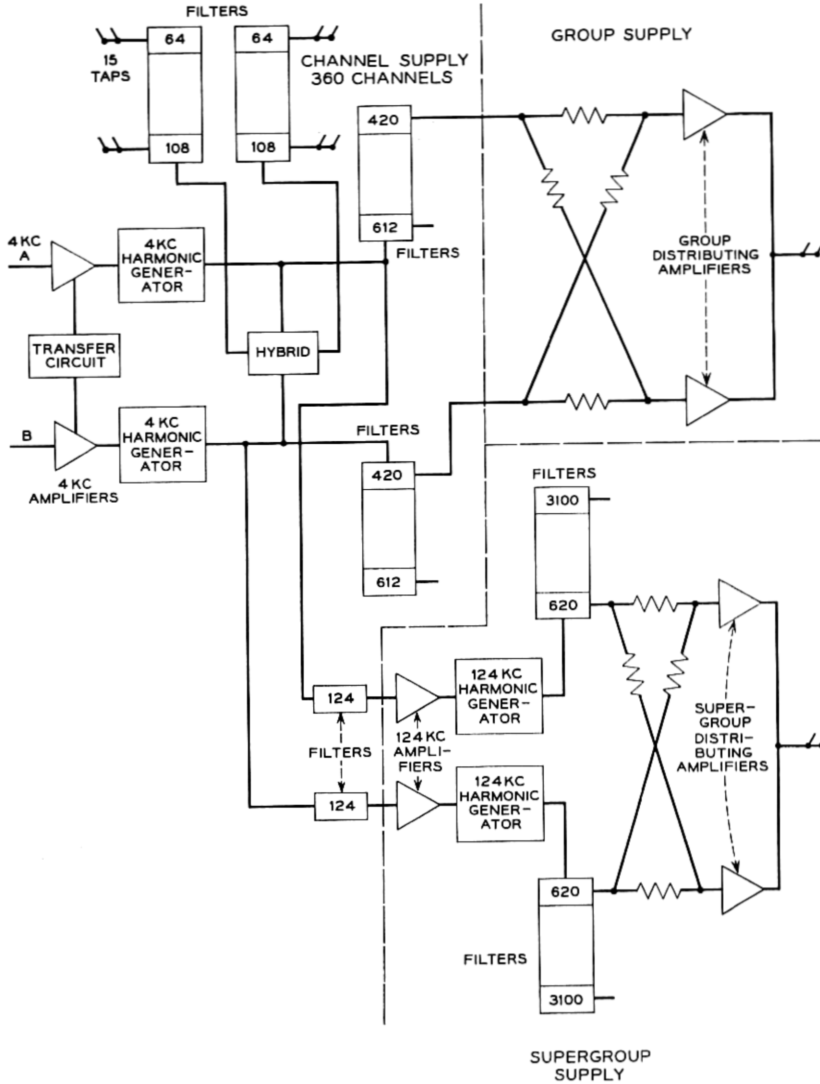

Fig. 1 — Electron tube carrier supply.

Fig. 1 is a simplified schematic diagram of an electron tube carrier supply. All carrier frequencies are multiples of 4 kc, the frequency spacing of the channels. These carrier frequencies are produced by driving two harmonic generators with separate 4-kc sine wave sources designated A and B. Only one of the harmonic generators is permitted to operate at any time, the other one being disabled by the transfer circuit. The working harmonic generator feeds two similar banks of channel carrier filters via a hybrid transformer. Each pair of filters selects a carrier frequency and feeds it to as many as 30 channel modems. The figure is simplified, in that the even and odd harmonics actually come out of the harmonic generator on two different busses, and the filters are divided into even and odd sets, each fed by a hybrid.

The group carriers are all odd multiples of 4 kc, and are obtained in a manner similar to the channel carriers, except that duplicate filters are used rather than a hybrid, and distribution amplifiers are needed because of the power levels required by the group modulators.

For the supergroup carriers, the 124-kc harmonic component is filtered and fed to another harmonic generator which produces the supergroup carriers as multiples of 124 kc. Although not shown in Fig. 1, the equipment also generates 92-kc group pilots and 64-kc line pilots by the same techniques discussed above.

This electron tube carrier supply represents a highly centralized design. The interdependency of the "channel" carrier supply on the one hand, and "group" or "supergroup" carrier supplies on the other, is at once apparent; the latter will not operate without the former. Also, since the group and supergroup supplies serve up to 3000 channels, they are made extremely reliable by built-in redundancy. This redundancy is reflected all the way back to the 4-kc harmonic generators, which are duplicated and protected by the automatic transfer circuit.

The resulting protection of the 4-kc harmonic generators is also available to the channel carrier supply, even though it is not as necessary for its 360 channels as it is for the 3000 previously mentioned. This bonus protection comes at a price: each time a 360-channel mark is passed in the office-growth pattern, a new pair of harmonic generators complete with automatic transfer must be installed.

2.2 *Recent Developments in Carrier Application*

The electron tube equipment just described has been usefully and economically applied on a large-scale basis, mainly in multiplexing for 1860-channel L3 coaxial systems[1] and for 600-channel TD-2[2] microwave radio channels.* In the meantime, however, frequency-division techniques have been applied successfully to shorter and shorter trunks,

* The distinction should be emphasized between a voice or telephone channel, which is roughly 4 kilocycles in bandwidth, and a radio channel, which is many megacycles in bandwidth and carries many telephone channels.

and to smaller and smaller installations. A single N carrier[3] 12-channel terminal in an office, for example, is entirely practical on an economic basis.

Similarly, the "ON" carrier terminal has been applied as a 96-channel multiplex for the TJ and TL short-haul microwave radio systems.[4] The channel capacity is limited due to the loading effect of the transmitted carriers. The L-type multiplex, however, can be used to stack 240 or more channels for transmission on these radio systems, since carriers are not transmitted. The cost of the electron tube L-type equipment usually makes this prohibitive, unless the L carrier supply is already in the office and unused taps are available. The nature of the short-haul radio route tends to make this favorable circumstance improbable.

Thus, we see that the L terminal approach (single-sideband) has been technically but not economically attractive for the low density application of frequency-division techniques. Yet the low density carrier-derived trunk is today very common, and is becoming more so all the time. This fact has been paramount in setting the detailed design objectives of the new multiplex carrier supply (hereafter referred to as "transistor carrier supply"), and in addition has led to the development of the L60A and L120A packages.*

III. OBJECTIVES

The technical performance objectives of the transistor carrier supply, like those of the electron tube type, are set by the nature of the modulators it supplies. A carrier power considerably higher than the signal power is generally required by the modulators to enhance their linearity and to stabilize them against variations in carrier power. Thus, the essential requirements for the carrier supply are frequency accuracy and sufficient power, with a fairly lenient requirement on amplitude stability.

In the case of carrier supplies for channel modulators, these requirements are somewhat modified because of an additional objective: the channel modulator should have a specific amplitude limiting characteristic. To allow limiting at the proper signal level, the channel modulator is supplied with carrier power considerably reduced with respect to that supplied a group or supergroup modulator. Since the channel

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* This paper describes the L600A and L1860A carrier supplies, as well as channel carrier supplies. The L60A and L120A circuits are similar, but the channel carrier supply is integrated with group and supergroup supplies in one package.[6]

modulator is thus made more sensitive to carrier level variations, the channel carrier supply must be more stable. This is more fully described in Section 5.2.

The essential requirements discussed above do not differ from those satisfied by the electron tube carrier supply. However, additional ones were established: lower cost, easier maintenance, miniaturization, and general modernization. Finally, a very specific objective formed early in the design was decentralization of the carrier supply, and integration with the equipment it serves. This represents an important step in making the new multiplex attractive for small installations, and is also consistent with the general desire to reduce the volume of interbay cabling. The decentralization objective must, of course, be tempered with the continuing need for economy in large density installations.

IV. NEW MULTIPLEX CARRIER SUPPLY

4.1 *Design Approach*

In accordance with the decentralization objective, the transistor carrier supply consists of two basic equipments: the channel carrier supply, which is located with the 30 channel banks it serves (three bays); and the group and supergroup supply, which mounts in one of the six multiplex bays it serves.

It may be inferred from the above that the multiplex is still not completely integrated, since the channel banks and the rest of the multiplex tend to be independent. This is as it should be, since most offices do not terminate all channels at voice-frequency, but pass some through the office at group or supergroup frequencies. In the case of the transistor multiplex, it is no longer necessary to install parts of a channel carrier supply merely to drive group and supergroup carrier supply equipment.

Although the group and supergroup supply is common to six bays (three transmitting and three receiving), each of these bays has its own local group carrier distributing amplifiers and busses. This reduces the number of cables from the group carrier supply proper from one per modulator to one per frequency, thus effecting a cable reduction of 50 to 5. Although it is primarily a cable-saving device, the local distribution approach also reduces the power requirement on individual transistor output stages by about 8 db by virtue of distributing a given carrier via six secondary amplifiers rather than one.

Channel bank bays not containing a carrier supply could benefit by a 10 to 1 reduction of interbay cables if local distribution arrangements were provided for them. The arrangement chosen, however, (no local distribution busses) obviates the need for amplifiers completely, except for the one associated with the harmonic generator. This is possible because of the modest power requirement of a channel modem as compared with that of a group or a supergroup modulator, as mentioned before. Thus, the design is an economical and reliable one, and the required cables normally feed three adjacent bays, and so do not enter the cable racks.

4.2 *Reliability*

The question of carrier supply reliability is an interesting one, and must be discussed together with maintenance and transmission hits, these three subjects being intimately related.

The electron tube carrier supply, being common to as many as 3000 channels, was developed to satisfy an extreme reliability requirement. Consequently, it has much redundancy and automatic switching. For example, each 360 channels of carrier supply is duplicated and automatically protected, largely because it contains equipment for group and supergroup supplies for up to 3000 channels. In the new design, the carrier supply amplifiers are not automatically protected, or duplicated on a one-for-one basis, unless they serve more than 360 channels. This is because the group and supergroup carrier supplies are independent of the channel carrier supply, and also because the inherent reliability of the transistor amplifiers is expected to be substantially better than that of the electron tube amplifiers.

The new transistor amplifiers are plug-in, and are thus readily replaced in case of failure. Amplifiers serving 360 channels or less, though not duplicated, are protected by spares common to several bays. These spares are activated and provided with alarms so as to be readily available if needed.

Amplifiers common to more than 360 channels are automatically protected on a one-for-one basis. The switches used for this are not hitless, but are activated only upon a failure. They are not used for routine maintenance, since this is performed on working units on an in-service basis. Thus, the need for frequent switches has been removed, rather than incorporating an expensive hitless arrangement.

4.3 *Description*

The transistor multiplex equipment (L600A or L1860A) is used as all or part of the terminal equipment for several types of line facility. For

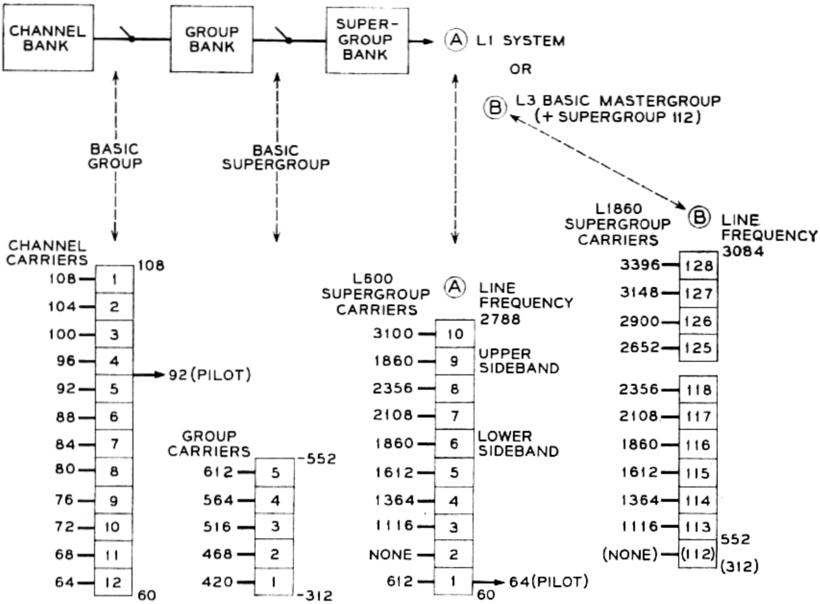

Fig. 2 — Line and carrier supply frequencies.

present purposes, these facilities may be considered to have either an L1 or an L3 line frequency assignment. The line frequencies and the required carrier frequencies are depicted in Fig. 2. Here an L1 system is assumed to include a 600-channel (ten-supergroup) facility—for example, a TD-2 radio channel. An L3 system is considered to be an L3 coaxial line or a TH radio[5] channel, 1860 channels (31 supergroups) in either case. For the L3 system, an additional two steps of modulation are required to place the two upper mastergroups at line frequency.* These additional steps of modulation are provided by L3 mastergroup equipment which works with, but is not a part of, the transistor multiplex. The master group equipment is presently of the electron tube type.

The transistor multiplex for the L1 system is called "L600A multiplex," while that for the L3 system is called "L1860A multiplex."[6] Fig. 3 shows the L600A multiplex carrier supply. The channel carrier supply makes use of harmonics of 4 kc as in the old supply, with differences in the protection features and isolation from the other carrier supplies as previously discussed. In addition, a single set of 12 filters† is used for all 360 channels, thereby reducing the number of filters required by a factor of two.

* An L3 mastergroup consists of ten or eleven supergroups.
† Carrier supply filters are described in a companion paper.[7]

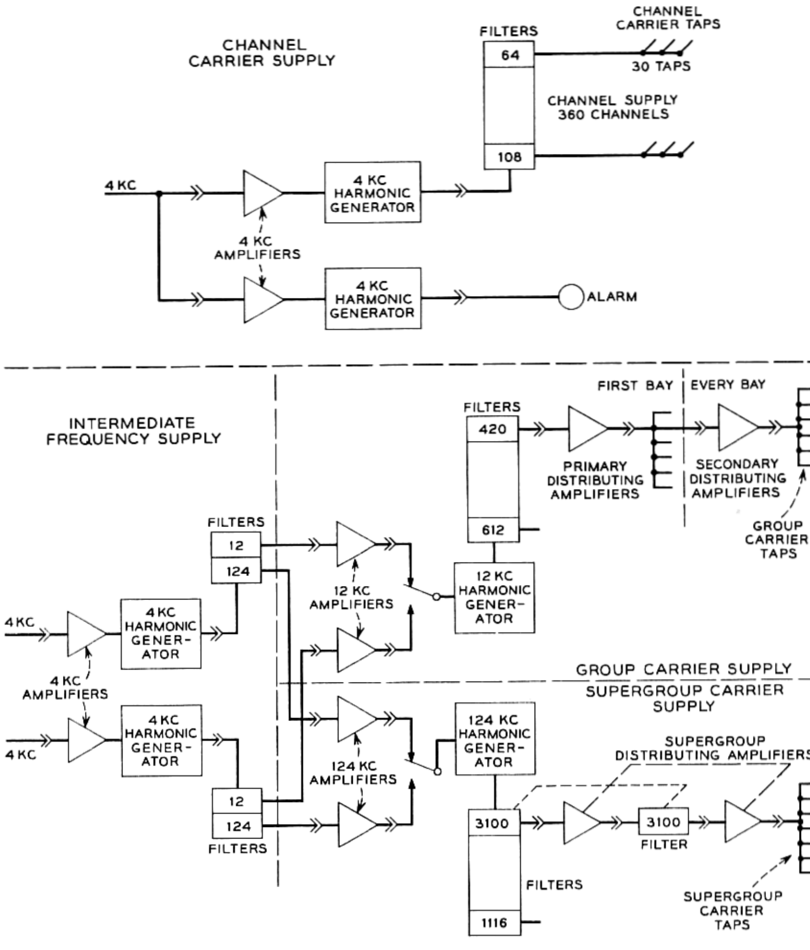

Fig. 3 — L600A carrier supply.

The balance of the carrier supply has its own pair of 4-kc harmonic generators, fed from additional taps on the 4-kc primary frequency distributing bus.* These generators are used to derive only four frequencies: 12, 124, and (not shown) 64 and 92 kc. The former two frequencies form basic frequencies for the group and supergroup carrier supplies, respectively, while the 64 and 92 kc represent line pilot (as

* A new 4-kc primary frequency supply has also been designed, and is described in a companion paper.[8]

required) and group pilot respectively. The equipment unit supplying the above four frequencies is called the "intermediate frequency supply."*

The 12-kc filters and amplifiers are duplicated. A relay selects either output to feed the harmonic generator (saturable inductor), and automatically switches to the other output in case of a failure. It should be noted that the group carrier frequencies are derived as harmonics of 12 kc rather than 4 kc. This results in easing the discrimination requirements on the group carrier filters, with attendant filter economies. The group carrier filters feed primary distributing amplifiers, which distribute the five frequencies to six bays. From there, the local (secondary) distributing amplifiers feed the carriers to all group modulators in the particular bay.

The operation of the supergroup carrier supply is generally similar, except for detailed differences in the distribution amplifier arrangements, the different base frequency (124 kc), and the different mode of generation of the upper four carriers in the L1860A application, these carriers not being multiples of 124 kc.

V. CIRCUIT DESIGN

5.1 *Introduction*

The individual carrier supply circuits consist of harmonic generators, filters, single-frequency drive amplifiers, and wideband distributing amplifiers. The passband characteristics of the latter are such that a single group (or supergroup) amplifier will handle any group (or supergroup) frequency.

Since the same basic saturable-inductor harmonic generator is used in several parts of the carrier supply, its operation is described only in connection with the group carrier supply.

The channel carrier supply description includes a discussion of the translation of system objectives to a requirement on drive amplifier stability. This setting of requirements, although obviously necessary for all circuits, is given only once as an example.

5.2 *Channel Carrier Supply*

The channel carrier frequencies, harmonics of 4 kc from 64 to 108 kc, are derived from the channel harmonic generator circuit by means of an

* As described later, the intermediate frequency supply for the L1860A provides an additional frequency of 80 kc.

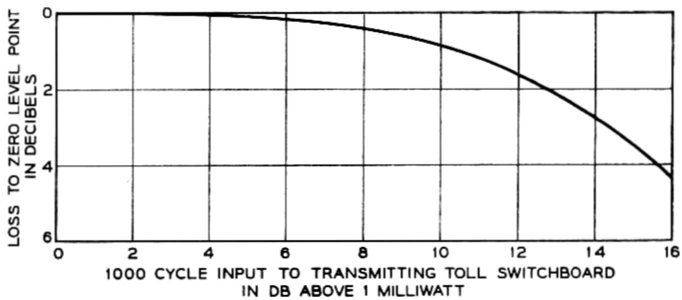

Fig. 4 — Limiting characteristic of channel modulator.

amplifier, pulse-forming network, and filter circuit. Distribution of the carriers is accomplished through a 30-tap capacitive distribution circuit.

Amplitude stability of the channel carrier supply is of prime importance if the system is to meet the transmission requirements of Direct Distance Dialing and future data systems. For most modulators, it is customary to supply carrier power at a much higher level than the signal power. This has two beneficial effects:

1. Variations in carrier amplitude with typical modulators are reflected as loss variations in the transmission path by only about one part in ten; i.e., a 1-db change in carrier power results in only 0.1-db change in transmission. This effect is called a "stiffness of 10:1."
2. High order (c ± mv) products which frequently overlap to produce interchannel crosstalk are reduced.

The channel modulator, however, performs one additional function which changes the requirements and calls for much lower carrier-to-signal power. This additional function is power limiting, and is discussed below.

In single-sideband suppressed carrier systems, the system load depends on the number and power of the talkers active at any one time. Provision must be made to limit automatically the power of each talker so that overload of the system will not occur if, during the busy hour, an inordinate number of loud talkers is present at one time. Power limiting also protects the system from test tones accidentally applied at too high a level.

To achieve the necessary limiting, the carrier power provided to the channel modulators is 0 dbm* per modulator. This gives the desired limiting characteristic as shown in Fig. 4. Undesirable modulation products due to the low carrier power are reduced to acceptable levels

* db above one milliwatt.

by the channel bank filters, and the limiting effect on loud talkers does not reduce intelligibility or even impair naturalness to any appreciable extent. The low carrier power does, however, reduce the "stiffness" to a ratio of approximately 2:1 and thus imposes tight requirements on channel carrier stability.

The requirement on amplitude stability for the channel carrier amplifier may be derived in the following manner.

The 4000-mile requirement for message system net loss stability in order to satisfy the needs of Direct Distance Dialing will be taken as:

1. Sudden step variations in level shall be less than ±0.25 db.
2. Average drift variations (bias) of the losses of a group of trunks from design value shall be less than ±0.25 db with a distribution grade (standard deviation) from this average of less than 0.75 db.

If one allocates one-half of the bias to the line and one-half to the terminals that make up the 4000-mile channels, the bias (X) of any one terminal will be given by

$$\sqrt{n}\, X = 0.125 \text{ db}$$

where n is the number of links in tandem, and random distribution of link biases is assumed. If it is further assumed that the maximum number of links (n) in tandem is five, then

$$X = 0.056 \text{ db.}$$

What appears to be a stringent requirement on the amplifier is relaxed due to two things: the modulator stiffness, though not great, is 2:1, and the harmonic generator has its own limiting action which produces an additional stiffness of 5:1. Thus the requirement derived above is relaxed by some 10:1, and each amplifier should therefore exhibit an amplitude stability of 0.56 db.

Fig. 5 shows the amplitude stability of the 4-kc drive amplifier vs variations in temperature and office battery voltage. The loss variation of a typical channel carrier filter vs temperature is of the order of 0.2 db over the expected temperature range (40 to 120 degrees fahrenheit).

Fig. 6 is a simplified circuit schematic of the amplifier. Q_1 is a 16A diffused-silicon transistor used in the common-emitter configuration. This is followed by Q_2, a 20C transistor in a phase splitting circuit which drives Q_3 and Q_4, two 16A transistors used as emitter followers. These drive the output stage consisting of Q_5 and Q_6, two 20G transistors in a class B output circuit. The transformer L1 provides series feedback around the amplifier to stabilize the circuit for variations in the μ path.

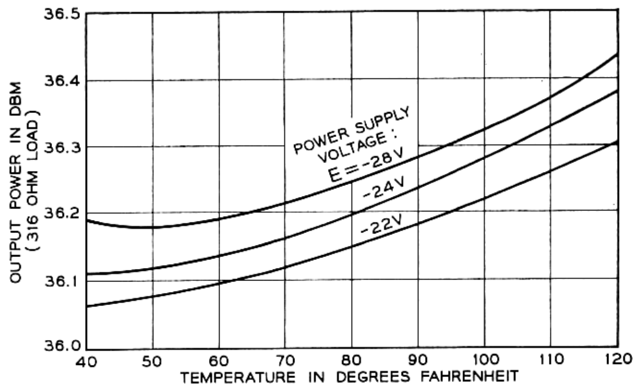

Fig. 5 — 4-kc drive amplifier — output power vs temperature and office battery variations.

5.3 *Intermediate Frequency Supply*

The intermediate frequency supply circuit is used to generate the basic frequencies required for the group, supergroup, and pilot supply circuits. The harmonic generators and filter circuits are duplicated and feed dual inputs to the group and supergroup circuits. Also included are the 64- and 92-kc pilot supply circuits. The pilot supply circuits contain amplitude stabilizers, since any change in transmitted pilot level would be interpreted (by regulators or maintenance forces) as a change in line or terminal gain. The stabilizers reduce pilot level variations of several db to a small fraction of a db.

The stabilizer is essentially a zero-gain circuit in which the pilot is amplified by two common-emitter stages, symmetrically clipped by diodes, and filtered to reject harmonics. The output power is held to within a few hundredths of a db for input variations up to ± 4 db.

The stabilizers for each pilot frequency are duplicated and switched. Resistive primary and capacitive secondary busses distribute the pilots to the appropriate circuits.

The L1860A intermediate frequency supply is the same as described above, except that 80 kc is produced as well as 124 kc for the supergroup drive frequencies. The 64 kc is not required, as the L3 line pilots are produced by L3 pilot supply equipment.

5.4 *Group Carrier Supply*

Five carrier frequencies are required to translate the basic group spectrum (60–108 kc) to the five assigned positions in the frequency

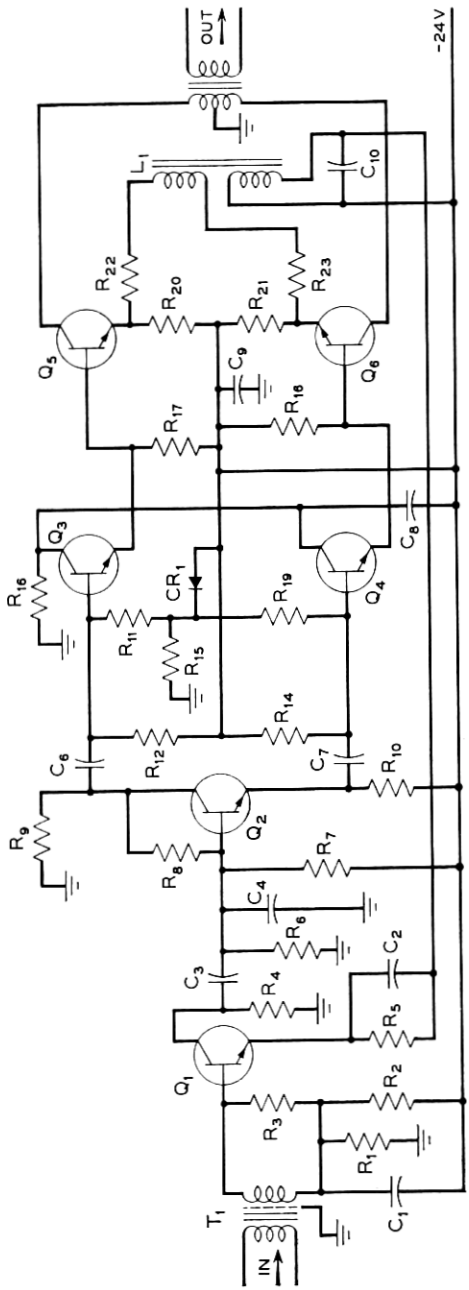

Fig. 6 — 4-kc drive amplifier schematic circuit.

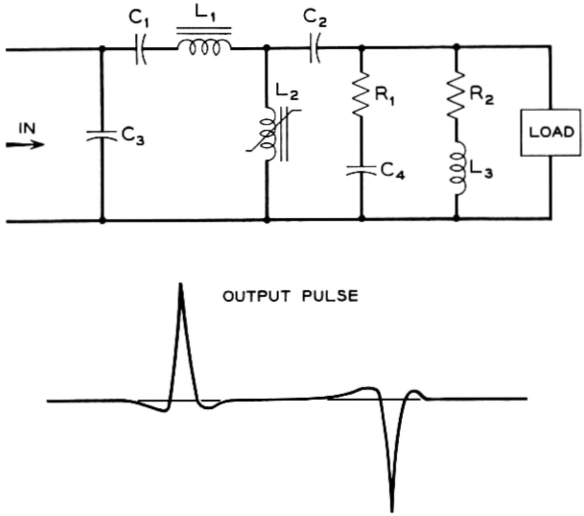

Fig. 7 — 12-kc harmonic generator circuit and waveform.

band of 312 to 552 kc; these carrier frequencies are 420, 468, 516, 564, and 612 kc, corresponding to groups one to five respectively. These frequencies are generated by the 12-kc harmonic generator circuit. The 12-kc amplifier which drives the harmonic generator is almost identical with the 4-kc amplifier previously described.

The harmonic generator circuit, shown in Fig. 7, consists of a high-Q series LC circuit C_1, L_1 tuned to 12 kc, a saturable inductor L_2, a differentiator circuit C_2, and an impedance correcting network R_1, C_4, and R_2, L_3.

Pulses from the harmonic generator circuit are formed in the following manner. Initially, inductor L_2 is in a nonsaturated state and has a high impedance with respect to the series circuit L_1, C_1. This allows current to flow through L_1, C_1, and charge capacitor C_2. When the charge is sufficiently large, inductor L_2 saturates, becoming a very low impedance with respect to the rest of the circuit. Capacitor C_2 rapidly discharges through L_2 and the load, producing a pulse of short duration* each half-cycle of the 12-kc drive frequency.

Fig. 8 shows the group primary distribution circuit consisting of a filter and pad circuit, a 232A amplifier, and a primary distribution circuit.

The 232A amplifier, shown in more detail in Fig. 9, is a two-stage

* Selection of pulse width is treated in Appendix I.

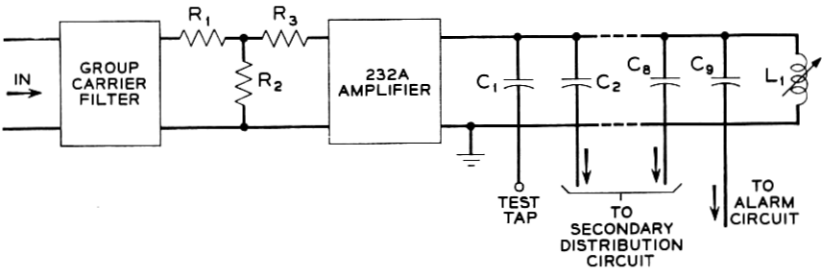

Fig. 8 — Group primary distribution circuit.

transistor circuit. The input stage utilizes a common-collector circuit while the output is a common-emitter stage. Local feedback, both shunt and series, is used in the output stage Q_2. Potentiometer R_9 provides a gain control to vary the gain of the amplifier between 22.5 and 27.5 db. Voltage regulation diode CR_1 provides stabilization of the output stage against battery variations. Transformer T_3 connects the output of the amplifier to the primary distribution bus.

The primary distribution bus (Fig. 8) supplies the group carrier frequency to six working taps, one test tap, one alarm tap, and one spare tap. The six working taps supply six group secondary distributing circuits, one located in the same bay, the others in five other bays. Inductor L1 is used to cancel the capacitive reactance of the tap capacitors and present a good resistive load to the 232A amplifier.

The group secondary distribution circuit, shown in Fig. 10, consists of a 230A amplifier and a distributing bus. It receives the group carrier

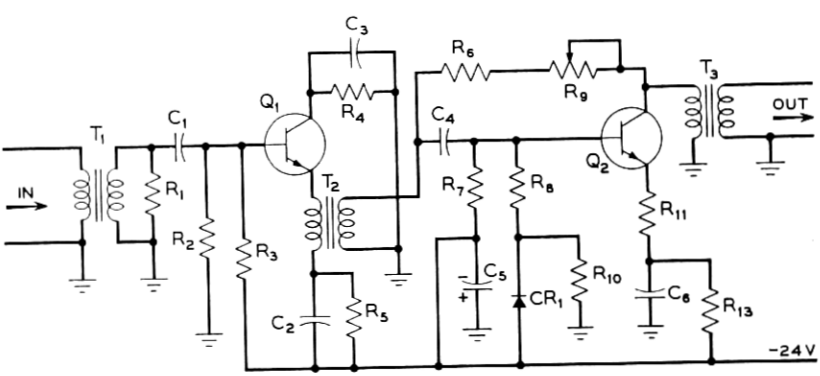

Fig. 9 — 232A amplifier circuit.

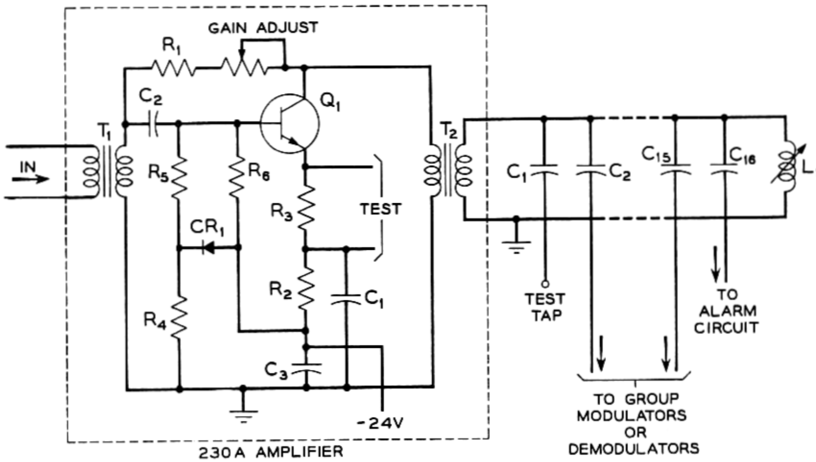

Fig. 10 — Group secondary distribution circuit.

frequency from the primary circuit and distributes it locally to the group modulators or demodulators as required. The amplifier is a single stage of power amplification required to raise the power to distribute locally in the bay. The circuit is a common-emitter stage employing both shunt and series feedback. Gain control is in the shunt feedback path to adjust the gain between 9.5 and 14.5 db. Stabilization of the gain of the amplifier against battery voltage variation is attained by use of a zener diode (CR_1).

The distribution bus has 16 taps: 13 working, one test, one alarm, and one spare. The group 5 spare tap feeds a Supergroup 1 modulator or demodulator.

5.5 *Supergroup Carrier Supply*

Like other parts of the carrier supply, the supergroup carrier supply is intended for use in both L600A and L1860A terminals. In the case of the supergroup supply, however, certain parts are optional, having application to a specific terminal.

When used with the L600A terminal, a 124-kc harmonic generator with appropriate filters makes available seven frequencies ranging from 1116 kc (SG3) to 3100 kc (SG10) as shown in Fig. 11. An eighth supergroup frequency, 612 kc (SG1), not a harmonic of 124 kc, is furnished by the group carrier supply. One supergroup requires no carrier (SG2), and two supergroups share one carrier frequency (SG6, SG9).

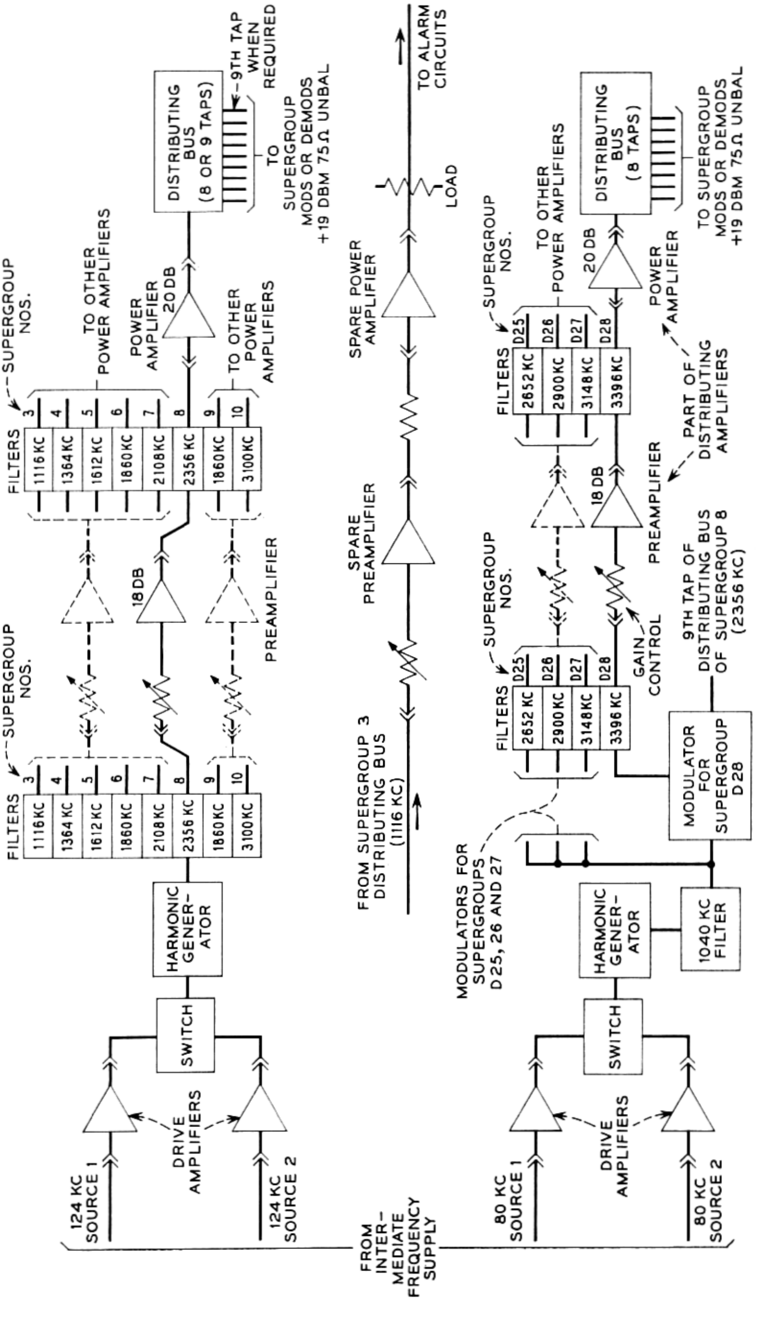

Fig. 11 — Supergroup carrier supply.

In an L1860A multiplex, four other frequencies shown in Fig. 11 are required which are not harmonics of 124 kc. These frequencies are obtained by mixing 1040 kc with the frequency used also for supergroup 5, 6, 7, or 8. An additional harmonic generator with an input frequency of 80 kc is made available as a source of 1040 kc. The 80-kc and 124-kc inputs required for the supergroup supply are provided by the intermediate frequency supply as previously described.

Both harmonic generators,* like the 4- and 12-kc generators, make use of saturable inductors to generate the pulses from which the supergroup frequencies are derived. Consider the 2356-kc frequency, for example. The small size of the saturable inductor limits the output of this frequency to +4 dbm at the output of the first section of the filter shown in Fig. 11. The harmonic generators are driven by an amplifier which will be referred to as the "drive" amplifier. The design of the drive amplifier is very similar to that of the power amplifier of the distribution module described later. The output of the amplifier is stepped up in voltage in the double-tuned circuit which couples the amplifier to the saturable inductor. The selectivity of this circuit causes the saturable inductor to be driven by a symmetrical wave, thereby equalizing the spacing between positive and negative pulses to insure predictable amplitude of the desired harmonics. Bandpass filters are used to select harmonics corresponding to the desired supergroup frequencies; these suppress adjacent harmonics by about 70 db.

Each distributing bus of the supergroup carrier supply drives eight modulators and/or demodulators at a level of +19 dbm. Even though supergroups 6 and 9 share the same carrier frequency (1860 kc) these supergroups are supplied from separate amplifiers and distribution busses. Uniform operation of the amplifiers, resulting in lower power transistor junction temperature, and uniform test procedures outweigh the economy to be gained by doubling the output of a single amplifier at 1860 kc.

A distribution amplifier is shown in Fig. 12. An operating power gain of 37 db is required to raise the +4 dbm level of harmonic output to +29 dbm while overcoming an average 12 db loss in the gain control, second half filter and pad. Amplifiers meeting these requirements are referred to as distribution amplifiers. These are designed for plug-in connection to simplify the stocking of spare amplifiers, and have sufficient bandwidth so that the single design suffices for all supergroups.

The distribution amplifier is subdivided into two separate amplifiers: a preamplifier and a power amplifier. This arrangement allows some

* These operate similarly to the 12-kc harmonic generator described under "group carrier supply."

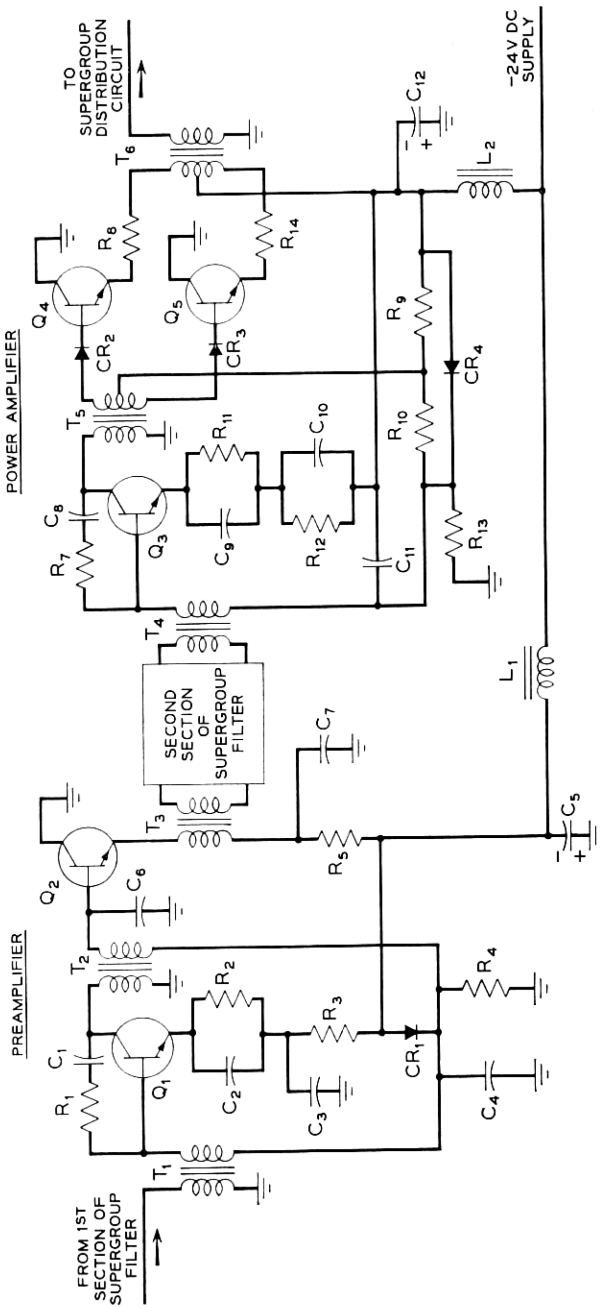

Fig. 12 — Supergroup carrier distribution amplifier circuit.

selectivity to be introduced between the two amplifier sections to filter out noise generated in the preamplifier and falling in the transmission band. To obtain this selectivity, the harmonic selection filter previously referred to is arranged as a two-part filter. The part preceding the preamplifier provides selectivity against harmonics, while the part following the preamplifier provides selectivity and also filters out noise.

The preamplifier is transformer-coupled with two transistor stages having an insertion power gain of 18 db. A frequency shaping network, part of the common emitter bias circuit of the amplifier, provides equalization over the supergroup carrier frequency range. The shunt (C_1, R_1) and series (C_2, R_2) feedback of the first stage are proportioned to control the impedance terminating the filter. The low output impedance of the common-collector second stage terminates the input side of the second half of the filter through transformer T_3.

The power amplifier is a similar two-stage broadband amplifier with an operating power gain of 20 db. The first stage drives a class AB common-collector push-pull power stage. Under normal operating conditions the output power delivered by the amplifier is less than its power capability. By operating the push-pull output stage as a class AB stage a saving in emitter current is realized. Any reduction of current in the power transistors is important, as there is a corresponding reduction of transistor junction temperature. The junction temperature is kept within proper operating limits by attaching the common-collector power transistors through an aluminum block to the chassis frame.

The distribution circuit combines a tuned impedance transformation circuit with a capacitive type distribution bus. Tuning is provided to reduce harmonics. The distribution bus is designed to furnish +19 dbm to each of eight modulators and/or demodulators. Resistive loads are provided to terminate unused bus taps.

When the supergroup carrier supply is part of an L1860A multiplex, supergroups 9 and 10 are not required. Supergroups D25, D26, D27, and D28* are added and require, as previously mentioned, a source of 1040 kc for their formation.

The four added supergroup carriers (2652, 2900, 3148, and 3396 kc) are obtained by mixing 1040 kc with the carrier frequencies of Supergroups 5 through 8 (1612, 1860, 2108, and 2356 kc). The 80-kc harmonic generator required to generate 1040 kc differs from the 124-kc harmonic

* In the L3 carrier system, supergroups 25 through 28 were formed using two stages of modulation. In the application of L multiplex to L3 carrier systems, new carrier frequencies have been made available so these supergroups could be handled just as any other supergroup; for example, SG5 or SG8. The new supergroups are identified by the letter D, D25 through D28. New and old systems are compatible.

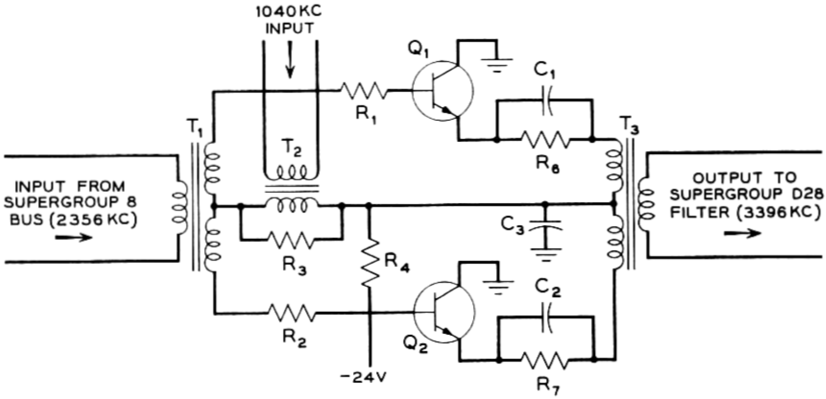

Fig. 13 — Modulators for directly formed supergroup carriers.

generator only with respect to frequency-selective components. The same drive amplifier may be plugged into either harmonic generator, and the protection and alarm circuits of both generators are identical.

The four modulators required to generate the new directly formed supergroup frequencies are identical; Fig. 13 shows the modulator for supergroup D28. A transistor modulator was chosen to secure some power gain, and this modulator is balanced to minimize interaction between 1040 kc and the supergroup frequencies with which it is mixed.

5.6 *Protection and Alarm Features*

A protection and alarm system is provided for the group and supergroup supplies, (1) to actuate office alarms whenever any carrier power falls below a preassigned level, (2) to light a lamp to identify the unit which has failed, (3) to provide automatic switching to a second source of input to the harmonic generator in cases of failure of either source, and (4) to provide a major alarm when all circuits associated with a harmonic generator fail.

With the exception of the channel carrier supply, which uses the 4-kc primary frequency directly, inputs to all L multiplex carrier supplies require frequency multiplication of the 4 kc in the intermediate supply. For maximum reliability, therefore, parallel circuits are provided. It would take a simultaneous failure of both amplifiers to disable the group and supergroup carrier and pilot supplies. Alarms are provided for each circuit to detect a failure.

The 12, 80, and 124-kc outputs of the intermediate circuit are each double-fed through separate drive amplifiers and relay contacts to the group and supergroup harmonic generators. In each case the relay contacts select the output of only one amplifier to drive the harmonic generator. The relays are controlled by the output of the associated "drive" amplifier. The relay control circuit of the L600A supergroup supply, which is typical, is shown in Fig. 14. This figure has been simplified by the omission of contact protection and other circuit refinements not essential to the understanding of the circuit. It will be seen from this figure that a portion of the output of each drive amplifier is rectified for the operation of a relay. These relays (K_1 and K_2) are held operated as long as the outputs of their respective amplifiers do not fall below a preassigned level.

The output of the no. 1 drive amplifier is shown connected to the harmonic generator circuit through contacts of relay K_4. Assume this drive amplifier fails; its associated relay K_1 releases, applying current to the polarized relays K_3 and K_4. The contact springs, which move in the direction of the arrow when positive voltage is applied at (x), connect drive amplifier no. 2 to the harmonic generator. A second circuit closed by the release of K_1 lights the amber alarm lamp DS3, causing current to flow through pulse transformer T_1. The build-up of current in the primary of T_1 causes a pulse of secondary voltage which passes through the diode gate CR_5 to the minor alarm circuit.

When the trouble has been cleared and drive amplifier no. 1 is reconnected, relay K_1 pulls up, extinguishing the amber minor alarm light. To avoid a service interruption at this time, relay K_3, in the absence of current through its windings, holds its last operated position by means of a permanent magnet latch. It would take a current of the opposite polarity, as caused by the failure of drive amplifier no. 2, to cause the relay contacts to return to their original position. Amplifier no. 1 is not restored to service, but is connected to the green ready lamp DS_1, which doubles as a standby load. Amplifier no. 2 continues as the working amplifier until it fails.

Failure of both drive amplifiers, causing release of the K_1 and K_2 relays, permits current to flow through resistor R_3 and the winding of the major alarm relay K_5. Operation of the major alarm relay lights the red major alarm light DS_5 and sends a pulse of current to the major alarm circuits through pulse transformer T_2. It will be seen that the break contact of this relay supplies current to the minor alarm lamps of the supergroup distribution modules. These are locked out, since they would convey only misleading information.

The group and supergroup supplies each require an amplifier ahead of the distribution bus for each frequency. The output of each of these

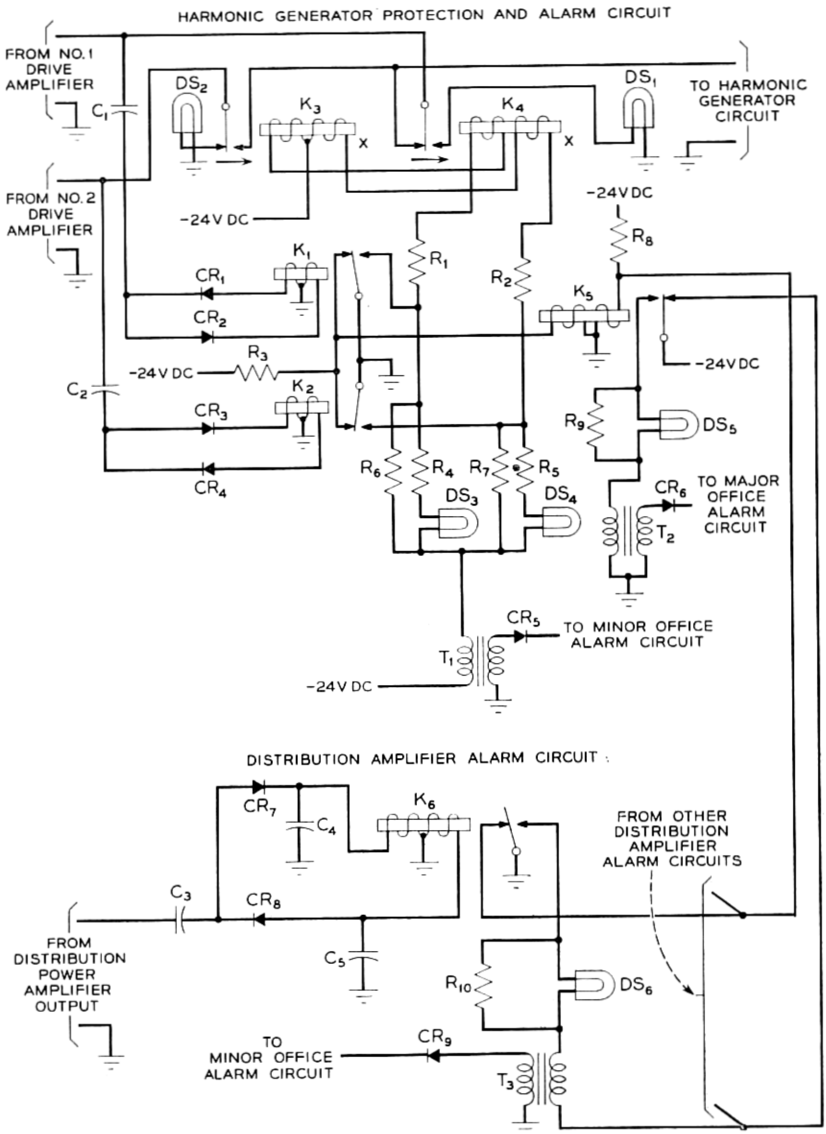

Fig. 14 — Supergroup carrier supply protection and alarm circuit.

distribution amplifiers is monitored by a full-wave rectifier and level-sensing relay similar to that already described. The supergroup distribution amplifier alarm circuit, which is typical, is also shown in Fig. 14. The make contact of relay K_6 of this circuit prevents operation of the major alarm relay K_5. To operate the major alarm relay K_5, all distribution amplifier outputs must fail. When any distribution amplifier fails, the relay of its alarm circuit releases, lighting the amber minor alarm light DS_6 and causing current to flow in the primary of the pulse transformer T_3. The secondary pulse passes through the diode gate to the minor alarm circuit. The major and minor alarm pulses referred to are converted to relay closures for operation of the standard office alarms by a centrally located office alarm amplifier. The principal advantage of the pulse alarm system is that each trouble sends but one pulse to the office alarm amplifier. In effect, every branch of the alarm circuit has an instantaneous automatic reset.

The control circuit for the 12-kc (group) and 80-kc (directly formed supergroup) supplies will not be described, as these control circuits are basically the same as those of the L1860A supergroup carrier supply.

Since the channel carrier supply is located with the channel banks rather than with the group and supergroup multiplex, the channel carrier alarms are arranged to couple independently to the standard office alarm system.

VI. EQUIPMENT DESIGN

6.1 *Introduction*

To complement the new carrier supply circuits, a completely new equipment approach has been conceived. This consists of an efficient modular packaging technique and, even more fundamentally, a decentralization of the equipment.

The old carrier supply design, because of the dictates of cost, component sizes, and reliability requirements pertaining to large offices, had been considered common equipment, analogous to the office battery supply. Separate bays were required for the pilot supply, channel, group, and supergroup carrier supply equipment. These bays were all dependent on the harmonic generator which was located in the channel carrier supply bay. Because of this and the stringent cable loss and crosstalk requirements, considerable constraint was placed on office layouts of L-terminal equipment. However, since floor space savings were not the primary objective of the old design, it was more than adequate. When we reflect on the large telephone office expansion of the past decade as well as the predictions of further increases, we realize that a reduction in the size of the carrier supply equipment and interbay cabling is now necessary.

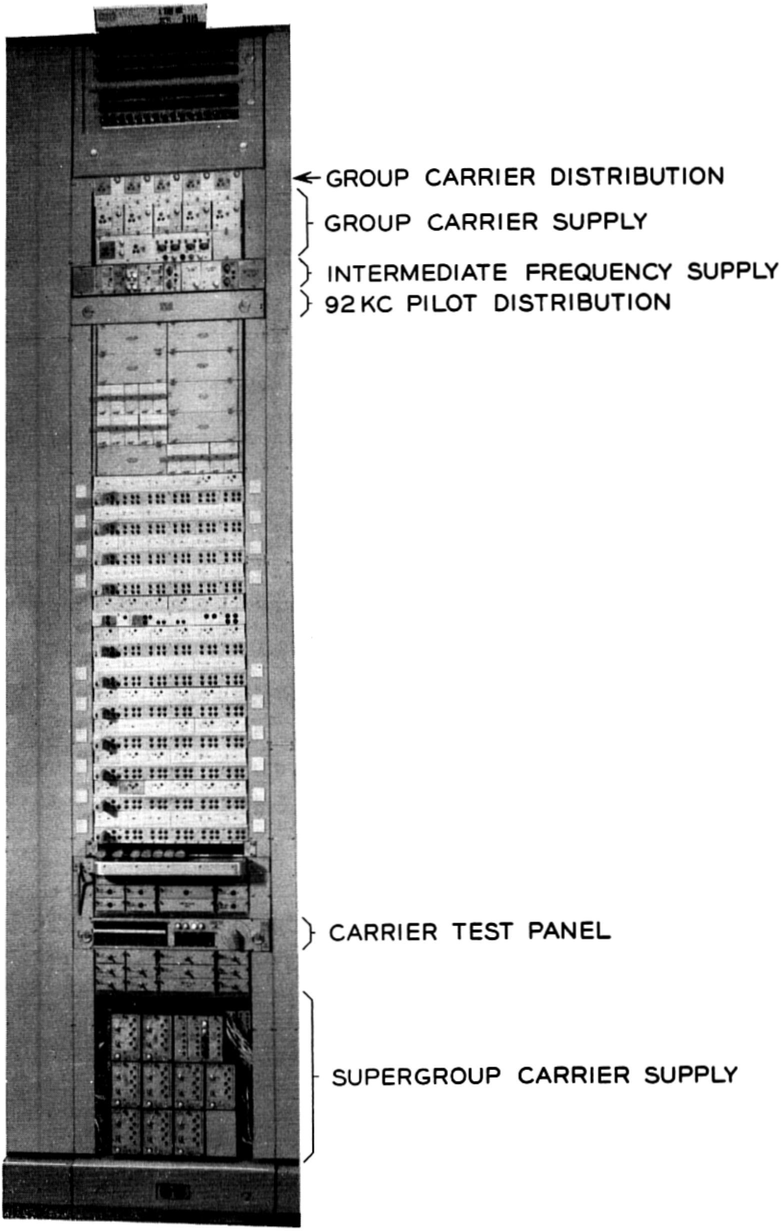

Fig. 15 — Carrier supply in transmit bay.

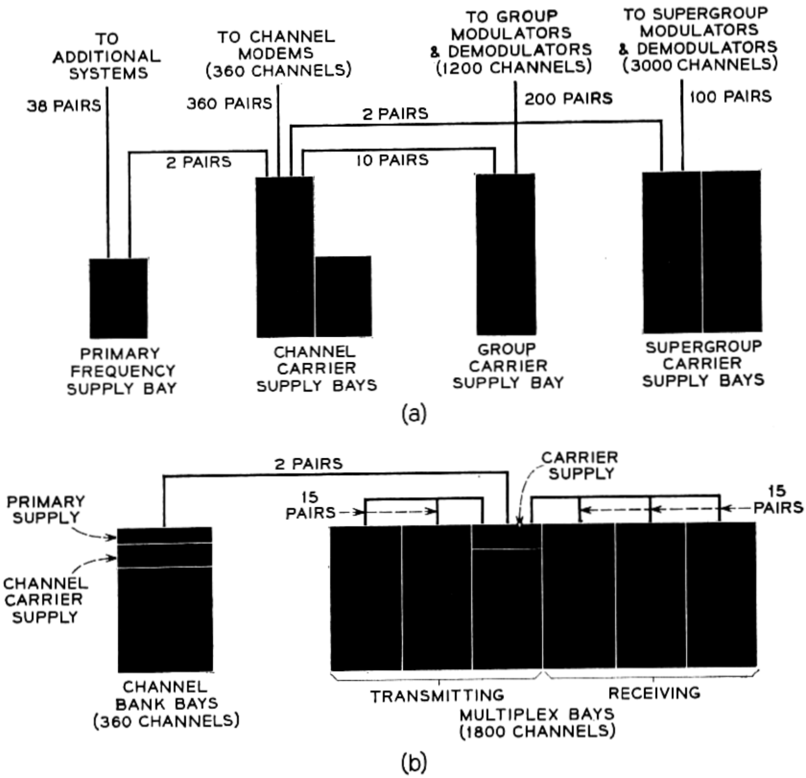

Fig. 16 — Cable comparison.

6.2 *Bay Arrangements*

The philosophy of decentralization, as applied to the transistor carrier supply designs, consists primarily of combining the carrier and pilot generators, amplifiers, and distribution facilities with, or in the immediate vicinity of the associated transmission equipment. The common portion of the carrier supply for three transmitting and three receiving multiplex bays is located in the first transmitting bay. This is shown in Fig. 15.

Since channel banks are located in the equipment area of the office and the group and supergroup bays of the transistor multiplex in the maintenance or patching area, separate, independent harmonic generators have been provided. This permits the elimination of the major part of the interbay cabling and replaces it with intrabay wiring, resulting in large savings in the cabling costs as well as needed relief for

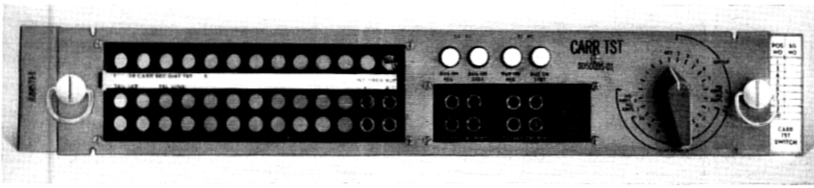

Fig. 17 — Carrier test panel.

offices with cable congestion problems. A cable comparison between the old and the new carrier supply is shown in Fig. 16.

The carrier and pilot supply equipment required for the group and supergroup multiplex bays is divided into the following units: intermediate,* group, and supergroup. Each unit is factory assembled, wired, and tested and mounted as part of the shop-wired bay, thereby reducing costly installation effort. Each design has been patterned specifically for use in floor-saving back-to-back bay lineups. Active equipment is connected into the bay circuits on a plug-in basis which permits rapid service restoration and planned growth with minimum investment in equipment for the initial channels.

In addition to the inherent reliability obtained through careful system design and selection of high quality components and connectors, alternate units are automatically switched into service in the event of a failure affecting more than 360 channels. Consistent with the current protection philosophy, for circuits common to a lesser number of channels, monitored spare units are provided as a standard part of the equipment.

The extensive use of in-service testing as well as convenient test facilities have greatly eased the maintenance burden. An example is a new carrier test panel, shown in Fig. 17, which permits measuring all carriers on a switch basis. Supplementary outlets are also provided to obtain a 64- and 92-kc frequency for test set calibration.

Up to this point the carrier supply equipment described has been primarily for the groups and supergroups. Of equal importance is the channel carrier supply, which has also been miniaturized to the extent that it is now a part of the channel bank bays. A standard three-bay layout is shown in Fig. 18.

This new arrangement includes the channel bank equipment, carrier supply, and fusing for 360 channels and facilities for mounting the primary frequency supply (in place of one channel bank) when required. The channel banks are the transistor A5 type, which have been in regular

* The intermediate supply is here taken to include the pilot supplies.

Fig. 18 — Arrangement for 30 A5 channel banks and associated carrier supply.

production since the Fall of 1960.[9] By dispersing the carrier supply over two bays and increasing the fuse panel capabilities, ten channel banks are mounted in each bay. Since a majority of the connections are voice connections to 4-wire patch bays and since channel banks are often provided singly, channel bank bays are not shop-wired. The channel modem units are removable. Consistent with this and the over-all multiplex design philosophy, active units of the channel carrier supply are plug-in. This supply is independent of the group and supergroup carrier supply, generating and distributing all channel carriers locally.

To summarize, fourteen 11′-6″ bays of carrier supply equipment were formerly required to provide channel, group, and supergroup carriers for 1860 channels. If the new transistor carrier supply were concentrated it would occupy slightly over one-half a bay. The part this plays in the future growth and planning for L multiplex facilities is quite apparent. Often miniaturization has resulted in higher equipment costs with the counter-balance being the floor space saved. Such is not the case with the multiplex equipment where lower unit costs were also achieved.

6.3 *Apparatus Mounted in Plastic*

The various equipments that comprise the carrier supply have been packaged in a manner consistent with the approach used in the associated transmission equipment. However, because of the wide range of carrier and pilot frequencies and the power requirements, some design latitude was necessary. A further design consideration was the relatively low demand of most of the carrier supply units as compared to most of the transmission units. This generally eliminates the use of mass production techniques since they become inefficient and therefore uneconomical in such situations. To counteract this, a process developed by the Western Electric Company and nicknamed "AMPLAS" was selected for much of the packaging.

Fundamentally, this process consists of hand- or machine-inserting components, by their pigtails, into a soft CAB* mold. A thermosetting epoxy material is poured into the mold and hardened. The CAB mold is stripped away from the assembly, leaving the epoxy board holding the components. Pencil wiring is used for interconnections with each connection individually soldered; however, mass soldering techniques are contemplated for the future.

Figs. 19 and 20 show the apparatus and wiring sides respectively of a typical carrier supply board. Based on experience to date, this packaging method has proven to be very economical.

In view of the similarity in construction of many of the specific carrier supply designs it would serve no useful purpose to describe them all; therefore, only a representative sample will be discussed in more detail.

6.4 *Group Carrier Supply*

The function of this unit is to generate, amplify, and distribute the five group carriers to secondary or local bay distributing facilities which in turn supply group carriers for 1860 channels. A photograph is shown in Fig. 21.

This is a completely shop-assembled, wired, and tested package. All

* Cellulose Acetate Butyrate.

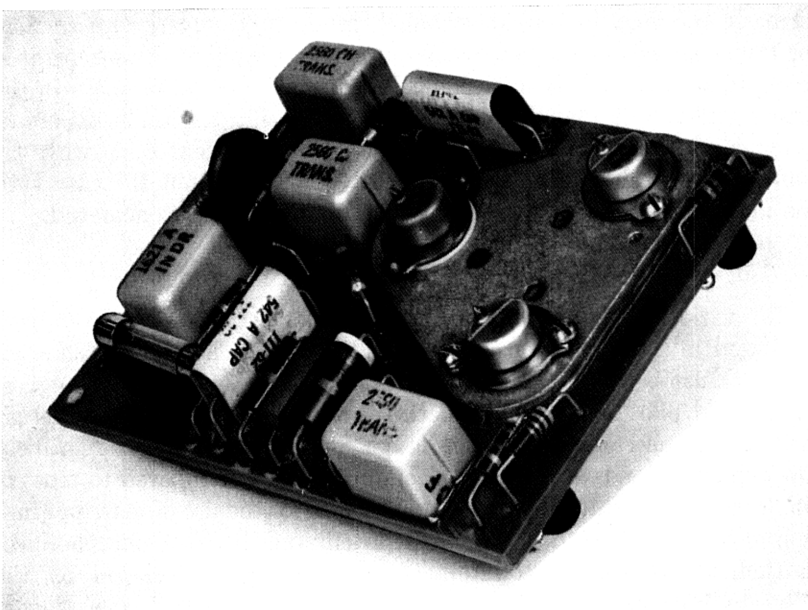

Fig. 19 — Amplas board — apparatus side.

Fig. 20 — Amplas board — wiring side.

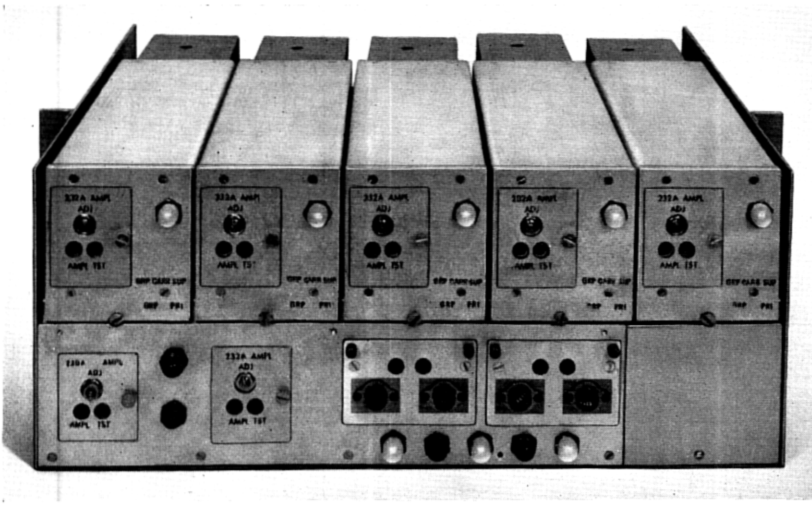

Fig. 21 — Group carrier supply.

active units are plug-in and in the case of the 12-kc amplifiers alternate units are automatically switched into service in the event of a failure. The lower shelf of this two-tier assembly contains a drawer-type chassis that includes the two 12-kc amplifiers, harmonic generator, alarm boards, and monitored spare distribution amplifiers. This arrangement provides for relatively easy replacement of even the passive components. Visual alarm indications previously described are provided on the front face to aid in making a quick determination of equipment troubles.

The upper shelf contains the five group distribution modules. Each module, complete with filter, amplifier, and distribution bus, is connected into the circuit by means of a plug. In this instance, the plug-in feature was used to facilitate the intra-panel wiring with the ability to replace defective modules coming as an added benefit.

A view of a module with the cover removed is shown in Fig. 22. Note the open chassis, which permits all shop connections to be made with a minimum of effort. The previously described AMPLAS-type board is used for the distribution bus.

Each module contains a 232A amplifier, shown in Fig. 23. This amplifier is used in any of the five group modules and can be replaced without removing the complete module. The rather large heat sink provided for the power transistor is connected directly to the front face in order to transfer heat quickly to the front radiating surface.

The complete group carrier supply is provided as a unit for the L600A

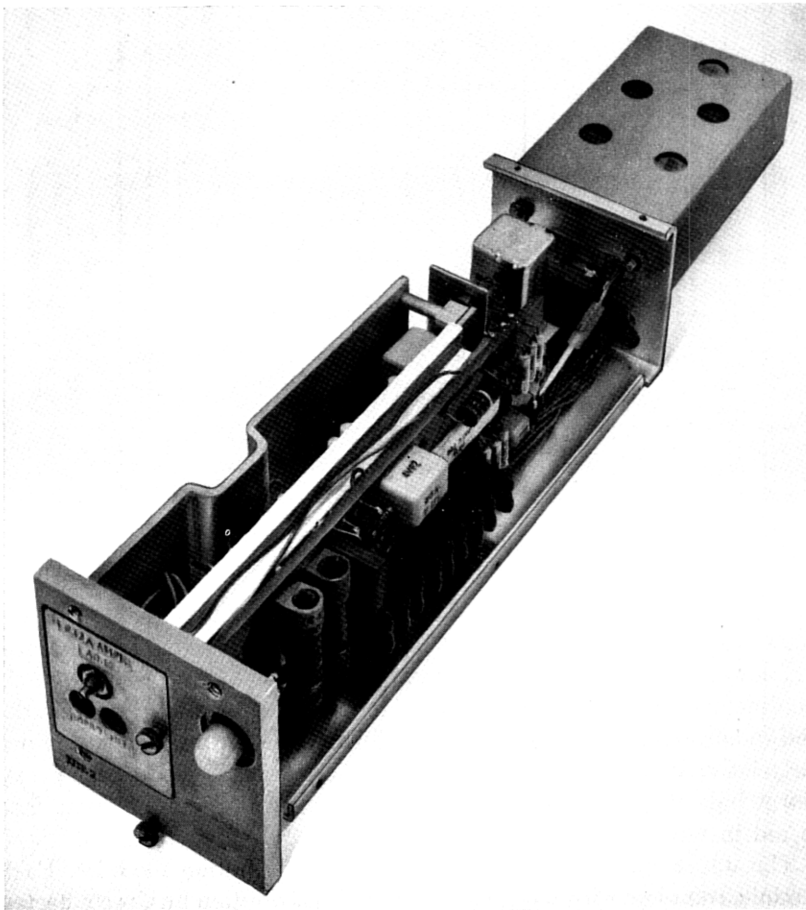

Fig. 22 — Group carrier primary distribution module.

multiplex bay; however, it is possible to provide a partial supply if desired by merely omitting modules.

6.5 *Supergroup Carrier Supply*

The design of the supergroup carrier supply presented one of the more challenging equipment undertakings since, in addition to miniaturization, it was necessary to have maximum flexibility for the ten-supergroup L600A application as well as the thirty-one supergroup L1860A application.

The complete supergroup carrier supply unit generates, amplifies, and distributes the supergroup carriers directly to the modulators and

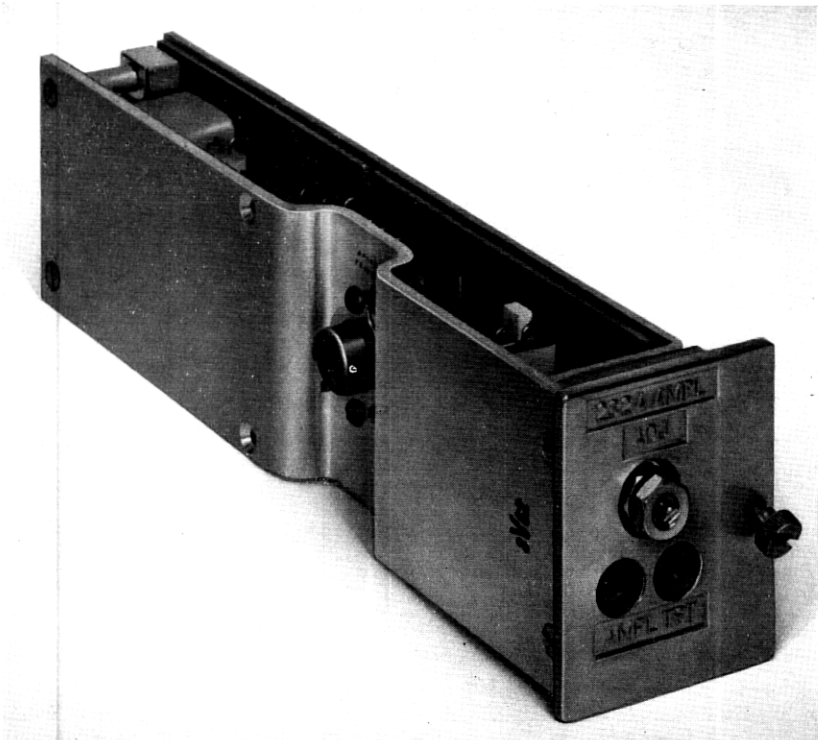

Fig. 23 — 232A amplifier.

demodulators. The shelf arrangement, shown in Fig. 24, is capable of providing all the necessary supergroup frequencies for any standard L600 application. The frequencies not required for a particular circuit arrangement need not be provided, but they can easily be added at a future date with a minimum of installation effort.

The three shelves are designated A, B, and C. The A shelf contains the 124-kc harmonic generator and the distribution modules for two carrier frequencies. The B and C shelves are primarily for mounting the remaining regular and spare distributing modules. For L1860A, a different A shelf containing the 80- and 124-kc harmonic generators and one distributing module is provided. Also a fourth shelf is added to provide distribution facilities for the four additional carriers required to directly form the upper supergroups.

Each shelf is a separate shop-wired unit with outside connections made through miniature coaxial plugs and jacks. Following the general multiplex pattern the amplifiers are plug-in, with harmonic generator

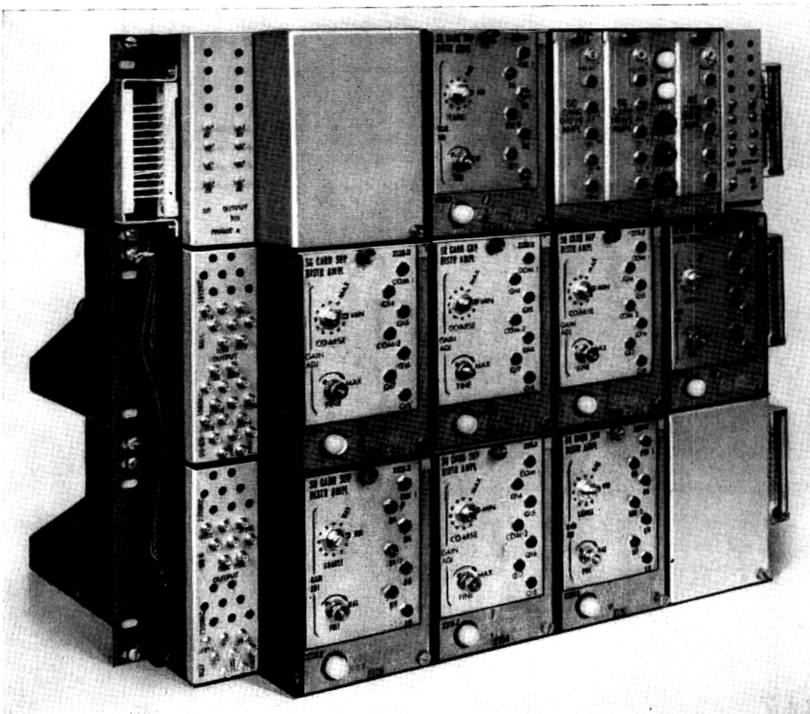

Fig. 24 — Supergroup carrier supply.

amplifiers protected on an automatic switch basis. The distribution amplifier, shown in Fig. 25, is identical for all frequencies; in fact, it contains the preamplifier and power amplifier on a common frame. The three transistors of the power amplifiers are mounted on a single triangular aluminum block which is in solid contact with the chassis to facilitate heat transfer.

All test outlets, adjustments, and output connections are located on the front surface for ease of maintenance. Each module contains a visual alarm indication to aid in quickly locating a defective unit. As the installation grows, additional outputs serving up to 1860 channels may be obtained from connectors located on the side distribution panels.

6.6 *Channel Carrier Supply*

The channel carrier supply is comprised of two separate major units: the channel harmonic generator and filter unit and the channel carrier distribution unit. In an ideal arrangement these will be located at the

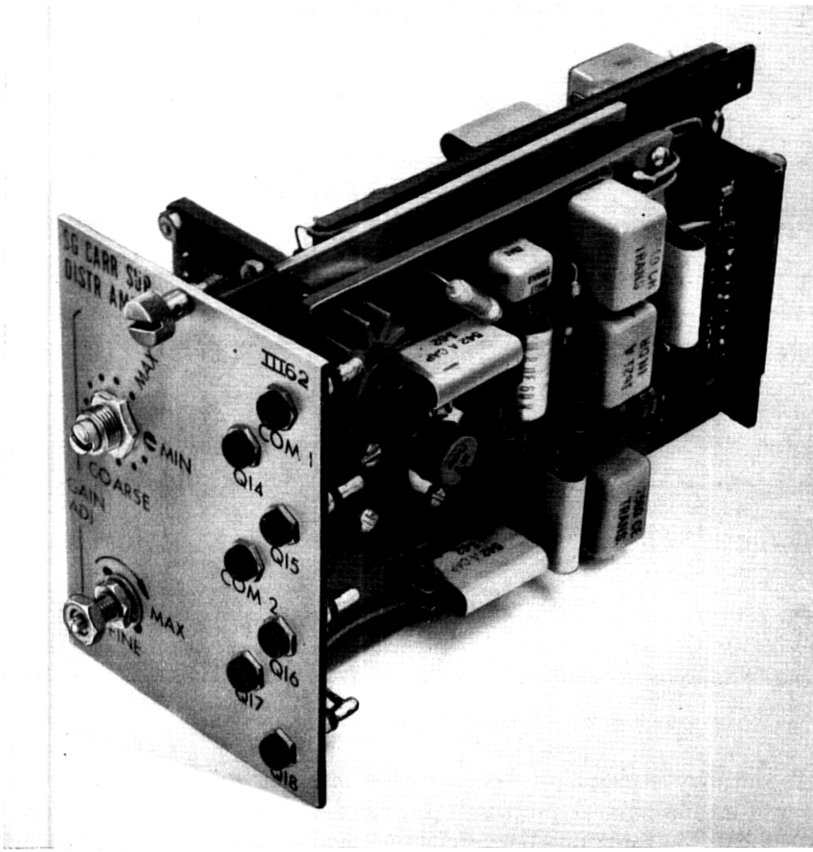

Fig. 25 — Supergroup carrier distribution amplifier.

top of adjacent bays. The channel carrier supply, as mentioned earlier, is located with the channel banks in the equipment area.

The generator and filter assembly departs from the module arrangement and follows the door-type structure of the A5 channel banks. It contains the amplifier, harmonic generators and filters necessary to supply channel carrier frequencies to 360 channels. The working amplifier is plug-in, and space is available for a spare monitored amplifier. Currently it is recommended that one spare amplifier be provided for each five regulars. All maintenance is from the front since these bays may be located in back-to-back lineups.

The distribution unit presented a design problem which is becoming increasingly common in this age of miniaturization when the component size reductions are not followed by equivalent cable reductions. This

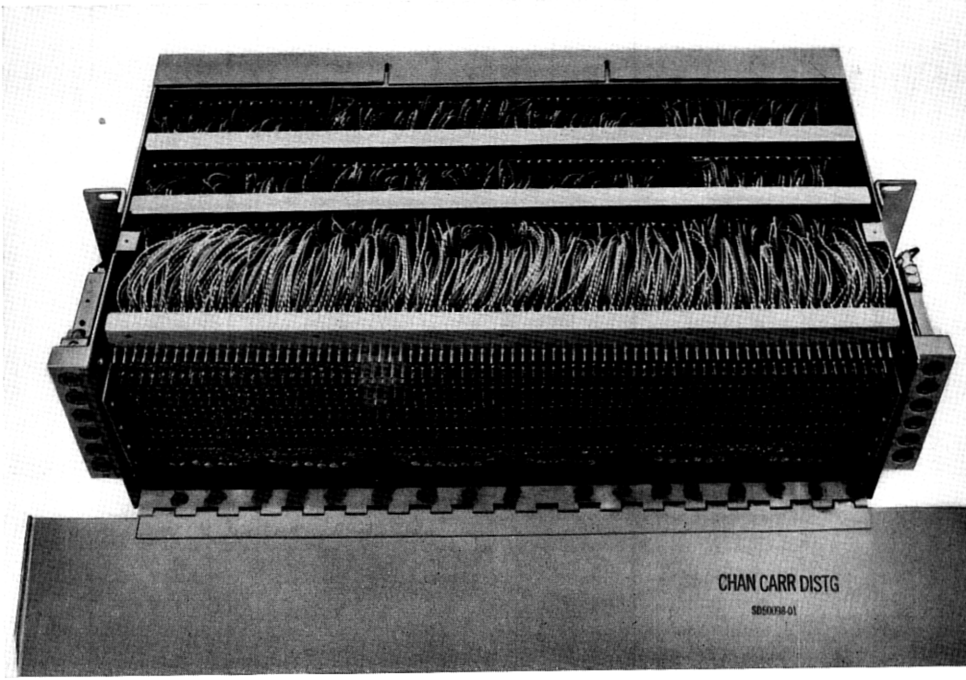

Fig. 26 — Channel carrier distribution unit.

will continue to plague us, because cable size reductions involve circuit as well as mechanical problems. In the distribution assembly, shown in Fig. 26, the same number of channel modems as in previous designs is supplied; however, the old design required about one bay of mounting space as opposed to 12 inches for the new design.

Means have been provided for the installer to connect 360 shielded pairs of wire to a terminal strip which terminates all distribution bus outputs. A screw-type adjustment similar to that used on the A5 channel bank and E6 repeater is available to facilitate adjusting the bus level as additional taps are used. Formerly this required a soldering operation. An additional feature is the jacks provided on the front of the panel for measuring the levels of the twelve distribution busses.

VII. CONCLUSION

A laboratory model of the carrier supply has been on field trial at Dallas, Texas, since March, 1962, with satisfactory results. The first commercial L600A installation, on a TJ microwave route in New Jersey, was cut into service in sections from July through September, 1962.

Fig. 27 — Pulse train.

VIII. ACKNOWLEDGMENTS

The system described here, as with the rest of the multiplex, is the result of the efforts of many people in several departments of the Bell Telephone Laboratories; specifically Systems Engineering, Systems Development and Device Development. Although unable to cite all those who participated in this design, the authors wish to acknowledge particularly the substantial contributions of F. C. Kelcourse and T. J. Haley in the circuit design area, and M. F. Stevens and L. F. Travis in the equipment design area, in addition to the authors of the companion papers.

APPENDIX

Selection of an appropriate pulse width for the harmonic generator circuits was investigated early in the design of the new multiplex carrier supply. In the old carrier supply this choice was somewhat restricted since the 4-kc harmonic generator supplied all of the channel and group carriers and was chosen primarily on the basis of generating sufficient power for the channel carrier supply, thus eliminating the need of channel carrier amplifiers. As a result, group carriers exhibited a negative slope-versus-frequency characteristic.

With the decentralization of the carrier units in the new multiplex and the specialized harmonic generators for the channels, groups, and supergroups, different pulse widths could be selected to best fit each application.

If one considers a continuous series of pulses as shown in Fig. 27* with a period $T = 1/f_R$, amplitude A and pulse width P and, further, that each pulse is perfectly rectangular, one can completely specify the harmonic content of any given pulse width P in the frequency interval of interest. From Fourier analysis, one can then define the wave function as:

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* The pulses feeding the "even" channel carrier filters may be represented directly by the described pulse train. Other pulses in the carrier supply may be synthesized by linear superposition of two pulse trains with amplitudes of opposite signs.

$$f(t) = \sum_{n=1}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t)$$

where

$$a_n = \frac{A}{n\pi} \sin nP \qquad (P \text{ in radians at } f_R)$$

and

$$b_n = \frac{A}{n\pi} (1 - \cos nP).$$

TABLE I

(a) Channel and Intermediate Supply

Amplitude of Harmonic Relative to Fundamental Pulse of Unit Amplitude and Frequency of 4 kc

Pulse Width (μs)		1	2	3	4
Harmonic Frequency (kc)	64	0.0079	0.0155	0.0225	0.0286
	108	0.0078	0.0148	0.0200	0.0231

(b) Group Carrier Supply

Amplitude of Harmonic Relative to Fundamental Pulse of Unit Amplitude and Frequency of 12 kc

Pulse Width (μs)		1	2	3	4
Harmonic frequency (kc)	420	0.0176	0.0088	0.0132	0.0154
	612	0.0117	0.0080	0.0062	0.0123

(c) Supergoup Carrier Supply

Amplitude of Harmonic Relative to Fundamental Pulse of Unit Amplitude and Frequency of 124 kc

Pulse Width (μs)		0.1	0.5	1.0	2.0
Harmonic Frequency (kc)	1116	0.0241	0.0694	0.0241	0.0454
	1612	0.0237	0.0281	0.0460	0.0316
	2108	0.0230	0.0056	0.0110	0.0210
	3100	0.0210	0.0027	0.0053	0.0104

In terms of the pulse parameters, the peak amplitude of any harmonic "n" is given as:

$$A_n = \frac{2A}{n\pi} \sin n\pi f_R P \qquad (P \text{ in units of time consistent with } f_R).$$

Table I shows an evaluation of the above expression for various pulse widths for both the channel (and intermediate), the group, and the supergroup carrier supplies. The numbers in Table I represent the relative amplitudes of the harmonics with respect to the pulse amplitude "A."

For the channel carrier supply a pulse width of 4 μsec was chosen as a good compromise between slope and amplitude. For the group supply 1 μsec was selected and 0.1 μsec was used for the supergroup carrier supply.

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