Circuit Design of the N3 Carrier Terminal

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In the circuit design of the N3 carrier terminal full use has been made of the advances in solid state art, crystal filter design techniques, and miniature ferrite transformer performance. Economies have been provided in power consumption, space requirements, and maintenance effort. Performance has been significantly improved over its predecessor the ON2 terminal in the areas of channel response, net loss stability, compandor tracking, and modulation distortion. Two concepts, new to the short-haul carrier field, have been employed in the N3 design. Frequency correction circuits are used to precisely correct for frequency shifts accumulated as the signal is transmitted over the N-repeatered line. A common carrier supply is utilized to provide extremely precise carriers economically for terminal use.

I. INTRODUCTION

During the late 1950's short-haul carrier systems began to undergo a comprehensive modernization program. The primary objective of this program was to achieve significant improvement in reliability and transmission performance of the short-haul family in order to meet higher standards for transmission of message, program, and data or other special services over intertoll trunks. Equally desirable improvements were sought in the areas of miniaturization, reduced maintenance, economical installation, lower power requirements, and flexibility. The first two phases of this program have been completed with the introduction of the N1A repeater and the N2 terminal — a twelve-channel double-sideband system. The third phase, the N3 carrier terminal, is described from a circuit standpoint in this paper.

The N3 carrier terminal, a new 24-channel single-sideband system, was designed to provide a considerable transmission improvement over its predecessor the ON2 system. It has been engineered to provide a 3-dB channel bandwidth between 200 and 3450 Hz and a net loss stability of ±0.5 dB over extreme operating conditions. A large part of the performance improvements[1] have been made possible by the rapid growth of the solid-state device art. With the N3 terminal, several new system concepts have appeared for the first time in the short-haul family. A common carrier supply for many systems as opposed to individual per channel oscillators is utilized. This provides for the economical generation of many extremely precise carriers for terminal use. A second new concept is the frequency correction circuit which removes frequency shifts accumulated along the repeatered line. Improvements in both crystal filter design and ferrite core transformers have also played an important role in obtaining the superior performance in the N3 terminal.

II. CARRIER TERMINAL

2.1 *Transmitting Terminal*

A block diagram indicating frequencies within a transmitting terminal is shown in Fig. 1. The input voice-frequency signal is first compressed and then applied to a channel modulator circuit. The channel modulator translates the signal, selecting the upper sideband, into a 4-kHz slot in the 148 to 196-kHz range. The twelve resulting outputs when combined in the resistive combining multiple form a solid lay-up of signals in this spectrum. In addition, six transmitted carriers (152, 160, 168, 176, 184, and 192 kHz) are combined at a precise level with the signal in the multiple. This composite signal is translated a second time to the 36 to 84-kHz band by the channel group modulator. A second composite signal is similarly translated to the 84 to 132-kHz band by a second channel group modulator. The outputs of these two circuits are combined in a hybrid coil network to form a low group signal consisting of 24 4-kHz channels and 12 carriers. Depending on the type of group units used, this signal can be transmitted in either the 36 to 132-kHz or the 172 to 268-kHz band. The line terminating circuit is used to interconnect the group circuits and the carrier line. The circuit provides plug-in span pads to build out the loss of short cable sections. Secondary lightning protection is incorporated to limit surges to approximately 30 volts. Finally, the line terminating circuit provides a flexible means of simplexing power over the line to energize up to three remote transistorized N1A repeaters or one electron tube N1 repeater.

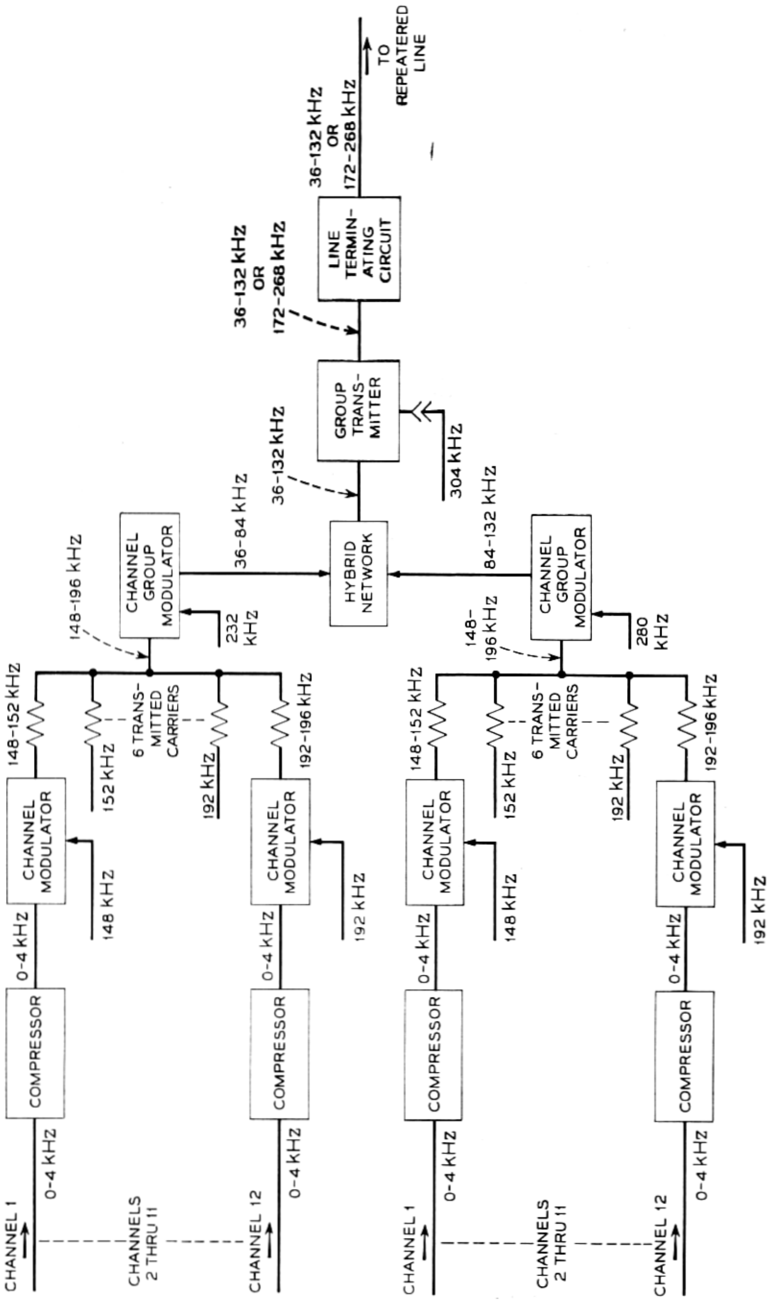

Fig. 1 — N3 transmitting terminal.

2.2 *Receiving Terminal*

A block diagram of the receiving terminal is shown in Fig. 2. The received signal is applied to either a low group or high group receiver circuit. The output is transmitted to the two channel group demodulators via a resistive splitting network. Each of the channel group demodulators selects and translates half of the low group band to the 148 to 196-kHz range. The appropriate carrier for demodulation is derived in the frequency correction circuit in such a fashion as to correct for any frequency shift in the incoming signal. The output from the channel group demodulator is applied to six double-channel regulator circuits. Each of the regulators dynamically compensates for over-all system gain variations on a pair of channels by regulating the carrier pilot between them to a precise level. Each of the dual outputs of the regulator circuit is applied to a channel demodulator circuit which contains a crystal channel band filter to separate a particular 4-kHz signal from the 148 to 196-kHz band. After demodulation to voice frequency the signal is applied to the expandor circuit which restores the original volume range.

A 48 to 21-volt power converter is used for powering each terminal. Since present types of transistors cannot efficiently operate with supply voltages much greater than 20 volts, approximately 50 per cent reduction in power dissipation is realized by using the converter. In addition, the converter contains a regulator circuit which provides an extremely well regulated voltage that is practically independent of wide fluctuations in the −48 volt central office battery. This feature essentially eliminates dependence of the net loss stability performance of the system on the office battery voltage variations. An alarm feature is also included to provide an indication when the converter output is out of limits.

III. COMPANDOR CIRCUIT

The companding technique is utilized to gain a noise and crosstalk advantage to achieve satisfactory transmission performance using the economical N-type repeatered lines. The compandor consists of two complementary circuits: a compressor in the transmitting terminal and an expandor in the receiving terminal.

The compressor reduces the range of signal volumes at its input by a factor of two. This is accomplished by a diode shunt variolosser followed by a constant gain three-stage feedback amplifier. A portion of the output of the amplifier is rectified and used as the control

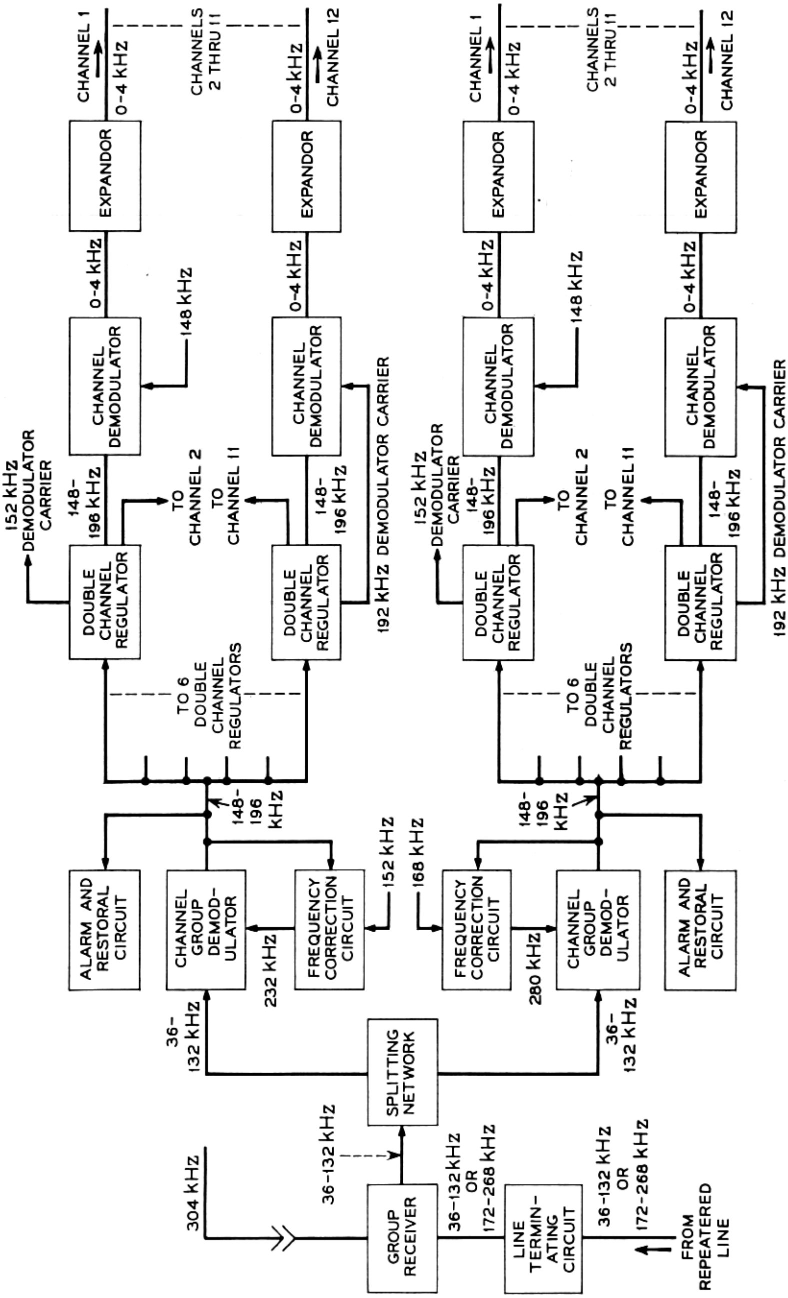

Fig. 2 — N3 receiving terminal.

signal to the variolosser. The action is such that the stronger signals are relatively unchanged while the weaker tones are raised in level. Thus, for a 60-dB input range, the output varies by only 30 dB.

The expandor increases the range of signal volumes that it receives at its input by a factor of two. This is accomplished by a series diode variolosser followed by a three-stage feedback amplifier. A portion of the input signal is amplified in a control amplifier, rectified, and used as the control signal to the variolosser. The action is such that the stronger signals are relatively unchanged while the weaker tones are lowered in level. Thus, for a 30-dB input range the output varies by 60 dB.

When a compressor in the transmitting terminal is followed by an expandor in the receiving terminal, the original volume range is restored with a tracking error which is typically less than 0.2 dB. The compandor used in the N2 carrier system, which from a circuit standpoint is identical to the N3 compandor, is described in detail in another article.[2] It is noteworthy that the expandor contains the only channel gain adjustment used for normal lineup and maintenance.

IV. CHANNEL MODEM CIRCUIT

4.1 *General*

The channel modem circuit consists of both the transmitting channel modulator circuit and the receiving channel demodulator circuit, both of which are packaged in a single plug-in unit. The channel modulator circuit provides the first step of modulation from voice to a 4-kHz portion of the 148 to 196-kHz band. The channel demodulator circuit provides the last step of demodulation from a 4-kHz portion of the 148 to 196-kHz band to voice frequency. Each of the twenty-four channel modem circuits in a terminal are identical. The various channel frequencies are selected by inserting the appropriate crystal channel bandpass filters and making the proper adjustment on the variable equalizer.

4.2 *Channel Modulator Circuit*

The channel modulator circuit shown in Fig. 3 consists of a temperature compensating input pad, a transistor switch-type modulator, a 6-dB isolating pad, and a crystal channel bandpass filter. The carrier drive for the modulator is supplied externally from the common carrier supply. The input pad contains a thermistor as one of the ele-

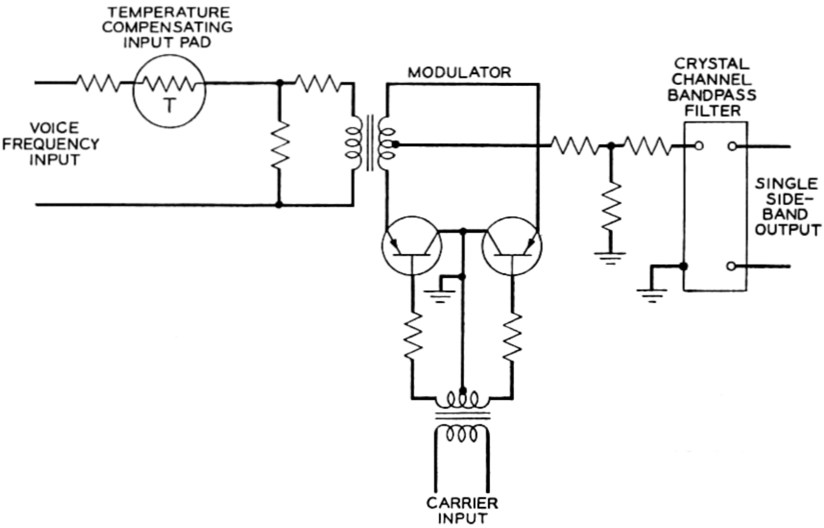

Fig. 3 — Channel modulator circuit.

ments such that the pad loss varies inversely with temperature and compensates for the entire modulator circuit. The transistor used in the modulator represents the only new semiconductor device developed especially for N3. This device consists of a matched pair of germanium alloy transistors with an inverse beta of at least 15 (inverse beta is the current gain when the collector is used as the emitter). The high inverse beta is required to minimize the carrier drive necessary for satisfactory operation of the modulator. The transistors are matched to provide sufficient carrier balance at the output of the modulator.

The modulator operation is most easily visualized by noting that the carrier controls the transistor switching; one transistor is "on" and the other is "off" for a given polarity of the carrier. The transistor operation is reversed for the opposite polarity of the carrier. With the transistors switching "on" and "off" in this way, the output termination is switched from one half of the secondary winding of the input transformer to the other at carrier frequency. Therefore, at any instant of time, one half of the secondary is properly terminated and the other is open-circuited. This operation reverses the polarity of the incoming signal at a carrier frequency rate and thus produces a double-sideband suppressed-carrier signal at the output of the modulator.

The resistors in the base leads provide a constant current source and a good carrier drive input impedance. For an input signal level of −15 dBm and a carrier drive of −6 dBm, the carrier leak at the output is at least 32 dB down on each of the sidebands. The 2A − B distortion product is approximately 48 dB down on either the A or B signal (each at −15 dBm). The modulator remains "linear" for input signals up to −11 dBm which represent +8 dBm at OTL. Following this modulator is a 6-dB pad to provide isolation between the modulator and crystal channel band filter. The characteristics of the channel filter which employs two self-equalized quartz crystal filter sections are shown in Fig. 4. Each of the twelve different filters was designed to pass the upper sideband (200 to 3450 Hz above the carrier frequency) in the 148 to 196 kHz range. The discrimination against the lower sideband is at least 55 dB while 30 dB of discrimination is provided 4 Hz above the carrier frequency. The in-band ripple is held to less than ±0.15 dB at 80°F and less than ±0.25 dB at 120°F.

4.3 *Channel Demodulator Circuit*

The channel demodulator circuit shown in Fig. 5 consists of a crystal channel bandpass filter, a 6-dB isolating pad on each side of the demodulator, a transistor switch type demodulator, a low-pass filter,

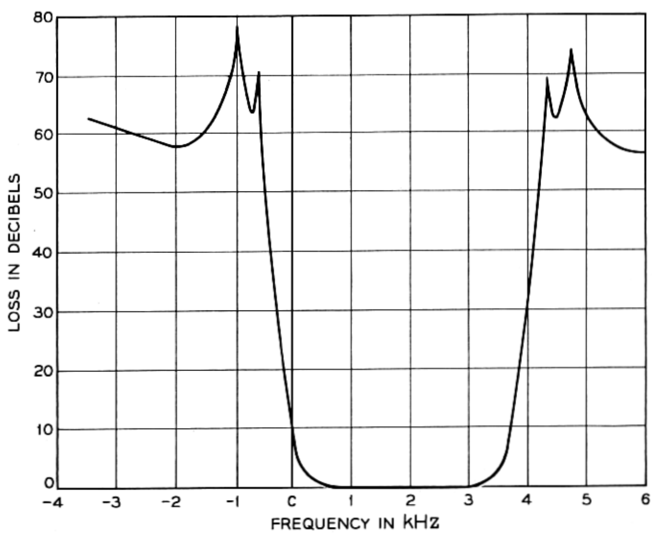

Fig. 4 — Measured insertion loss N3 channel band filter.

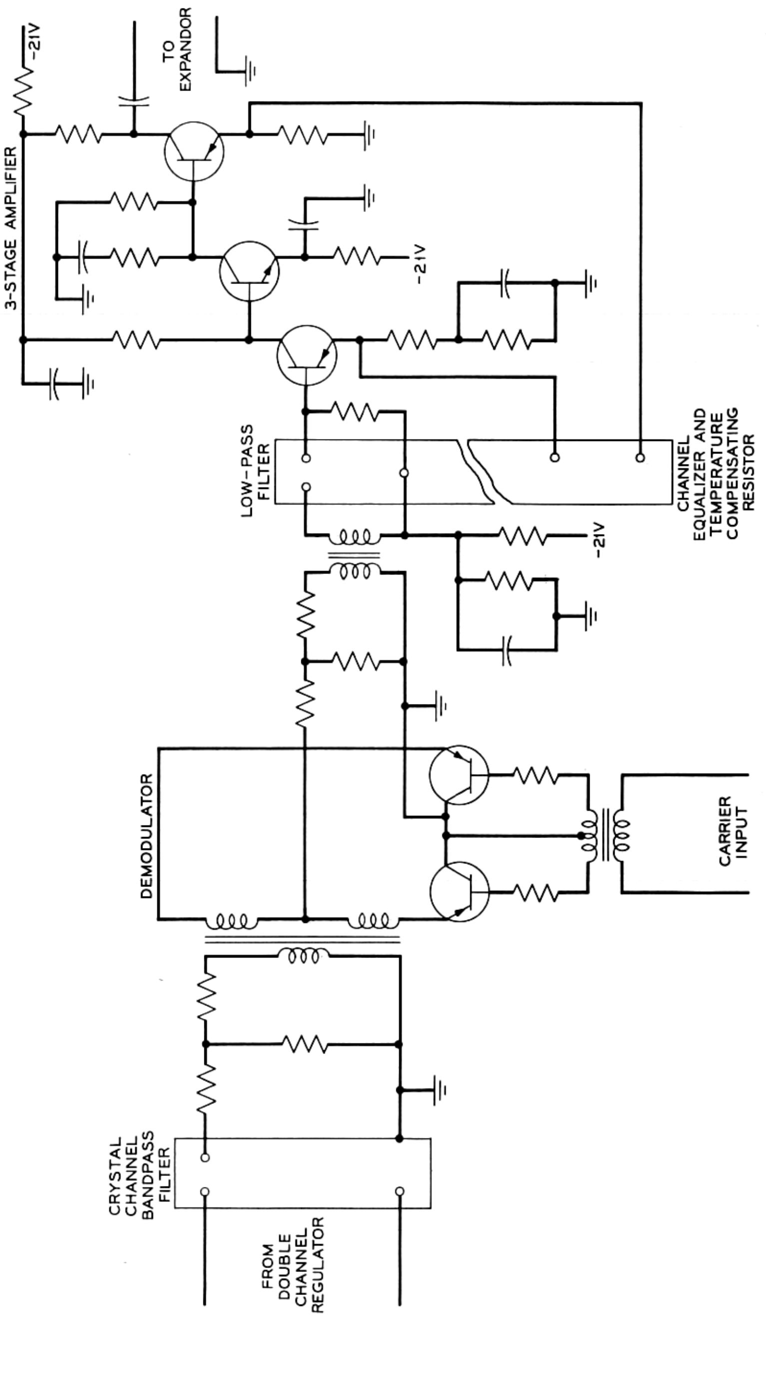

Fig. 5 — Channel demodulator circuit.

and a feedback amplifier. The carrier drive for the demodulator is supplied externally from either the common carrier supply (odd numbered channels) or the double channel regulator circuit (even numbered channels). The crystal channel bandpass filter, which is identical to that used in the channel modulator circuit, selects the proper 4-kHz sideband from the group of twelve present at the output of the double channel regulator. Following the filter is a 6-dB pad to provide isolation between the channel filter and the demodulator. The transistor demodulator translates the 4-kHz sideband down to the audio range. The low-pass filter, separated from the demodulator by a 6-dB pad, passes the audio band and rejects the higher frequency energy generated in the demodulator. A loss peak as shown in Fig. 6 is placed at 4 kHz to suppress any adjacent carrier energy present. The three-stage feedback amplifier following the low-pass filter includes as part of the feedback circuit a temperature compensating resistor and a channel equalizer. The positive coefficient resistor compensates for the entire demodulator circuit. The equalizer provides loss peaks which are transformed by the amplifier to gain peaks at approximately 120 Hz and 3650 Hz to equalize for the roll-off of both the transmitting and receiving channel band filters. The characteristics of the equalizer when operating in the feedback circuit of the amplifier are shown in Fig. 7. The position and shape of these peaks may be adjusted slightly by means of screw-down options to accommodate small differences in the various band filters for different channels. The open loop gain of the amplifier at midband (1000 Hz) is approximately 24 dB. At the band edges (200 and 3450 Hz) the feedback is reduced to approximately 22 dB due to the loss peaks in the equalizer. The open loop gain cut-off is about 1 MHz with more than 55 degrees phase margin to insure stable operation. The low-pass filter, equalizer, and temperature compensating resistor R_T are all pack-

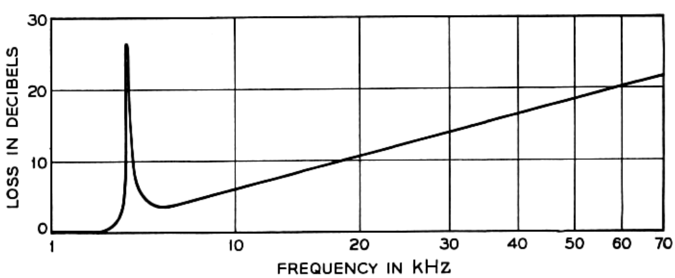

Fig. 6 — Low-pass filter.

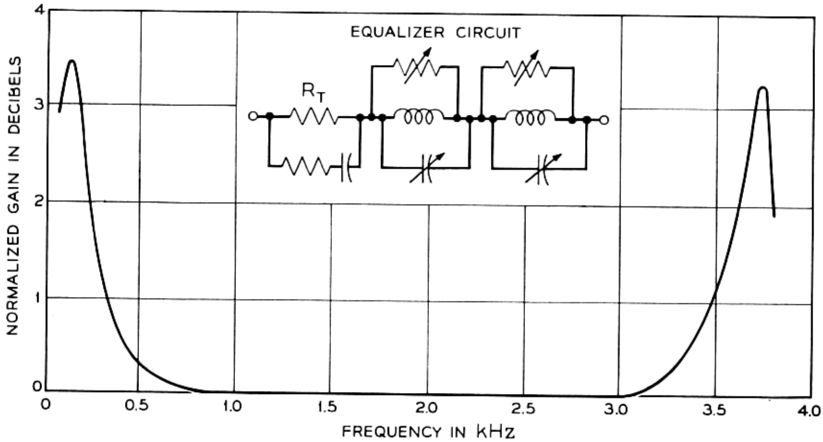

Fig. 7 — Frequency characteristic of demodulator amplifier including channel equalizer.

aged as a single piece of apparatus. For an output signal level of −5 dBm, which represents 0 dBm at OTL, the 2A − B distortion product due to the entire demodulator circuit is approximately 48 dB down on either the A or B signal. The circuit remains linear for output signals up to −1 dBm.

V. DOUBLE-CHANNEL REGULATOR CIRCUIT

Since the carrier to reference level sideband ratio is precisely established and maintained in the transmitting terminal, the carrier tone may be used in the receiving terminal as a pilot to provide regulation. The function of the double-channel regulator circuits (AGC circuit) is to automatically regulate each pair of channels by using the received carrier between them as a pilot tone. Basically the regulator is an amplifier, the gain of which is inversely proportional to the input level of a pilot carrier. Each of the twelve double-channel regulator circuits in a terminal is identical. The specific pair of channels to be regulated is selected by inserting a particular crystal carrier pick-off filter in the regulator unit. The input signal to the double-channel regulator circuit consists of twelve single-sideband 4-Hz signals and six carrier tones. Although only two of the signals and the carrier between them are of interest insofar as regulation is concerned, the additional carriers and signals which are present impose a severe intermodulation distortion requirement on the circuit. In addition to providing the regulating function, the regulator supplies one of the adjacent channels (even numbered channel) with a channel demodulating carrier. Since this carrier is derived from the carrier supply at the transmitting terminal, the process provides for error-free voice frequency recovery in all the even numbered channels.

The transmission path for the double-channel regulator circuit shown in Fig. 8 consists of a shunt variolosser and a 4-stage forward transmission amplifier. Negative feedback around the last three

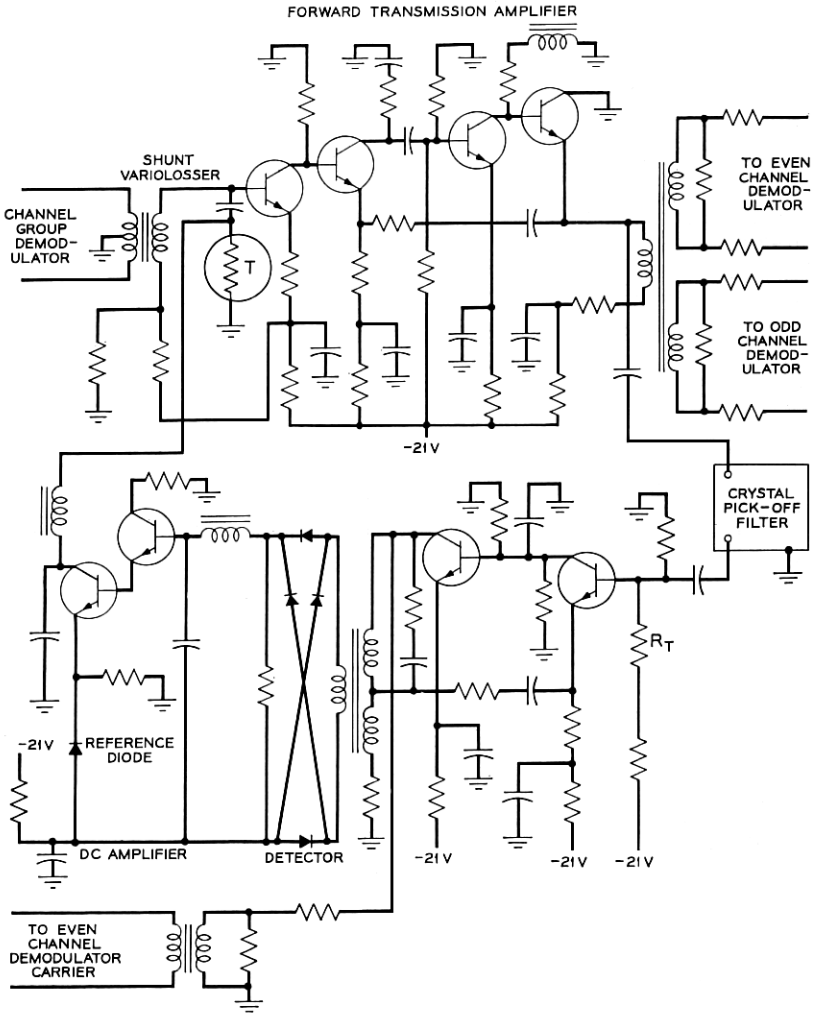

Fig. 8 — Double-channel regulator.

stages, in addition to local feedback on the output stage is employed to provide the necessary intermodulation distortion performance. At the normal operating level for a 0 dBm at OTL tone the 2A − B distortion product is approximately 112 dB down on either the A or B signal. A plot of the feedback ($\mu\beta$) phase and gain characteristics for the forward transmission amplifier is shown in Fig. 9. The high end gain cut-off occurs at approximately 10 MHz with a phase margin of 50 degrees. The low end gain cut-off occurs at 860 Hz. By using the following relationship, the phase margin at the low end was calculated to be approximately 60 degrees:

$$\left|\frac{\mu}{1-\mu\beta}\right| \Big/ \left|\mu\right| = \left|\frac{1}{1-\mu\beta}\right| = \frac{1}{2\sin\frac{\theta}{2}}$$

where

$$\theta = \text{phase margin}$$

$$|\mu| = \text{magnitude of } \mu \text{ gain at crossover frequency}$$

$$\left|\frac{\mu}{1-\mu\beta}\right| = \text{magnitude of closed loop gain at crossover frequency.}$$

The transformer output with a split secondary is used to provide

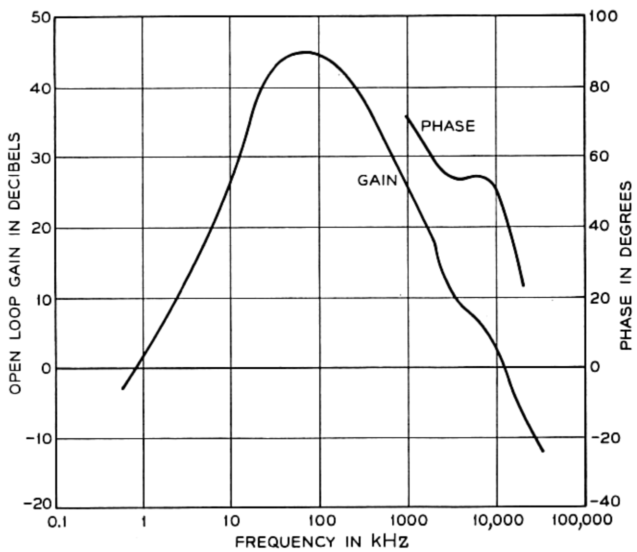

Fig. 9 — Open loop phase and gain of forward transmission amplifier.

separate outputs to the odd and even channel demodulators. By using an emitter-follower output stage and shunt feedback, a high degree of isolation is achieved between the two outputs. The small resistor in series with the primary of the output transformer reduces the isolation somewhat but is advantageous in improving the intermodulation distortion performance of the transformer. If one demodulator is removed, the level in the other will change by less than 0.1 dB. The low output impedance of the amplifier also permits a lower bridging loss of the crystal pick-off filter consistent with the ripple objective of 0.05 dB maximum in adjacent channels. Because of the frequency correction technique employed in the receiving terminal, the carrier pick-off filter can be made extremely narrow and thus achieve a high discrimination to all other frequencies. The carrier level at the output of the pick-off filter is amplified, rectified, filtered, and compared to the reference diode voltage. The difference or error voltage is amplified and used as the control current in the thermistor variolosser. Thus, if the regulator output level increases, the error voltage increases, the thermistor impedance decreases, and therefore the loss in the variolosser increases tending to reduce the output level. The regulation characteristic shown in Fig. 10 indicates approximately a 0.3-dB output change for a 30-dB input change. The over-all or envelope open loop gain characteristic is shown in Fig. 11. This characteristic was obtained by breaking the loop at the input to the dc amplifier

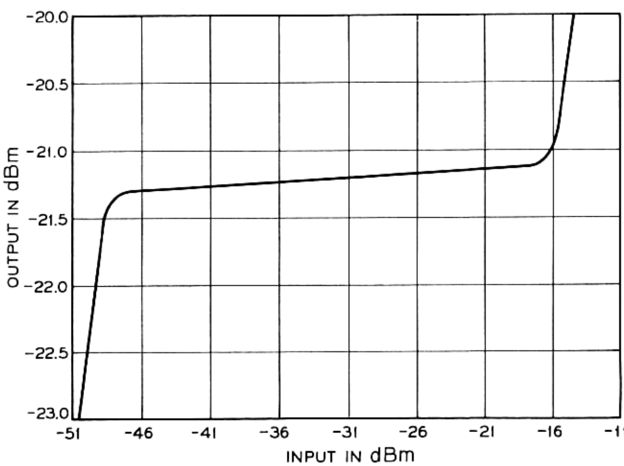

Fig. 10 — Regulation characteristic.

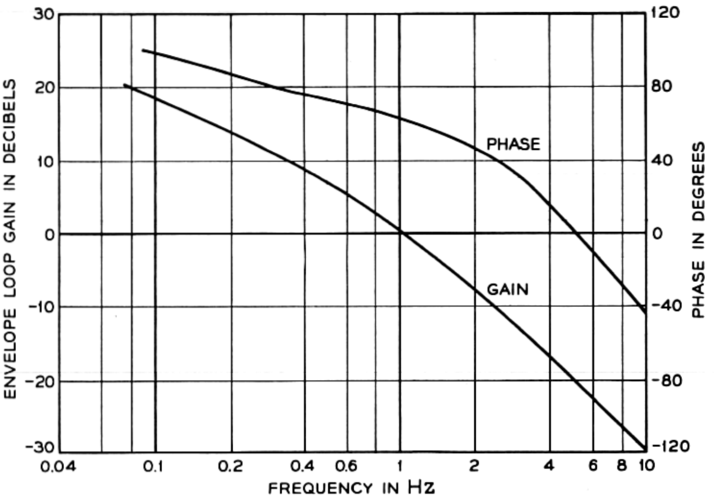

Fig. 11 — Envelope open loop phase and gain characteristic of double channel regulator.

and measuring the low frequency gain and phase. The high end cut-off occurs at approximately 1 Hz with a phase margin of 63 degrees. This extremely low cut-off frequency is very desirable so that the regulator will tend to discriminate against and not regulate or follow, carrier beats.

Temperature compensation of the entire regulator circuit is accomplished by means of a positive temperature coefficient shunt resistor R_T following the pick-off filter. A tap at the output of the two stage amplifier is used to provide the even channel demodulating carrier.

VI. CHANNEL GROUP MODEM CIRCUIT

6.1 *Channel Group Modulator*

In the transmitting terminal, the input signal to the channel group modem consists of 12 single-sideband signals plus 6 transmitted carriers in the 148 to 196-kHz range. The function of the channel group modulator is to translate this signal to either the 36 to 84 or 84 to 132-kHz ranges using a frequency of 232 or 280 kHz supplied from the common carrier supply. The channel group modulator circuit consists of a diode ring modulator and a single stage carrier drive amplifier.

The amplifier raises the incoming carrier by 7 dB and provides optimum impedances at the input and output for the carrier supply and modulator. The outputs of two channel group modulators are subsequently combined to give a composite signal in the 36 to 132-kHz band containing 24 sidebands and 12 carriers before being applied to the group transmitter.

6.2 *Channel Group Demodulator*

In the receiving terminal, the output of the group receiver is applied to two channel group demodulator circuits via a resistive splitting pad. Each half (36 to 84 or 84 to 132 kHz) of the low group signal is selected and demodulated into the 148 to 196-kHz band. This signal is then amplified for transmission to the double-channel regulator circuits. As shown in Fig. 12, the input signal to the channel group demodulator circuit is filtered to select the proper half of the low-group signal before being demodulated. The demodulator consists of a double-balanced diode ring-type demodulator. The single stage carrier driver amplifier provides gain, isolation, and optimum input and output impedances between the carrier source and the demodulator. The low-pass filter following the demodulator passes the 148 to 196-kHz signal and rejects the higher frequencies generated by the demodulator. Approximately 25 dB of negative feedback is incorporated in the 2-stage hybrid-feedback amplifier to stabilize the gain and provide an adequate intermodulation performance. When the modulator and demodulator circuits are connected in tandem the frequency characteristic obtained is shown in Fig. 13.

VII. FREQUENCY CORRECTION CIRCUIT

The signal entering an N3 receiving terminal, after being transmitted over an N-repeatered line, will have been shifted in frequency: a large shift being in the order of 100 Hz. This shift is due to an accumulation of small errors present in each of the 304-kHz oscillators in the frogging repeaters along the line. A frequency shift of this magnitude, if not corrected, would greatly deteriorate the over-all N3 performance. Since voice-frequency equalizers are used to equalize the extremely sharp carrier frequency crystal band filters, a frequency shift would seriously affect the channel frequency response. In addition, the frequency error that would remain in those channels using local carriers for demodulation would be intolerable.

The function of the frequency correction circuit is to introduce a

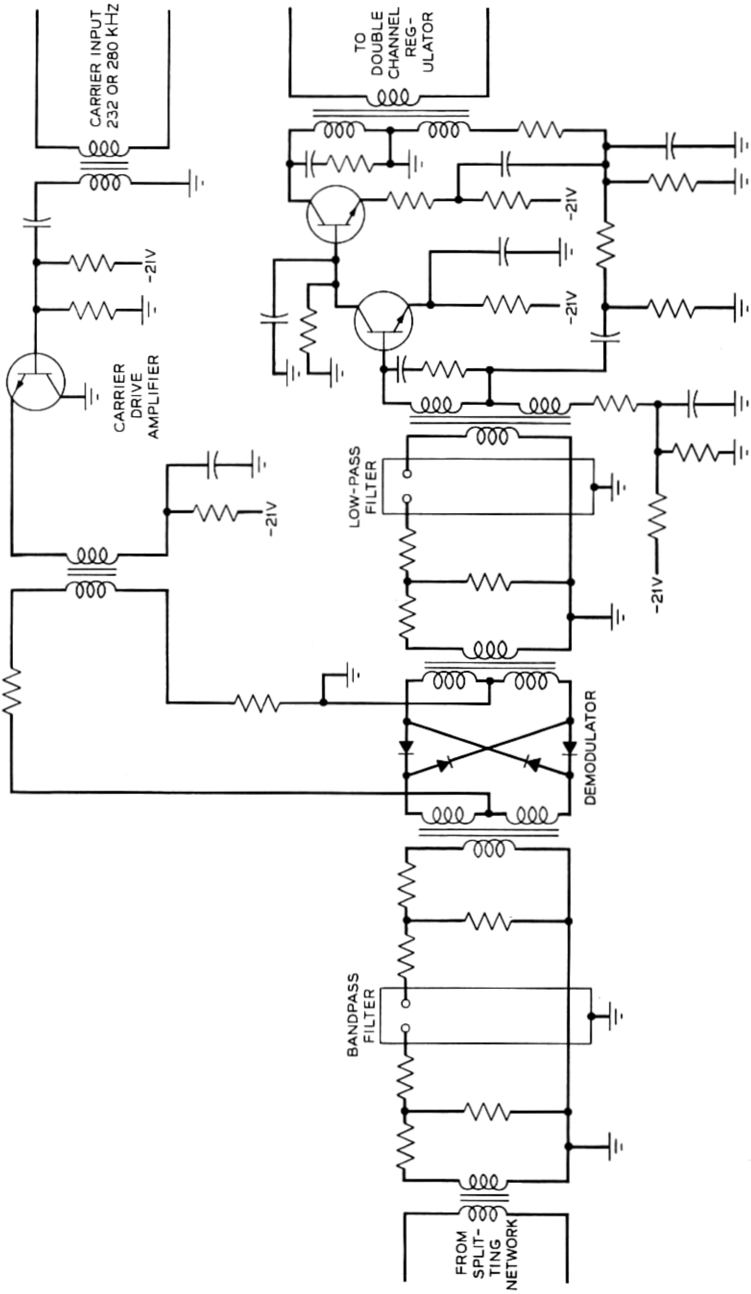

Fig. 12 — Channel group demodulator.

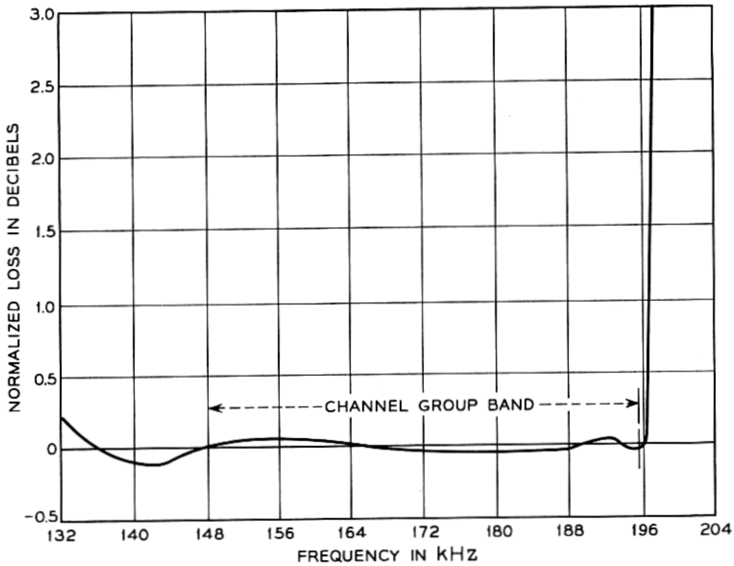

Fig. 13 — Frequency characteristic of channel group modulator and demodulator in tandem.

compensating frequency shift into the received signal so as to eliminate any frequency error accumulated along the line. In addition, this circuit substantially reduces the effects of frequency differences between the transmitting and receiving common carrier supplies. Two tones or carriers are required for this scheme: one, considered to be the reference, is derived from the receiving carrier supply and the other from the incoming signal.

The frequency correction circuit basically works on the phase-locked-loop principle.* The customary phase-locked loop has a severe disadvantage for applications of this type. It requires clearing the frequency spectrum around the carrier tone with which the loop works. A fundamental incompatibility exists between a wide capture range on one hand and high discrimination against nearby signals on the other. The frequency correction circuit overcomes this difficulty by incorporating two conventional loops and a switching control circuit to select the appropriate loop. One of the loops has the characteristic of capturing over a wide range of frequencies; the other is an extremely narrow

* Early N3 terminals used a forward acting frequency correction circuit instead of the technique described in this section.

band circuit which offers high discrimination to tones located close to the wanted carrier in the frequency spectrum. The function of the switching circuit is to switch in the wideband loop when the wanted carrier is sufficiently off-frequency, and then the narrow-band loop after a frequency lock has been achieved.

The block diagram shown in Fig. 14 will help to illustrate the operation of the frequency correction circuit. An incoming signal to the channel group demodulator consists of twelve single-sideband and six transmitted carriers in the 84 to 132-kHz portion of the spectrum. As indicated on the diagram this received signal has been shifted by some amount Δ during the course of its transmission over the N-repeatered line. The function of the channel group demodulator is to transform this signal into the 148–196 kHz range. This is accomplished by supplying a nominal 280-kHz carrier and selecting the lower sideband output. Initially, this output band may be shifted in frequency. During this initial period switches S1 and S2 are in the (a) position. A bridging amplifier connected to the output of the channel group demodulator amplifies this shifted signal which is applied to the pick-off filter and bypass pad. The amplifier contains an LC resonant

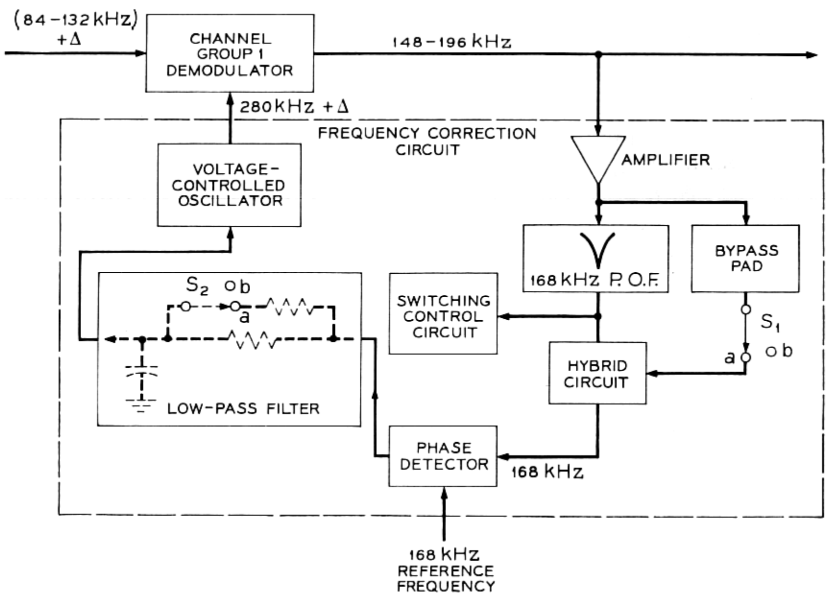

Fig. 14 — Block diagram of frequency correction circuit.

circuit to provide broad selectivity in the vicinity of 168 kHz (at the output of the channel group demodulator, one of the transmitted carriers is nominally at 168 kHz). Since the 168-kHz pick-off filter is only a few cycles wide, transmission is blocked through that path. The amplifier output signal is transmitted through the bypass pad, switch S_1, the hybrid circuit and into the carrier leg of the phase detector. The 168-kHz signal drive frequency for the phase detector is supplied from the precise N3 common carrier supply. The very low frequency output (nominally dc) is passed through the low-pass filter. Since switch S_2 is in the (a) position the low-pass filter is relatively wide band. The output provides the control signal for the voltage-controlled oscillator. This complete loop represents the wide-band loop which acts to bring the output of the voltage-controlled oscillator to a frequency of 280 kHz + Δ. As this point is approached, the 168-kHz carrier tone passes through the pick-off filter to the hybrid circuit. The switching control circuit senses this energy and after a short time delay switches S_1 and S_2 to the (b) positions thereby switching out the bypass pad and switching in the very narrow low-pass filter. The loop is now in the narrow-band mode and presents a high degree of discrimination to signals in the vicinity of the 168-kHz carrier. Therefore, if the incoming signal is shifted by an amount Δ, the voltage-controlled oscillator provides a clean channel group demodulating carrier which is also shifted by an amount Δ. Thus, the desired output signal has been corrected in frequency for the line shift.

The open loop characteristics of both the narrow and wideband loop are shown in Fig. 15. Except for an inherent 6 dB per octave slope in the rest of the loop, these characteristics are controlled by the two low-pass filter configurations. As noted on the curves the capture range for the wideband loop is 500 Hz and only 30 Hz for the narrow loop. The 500-Hz range for the wideband loop is required to allow for initial, temperature, and aging variations on the free-running oscillator in addition to the line shift error.

Since the outputs of the carrier supplies are derived by harmonic generation, the error at each carrier frequency will be different depending upon the error in the base generators and the particular harmonic that the carrier represents. Therefore, a residual error remains after frequency correction at all carrier frequencies except that of the reference tone. Based on a maximum base generator error of ± 7 parts per million, the worst case residual error is less than 0.6 cycle per second.

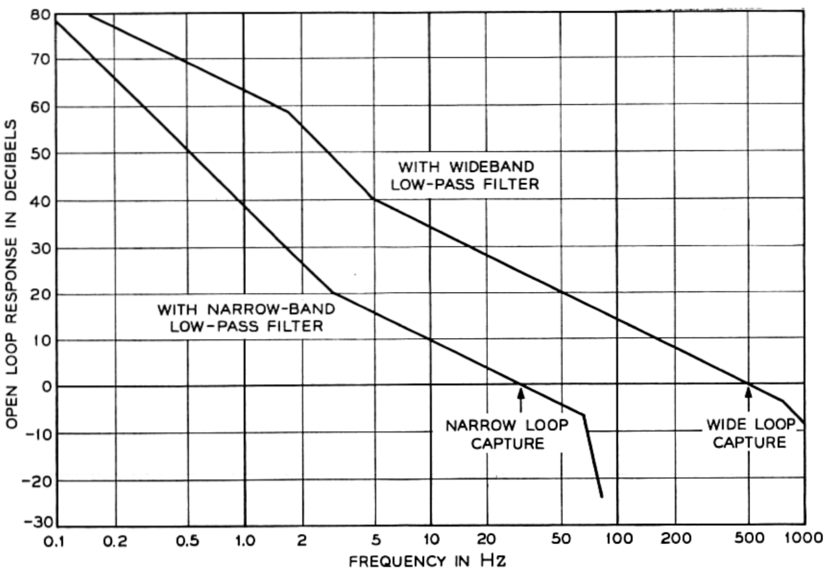

Fig. 15 — Open loop response of correction circuit.

VIII. GROUP TRANSMITTER CIRCUITS

The outputs of two channel group modulator circuits are combined in a hybrid coil network and applied to a group transmitter. This circuit may be required to transmit signals to the repeatered line in either the low group band (36–132 kHz) or the high group band (172–268 kHz). Therefore, two types of group transmitter units are available: a low group transmitter and a high group transmitter. The basic difference between the two types of group transmitter circuits is the inclusion of the modulator and associated circuitry in the high group transmitter. For this reason, only the high group transmitter shown in Fig. 16 will be discussed.

The single stage amplifier at the input provides approximately 11 dB of gain to the low-level low-group signal. The low-pass filter passes the 36 to 132-kHz band and rejects the unwanted modulation products generated in the channel group modulators. The slope equalizer allows the transmitted signal to be pre-equalized to partially compensate for the cable loss characteristic. Seven different equalizers are available for insertion in the circuit to provide a choice in slopes of 0, ±3, ±6, or ±9 dB for the channel 12 carrier of channel group 2 relative to the channel 1 carrier of channel group 1. The output of the equalizer is ap-

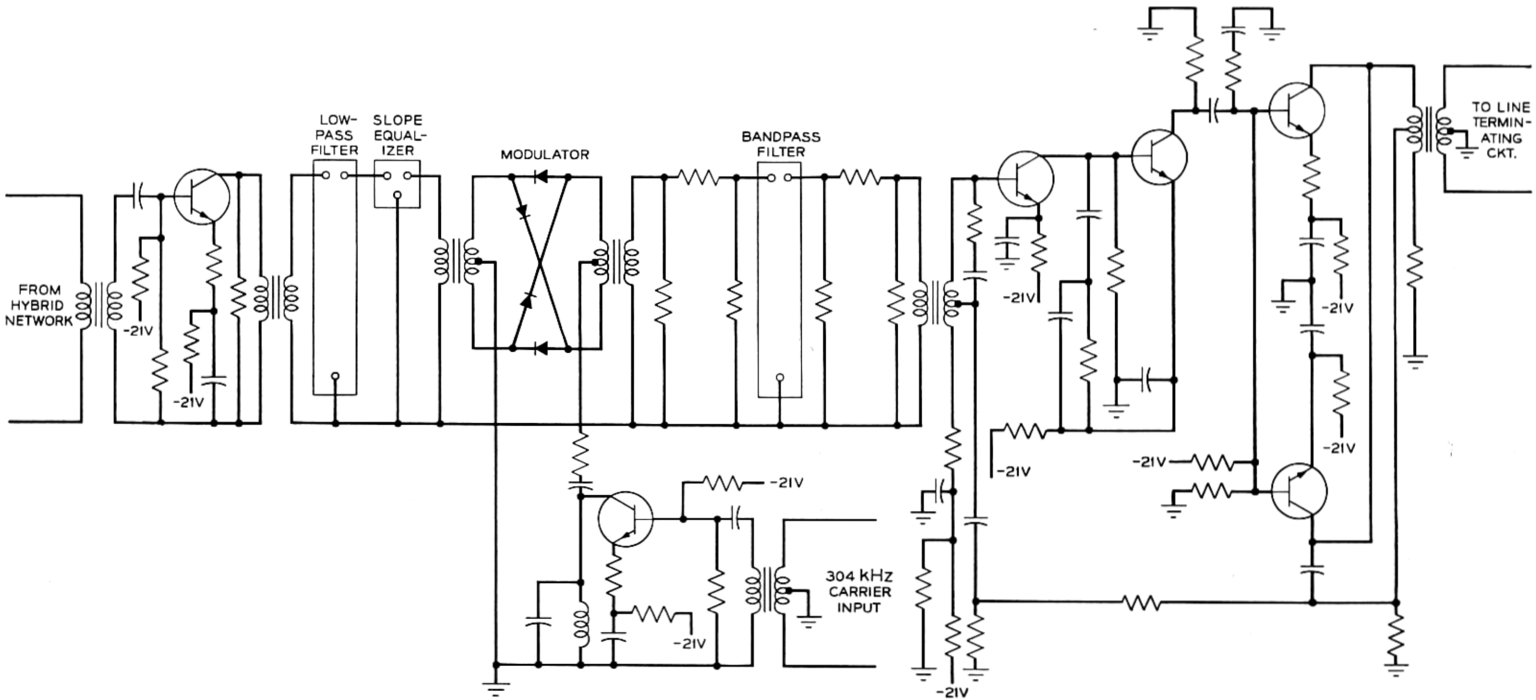

Fig. 16 — High group transmitter.

plied to the group modulator which consists of four diffused junction silicon diodes connected as a double-balanced ring modulator. The 304-kHz carrier for the group modulator is supplied from the common carrier supply and is amplified by a single stage buffer amplifier between the carrier supply and modulator. The bandpass filter following the group modulator transmits the high group band and rejects the unwanted modulation products from the modulator. The 3-stage amplifier provides approximately 60 dB of gain to the low level signal to obtain the proper levels for transmission over the carrier line. The third stage of the amplifier utilizes two transistors operating in parallel in order to handle the high output power levels with adequate intermodulation performance ($3F/F < -105$ dB for $F = 0$ dBm). As shown in Fig. 17, approximately 35 dB of negative feedback is employed both to improve the intermodulation performance and to reduce gain variations. At the high end cut-off better than 60 degrees of phase margin is achieved in addition to 17 dB of gain margin to insure the closed loop stability of the amplifier. The input and output impedances of the amplifier are precisely controlled by connecting the feedback circuit in the hybrid configuration. The hybrid connections also serve to stabilize the feedback independently of the amplifier terminations.

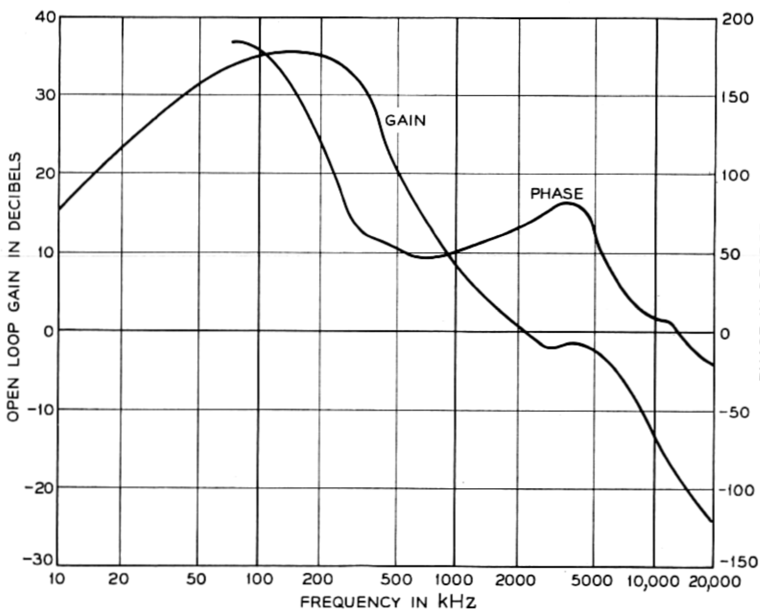

Fig. 17 — Open loop phase and gain response for hgt amplifier.

IX. GROUP RECEIVER CIRCUITS

The incoming signal to an N3 terminal may be in either the low group band (36–132 kHz) or the high group band (172–268 kHz). Like the group transmitters, it is necessary to provide two types of group receiver circuits: namely a low group receiver and a high group receiver. These two circuits are basically the same except for the inclusion of a demodulator and associated circuits in the high group receiver. Only the low group receiver shown in Fig. 18 will be discussed.

The low-pass filter at the input passes the low group band and rejects the unwanted out-of-band frequencies which may have been picked up due to crosstalk or other sources in the incoming line. As in the group transmitter circuit, slope equalizers are available for insertion in the circuit to compensate for the slope across the band due to the cable loss characteristic. In addition, the incremental slope adjustment circuit can be adjusted on a screw option basis to provide 0, +1, or −1 dB of slope in the gain characteristic across the low group band. The 3-stage amplifier following the slope equalizer provides approximately 53 dB of gain to the low level signals. A parallel output stage is employed to improve the intermodulation distortion performance. Shunt feedback is employed at the output of the amplifier while hybrid feedback is employed at the input for low noise performance and a good return loss. The shunt feedback connection at the output produces the low output impedance necessary for achieving isolation between the two channel group demodulators. The unusual shunt feedback connection on the output utilizes the transformer as an auto-transformer to provide the proper signal level to the thermistor. The resistor connected between the primary winding and ground is used for low frequency shaping. The open loop characteristics are similar to those shown for the group transmitter amplifier. However, due to the thermistor and slope adjustment circuit in the feedback path, wider variations occur in the gain and phase margins as these elements are selected or change value. The feedback circuit includes a thermistor for automatic gain control and an incremental slope adjustment circuit which is used as a fine adjustment to interpolate between the inserted equalizer values. The impedance of the thermistor is determined by the total output power. Thus, as the output level increases, the thermistor impedance decreases and the gain of the amplifier decreases tending to restore the output to its nominal level. This action reduces input level changes of ±8 dB to less than 1 dB at the output.

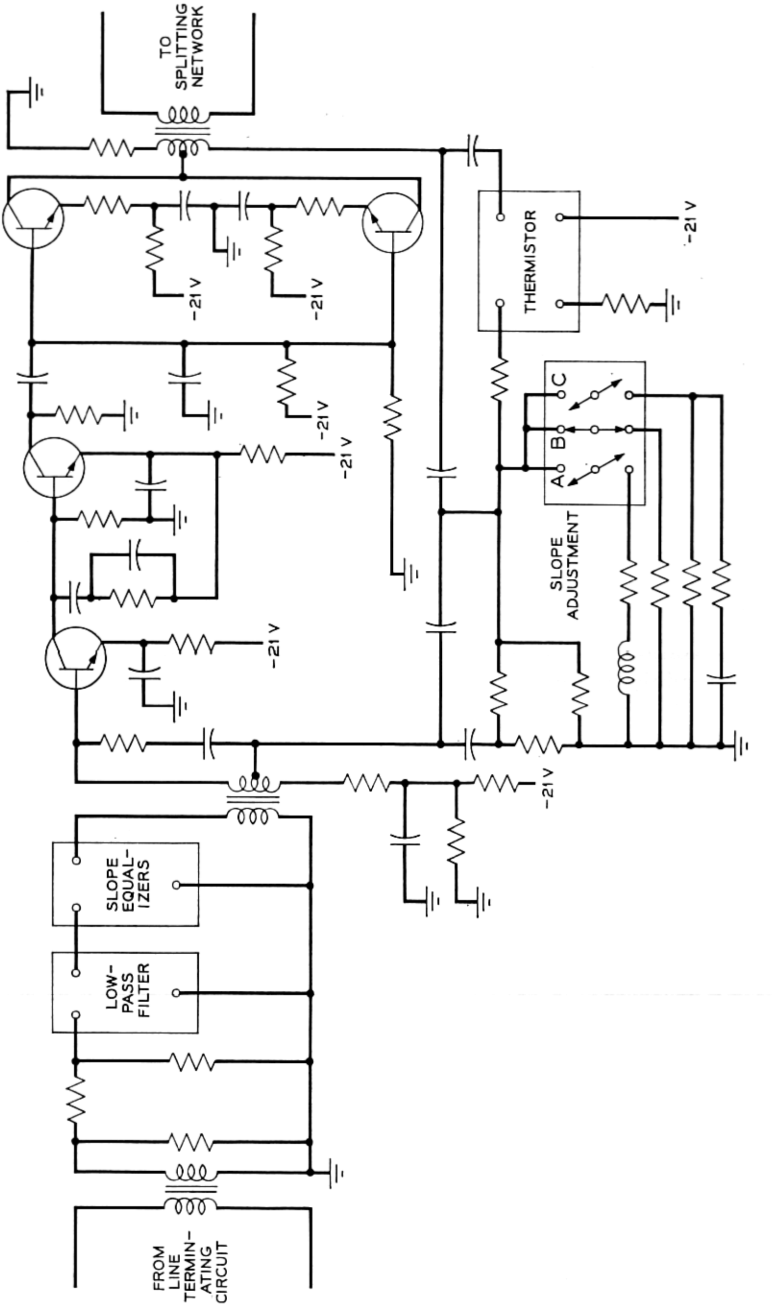

Fig. 18 — Low group receiver.

X. ALARM AND RESTORAL CIRCUIT

Separate carrier alarm circuits are provided for each channel group. Upon recognition of a received carrier failure, a carrier failure is forced at the far terminal and provision is made to release customers and apply a busy signal on the 12 channels. The circuit automatically monitors the transmission such that when the fault has been cleared the 12 channels at each end of the system are simultaneously restored to service.

The alarm and restoral circuit in conjunction with the external trunk release and make busy circuit automatically seizes control of the entire channel group in the event of a failure. When the total carrier power monitored at the output of the channel group demodulator circuit falls below the threshold level, the carrier office alarms are operated. The input to the channel group modulator is shorted for a period of 10 seconds to force a carrier failure in the associated alarm circuit at the far end of the system. By means of a ground signal, all 12 trunks are made idle. After a 10-second delay these trunks are made busy. The alarm circuits at this point are locked up and service cannot be restored until the automatic transmission tests are satisfactorily completed. A 2600-Hz tone is applied to the input of the channel modulator in the first test channel. The output of the channel demodulator is monitored for receipt of the 2600 Hz with an adequate signal-to-noise ratio. When this signal is satisfactorily received, the circuit in a similar fashion applies the tone to the input of the second test channel and monitors the output. When the 2600-Hz signal is satisfactorily received at the output of the second test channel, the signals to the make-busy circuit are removed and the system is automatically restored to service. An optional arrangement permits a single alarm and restoral circuit to control both channel groups in a terminal. In this case, however, all decisions are made on the transmission performance in only one of the two channel groups.

XI. N3 CARRIER-FREQUENCY SUPPLY

A novel feature of the N3 carrier system is the use of a carrier-frequency supply unit which furnishes all of the carriers needed for as many as 26 terminals. This common carrier supply provides the frequency stability and the amplitude control deemed necessary for a modern short-haul system and is economically competitive with other methods of carrier generation in all but the smallest installations.

Noteworthy features which enhance the operating flexibility of the new carrier supply include continuous monitoring to detect substandard performance, built-in automatic protection against service interruptions, convenient aids for easy maintenance, and alarms for all trouble conditions. The circuit design takes advantage of solid-state technology to minimize power consumption and space requirements. The N3 modulation plan[1] requires the generation of 16 different frequencies needed for modulation and demodulation. The channel modulators require 12 frequencies equally spaced at 4-kHz intervals and ranging from 148 kHz to 192 kHz. Two frequencies, 232 and 280 kHz, are required for the channel group modulators. One frequency, 304 kHz, is required for the group modulator. The one remaining frequency, 256 kHz, is needed for a modulator which will be part of the equipment for interconnecting the N3 and L systems. This modulator will shift the frequencies in the N3 channel group band, 148 to 196 kHz, to the A-type channel bank range (L multiple group band), 60 to 108 kHz. Thus, the N3 and L systems can be interconnected at channel bank frequencies rather than at voice frequencies.

The generation of many carrier frequencies, accurately and economically, is a basic need for any system and is a crucial requirement for a short-haul system. A study of the frequency stability attainable with crystal-controlled oscillators, similar to those used in the existing short-haul carrier systems, revealed a need for smaller frequency differences from terminal to terminal. Consideration of system performance objectives led to the decision to provide a high-grade 4-kHz oscillator at each location. By allocating all carrier frequencies to exact multiples of 4 kHz, the carriers can be generated as harmonics of a 4-kHz base frequency.

Synchronization of the carrier oscillators at the two terminals is hindered by the random frequency shifts introduced by the local oscillators used for transposing and inverting the channel groups at each repeater, i.e., frequency "frogging." Since a change in the repeaters is impractical, the only alternative is to correct the received carrier frequencies at each terminal. Frequency correction can be achieved rather easily if all of the carrier frequencies are harmonics derived from a single primary frequency source. If the carrier frequencies at the transmitting terminal and at the receiving terminal are obtained from similar harmonic generation processes, the terminal-to-terminal frequency errors can be made dependent only upon the two relatively precise base frequency oscillators at the transmitting and receiving terminals.

The foregoing considerations are the basis for the specification of

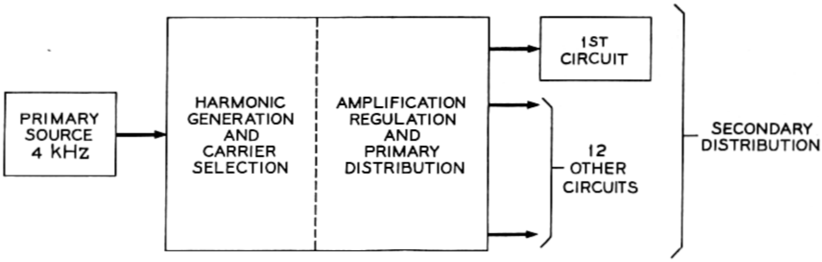

Fig. 19 — Carrier-supply — general plan.

requirements for the N3 carrier-frequency supply. The block diagram of Fig. 19 shows the functional plan. A primary frequency source operating at 4 kHz serves as an input to the carrier generator circuits. The primary frequency supply for the L Multiplex is a preferred source, when available, but a stable crystal-controlled oscillator has been designed for the N3 carrier-frequency supply to meet a frequency stability objective of ± 7 parts per million over an ambient temperature range from 32° to 120°F and including aging for a 12-month period.

All of the carriers are supplied to the terminal bays from the primary distribution panel in the carrier frequency supply bay. Each of the arrows shown in Fig. 19 represents a multiconductor cable which connects one secondary circuit to the common carrier supply and transmits 16 carrier frequencies. Each secondary circuit is located conveniently in a carrier terminal bay and is capable of supplying all carriers for two terminals.

The carrier voltages at the output of the primary distribution panel are relatively pure sine waves. The second and third harmonic content is at least 60 dB below the fundamental. All unwanted carrier frequencies are at least 58 dB below the wanted frequency at each output. Each carrier is regulated in amplitude to be within ± 0.5 dB of the nominal voltage. The 12 channel carriers are distributed at a level of $+11$ dBm into each 115-ohm circuit. The other carriers are furnished at a level of $+8$ dBm. At the input of each secondary distribution circuit, the amplitudes are adjusted to equalize the losses in different lengths of cable and to be within ± 0.5 dB of the nominal voltage. The six transmitted carriers which are used for regulation are maintained within limits of ± 0.1 dB. Although only 16 different carrier frequencies are distributed, 30 outputs are needed to furnish all of the carriers required for each terminal.

Provision of a common carrier supply for as many as 624 channels increases the importance of continuity of service. To provide the high degree of reliability required, it is essential that it be possible to duplicate all active components. A "failure" should cause an automatic transfer from the regular to the standby equipment. The automatic transfer to standby equipment should not be made unless the standby equipment is operating satisfactorily within the specified limits. Since such redundancy is costly, and in the smaller installations may be unwarranted, the addition of the standby equipment is made optional. Provision is also made for the addition of standby units when needed without requiring changes in wiring.

XII. GENERAL PLAN FOR CARRIER-FREQUENCY SUPPLY

Analysis of the requirements given in the preceding section leads to a general plan for the carrier-frequency supply. The important relationships can be placed in evidence by considering three functions separately. (*i*) Generation: Sixteen carrier frequencies must be produced as harmonics of a single 4-kHz input voltage from a primary source. (*ii*) Distribution: A large number of independent output voltages (1482) must be distributed to 26 terminals and each voltage must have a specified magnitude and frequency. (*iii*) Supervision: A comprehensive monitoring and automatic switching and alarm system must be furnished to assure continuity of service and to provide a visual status display for supervision.

12.1 *Primary Frequency Supply*

The primary frequency source for the carrier supply comprises a 4-kHz oscillator and an amplifier that provides sufficient excitation current for the harmonic generator. The essential components of the circuit are shown in Fig. 20. The dotted lines show the optional standby equipment that will provide protection against failure of a fully-equipped system. When the 4-kHz signal is available from the L Multiplex carrier supply, it is fed directly to the inputs of the two amplifiers. A built-in crystal-controlled oscillator is furnished whenever the L Multiplex carrier supply is not available and an internal frequency source for a self-contained system is required. In either case, both amplifiers are fully energized. The working amplifier drives the harmonic generator, and the standby amplifier delivers full output to a resistive load at all times. Each amplifier is equipped with monitoring facilities which determine whether the output current is within specified limits.

The amplifier shown in the block diagram of Fig. 20 is assembled

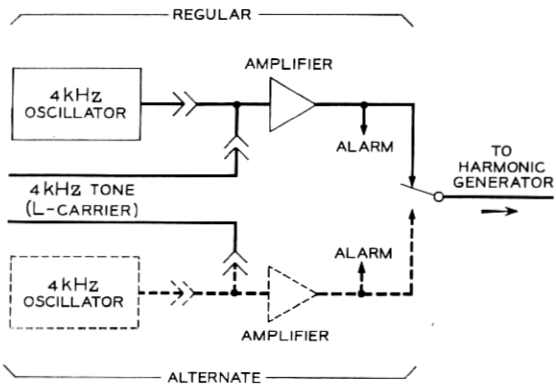

Fig. 20 — Primary 4-kHz source.

as part of the plug-in unit designated as the 4-kHz generator. The primary function of the circuit is to provide current to excite the harmonic generator. A second important function is to provide information to the switching and alarm system whenever the 4-kHz output current is not adequate to excite the harmonic generator properly. A relay initiates office alarms and an automatic switching transfer whenever the output is not within prescribed limits.

The 4-kHz amplifier circuit is shown in Fig. 21. It was designed to

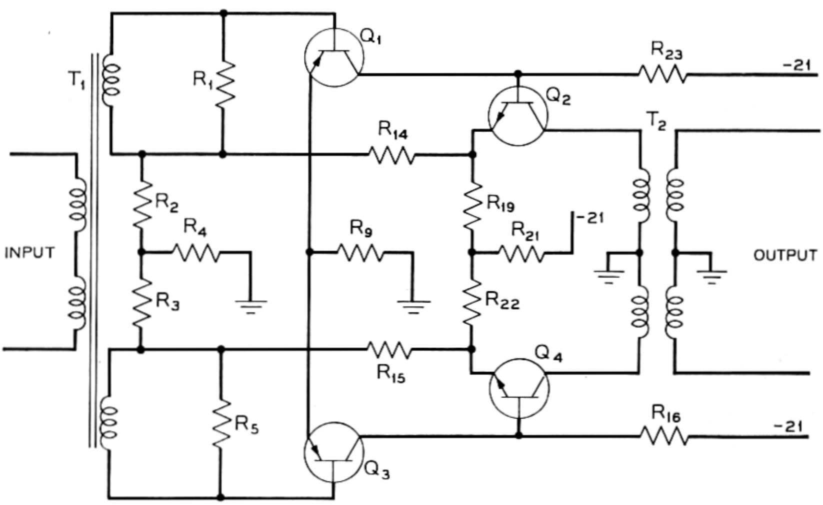

Fig. 21 — 4-kHz amplifier.

deliver sufficient output current to excite the harmonic generator when the input current is supplied by either the L carrier multiplex or the self-contained local oscillator. Both sources are capable of delivering 0 to 2 dBm to a 135-ohm load. However, the local oscillator must energize an oven alarm circuit which requires about half of the available power. For this reason, the amplifier was designed to present a 270-ohm impedance to the source and a 270-ohm shunt resistance is added whenever the power is supplied by the L-carrier multiplex. Thus, the input current to the amplifier is 1.5 ± 0.2 milliamperes. Since the current gain of the amplifier is designed to be 24 dB, the output current delivered to the harmonic generator is between 22 and 28 milliamperes for the range of inputs described above. The harmonic generator can be excited with smaller currents but this range is preferred.

The harmonic generator circuit includes a saturable magnetic core inductor, and the input impedance changes depending upon the magnitude of the input current. Since the harmonic generation process is controlled by the magnitude of the magnetizing force, a sinusoidal current waveform is preferred. Therefore, the negative feedback amplifier uses current feedback from the output mesh to maintain an output current amplitude that is relatively insensitive to changes in the impedance of the load. The ac voltage between the emitters of transistors Q_2 and Q_4 is proportional to the current through the output transformer. A fraction of this voltage is fed back to the input mesh. Since the feedback is proportional to the output current, the amplifier will approximate a constant-current source for exciting the harmonic generator. Thus, a sinusoidal input produces a sinusoidal output current even though the load impedance is nonlinear.

12.2 *Harmonic Production and Selection*

The harmonic generator and the filters which select the carriers for the N3 carrier supply are shown in Fig. 22. The harmonic generator circuit employs a saturable core inductor and produces an output waveshape that is very rich in odd harmonics of 4 kHz. Although the even order components on the spectrum are subject to some variation depending upon the symmetry of the hysteresis loop, they are at least 25 dB below the odd order components at the input to the filters. To produce even harmonics of 4 kHz, a full-wave rectifier is connected across the odd harmonic output. Fig. 22 shows the circuit that produces the harmonics and the bandpass filters that select the wanted carrier frequencies from the harmonic spectrum. By arranging the filters in two

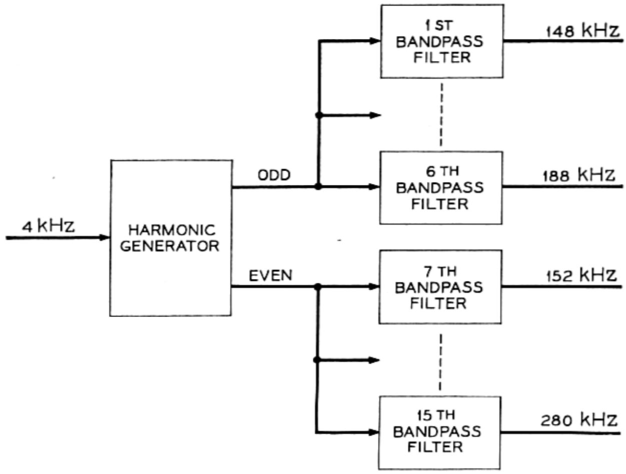

Fig. 22 — Harmonic generation and selection.

groups, one connected to the odd harmonic circuit and the other connected to the rectifier circuit, the unwanted components at the input to each filter are at least 8 kHz away from the wanted component, and the filter requirements can be relaxed. Six filters, with their inputs in parallel, are connected to the odd harmonic output terminals. Similarly, nine filters are connected to the even harmonic output terminals. If the diode bridge used for rectification is well balanced, the odd harmonics of 4 kHz are at least 25 dB below the even order harmonics at the input to the filters. The bandpass filters use crystal units to obtain narrow passbands with adequate out-of-band attenuation.

The circuit used for the simultaneous generation of a large number of harmonics of approximately equal amplitude is shown in Fig. 23. The essential circuit element is the nonlinear inductor, L_4, a coil which is operated with sufficient magnetizing force to drive its magnetic core material well into the saturated region. Thus, the inductance of the coil is large when the current through it is small, and its inductance is small when the current through it is large. The main performance features of the circuit can be reproduced by a crude model which attributes to the inductor, L_4, a sort of switching property. The primary current is constrained to be sinusoidal by the 4-kHz feedback amplifier. The impedance of the coil is high near the zero crossings of the current wave, and the capacitors, C_4 and C_6 are charged slowly. The impedance is low throughout the peak of the current

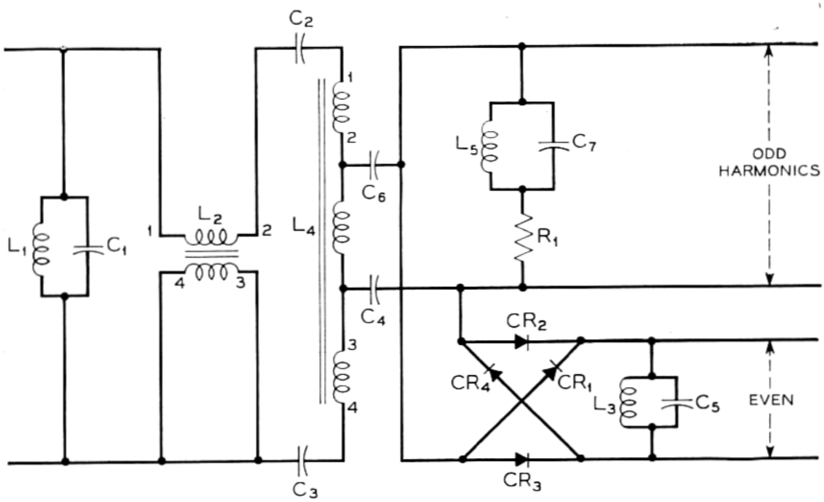

Fig. 23 — Harmonic generator circuit.

wave, and the capacitors discharge rapidly through the resistance of the load and the small inductance of L_4.

The waveforms shown in Fig. 24 have been drawn to illustrate the sequence of events during a complete cycle of the fundamental input wave. A simplified version of the harmonic generator circuit shown in Fig. 23 has been drawn to facilitate the following discussion. The output current pulse that is characteristic of this type of harmonic generator is actually more sharply peaked than the sketch shows. It is the narrowness of the discharge pulse that provides the principal contribution to the higher harmonics which are needed; and the circuit parameters are adjusted to maintain the harmonic distribution as uniform as possible over the frequency range of interest.

Within the interval (t_0, t_1), the amplitude of the sinusoidal current I_1 exceeds the threshold $+I_0$. The nonlinear inductor L_4 is in the saturated state where its inductance is low and the voltage drop across it is correspondingly small. The current I_2 which charges capacitor C_4 is very small. Within the interval (t_1, t_2), the amplitude of the current I_L is not sufficient to cause saturation. The inductance of L_4 increases suddenly at the threshold and the voltage drop across it increases. The current I_2 which charges capacitor C_4 increases. Charging continues until the current through L_4 is sufficient to cause it to switch to the saturated state at time t_2. The capacitor discharges

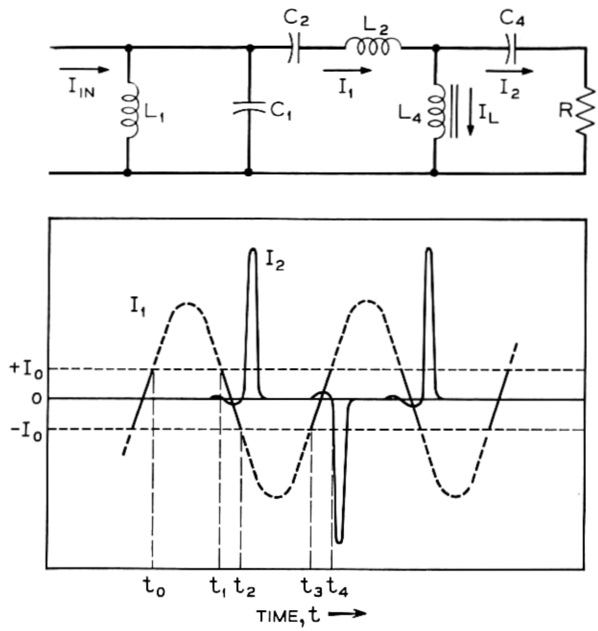

Fig. 24 — Typical pulse waveforms.

through the load resistor. The resistance, capacitance, and saturated inductance effectively in the circuit are adjusted to permit the current to rise to a high maximum, to damp the pulse, and to shorten the pulse duration to the point at which the highest harmonic required reaches the desired amplitude. The pulse dies away before the end of the cycle at time t_3. At that time, the currents and voltages are the same, except for reversals of sign, as those at the start. So, the current wave consists of an alternating succession of these positive and negative pulses. Thus, only odd-order harmonics are generated when the core of the nonlinear coil is unpolarized, as is the case here.

12.3 *Amplification and Regulation of Carriers*

The harmonic generation and selection process yields tones of the required purity but the available power is subject to moderate variation. Since the output of each of the crystal filters is low, an amplifier is required to provide sufficient power for 26 terminals. Therefore, each amplifier has been designed to provide regulation as well as power gain. Fifteen amplifiers receive inputs from the 15 bandpass filters. The one remaining amplifier receives its input from a frequency doubler; thus, an input of 152 kHz produces an output of 304 kHz. The sixteen amplifiers are all alike and each is equipped with monitoring facilities which determine whether the output current is within specified limits. A relay initiates office alarms whenever the output is not within proper limits.

Two independent amplifiers and a common monitoring circuit comprise a plug-in assembly which has been designated as the dual amplifier unit. Two dual amplifier assemblies, a working unit and a standby unit, are connected as shown in Fig. 25. The "failure" of either amplifier in the regular dual amplifier unit causes an automatic transfer to the alternate unit.

The circuit for one of the amplifiers on a dual amplifier unit is shown in Fig. 26. The nominal input to an amplifier is −5 dBm, but it may be as low as −14 dBm or as high as 0 dBm. For any input within this range, the power output is required to be between +22.5 and +23.5 dBm. Although the amplifier must provide sufficient gain to satisfy the power requirements of the carrier system, its most important performance characteristic is the ability to regulate automatically the amplitude of the output voltage.

The mechanism by which the regulation is achieved is an interesting feature of this circuit. The level of the input signal is raised by the gain of transistor Q_1 to provide a strong current drive for the "push-pull" output stage. During a part of each cycle when the signal is close to a zero crossing, the output stage acts as a linear amplifier and produces a corresponding voltage across the load. However, this con-

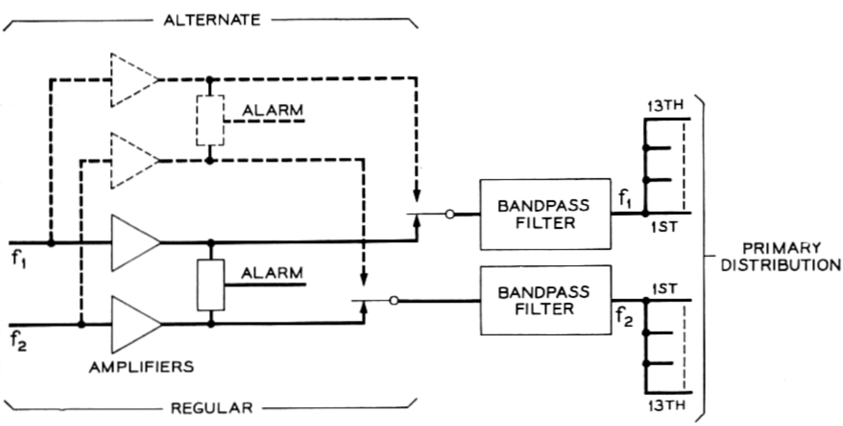

Fig. 25 — Amplification and distribution.

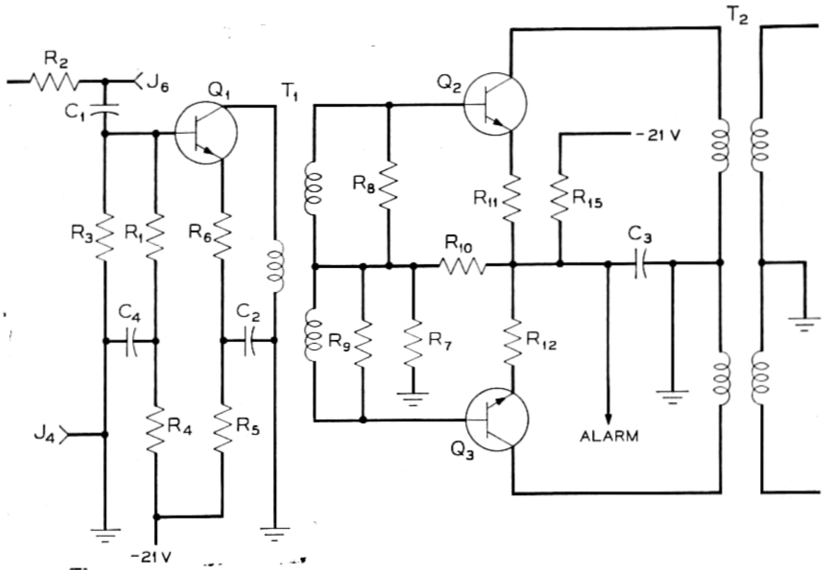

Fig. 26 — Regulating amplifier.

dition lasts for a small fraction of the cycle because bias and load have been chosen to force one of the transistors into saturation and the other into cut-off. During the subsequent interval, almost all of the voltage across capacitor C_3 appears across one-half of the primary winding of transformer T_2. The energy stored in C_3 is adequate to maintain a nearly constant voltage across the load during this interval. The process is repeated during the next half-cycle with the voltage being applied across the other half of the primary winding. The net effect is to produce across the load an alternating voltage having a trapezoidal waveform. The magnitude of this voltage is determined almost entirely by the voltage on capacitor C_3. Resistors R_{11} and R_{12} aid in producing odd symmetry in this waveshape; and hence, reduce the even-order harmonics in the output. The magnitudes of the odd-order harmonics will, of course, be substantial.

This mode of highly nonlinear operation produces a distorted output waveform; but a relatively simple filter will separate the fundamental component from the harmonics when the input signal is a single frequency sinusoid. Measurement shows that the amplitude of the fundamental component is almost constant for a wide range of input signal magnitudes.

During the operation of the circuit as a regulating amplifier, the transistors switch current pulses periodically from one half of the primary winding of transformer T_2 to the other. Alternating current flows in the output circuit of the transformer, and a voltage builds up across capacitor C_3. The duration of the current pulse depends upon the amplitude of the input signal, but the peak magnitude of the pulse is almost proportional to the voltage across capacitor C_3. Regulation is achieved by allowing this voltage to increase when the pulse duration is shortened; i.e., when the input signal decreases. This is accomplished by supplying all the current through resistor R_{15} which is connected to the -21 volt supply. The constant component of the voltage across C_3 depends upon the area of the current pulses, and this voltage must equal the supply voltage less the voltage drop across resistor R_{15}. This resistor, together with trimming resistors as required by a factory adjustment, provides the means for adjusting the output voltage to the required magnitude.

The output of the amplifier is delivered to a bandpass filter which is part of the primary distribution circuit. The unwanted harmonic voltages are suppressed, leaving a relatively pure sine wave of the wanted frequency. By placing the filter on the primary distribution panel, the plug-in amplifier assemblies can be made alike. They can be used interchangeably in all positions requiring the dual amplifier. Fig. 27 shows typical measurements of the variation in output power

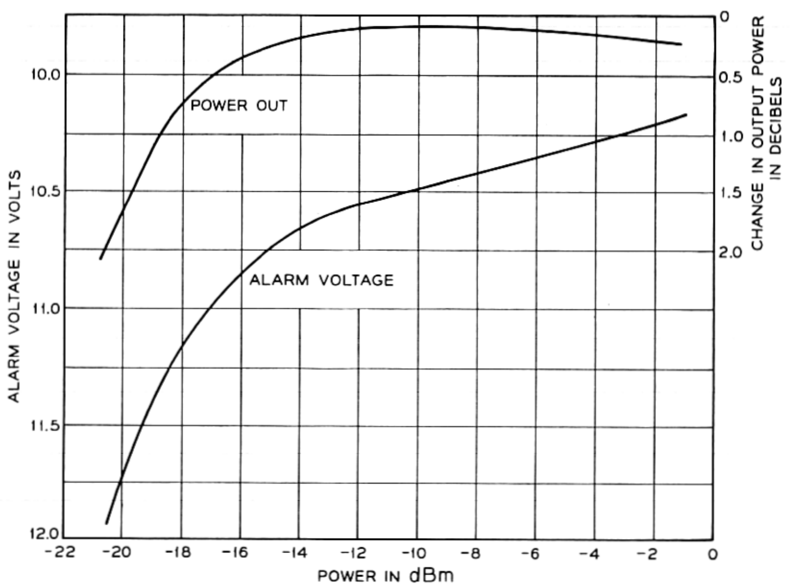

Fig. 27 — Regulating amplifier output power as a function of input signal.

as the input signal is varied over a wide range. Since the measurements were made at the output of the primary distribution system, the filter has selected the fundamental and suppressed the harmonics. The frequency is the same as the input signal, but the variations in amplitude have been drastically reduced.

Fig. 27 also shows the variation in the voltage across capacitor C_3. The magnitude of this voltage is directly related to the output voltage; and thus, it is a convenient means for monitoring the amplifier output. The curve has been labeled "Alarm Voltage" because this voltage is used to initiate alarms when the output power is not within specified limits.

The two regulating amplifiers in the dual amplifier unit share the common monitoring circuit shown in Fig. 28. The diodes CR_1, CR_2, CR_3 and CR_4 together with the associated resistors form a logic circuit. If the voltage on either the ALM IN A or the ALM IN B leads increases or decreases sufficiently, one diode conducts and applies a signal to the summing amplifier. The output of the summing amplifier which causes the trigger circuit to operate the relay K_1 is taken from the collector of Q_5. Either an increase on the Q_4 base or a decrease on the Q_5 base causes the collector voltage of Q_5 to decrease. Thus, the circuit permits establishing both upper and lower limits; and the relay operates whenever the signal is not between the limits. Transistors Q_9 and Q_{10} are connected to form a Schmitt trigger circuit. Regeneration occurs when the gain of the positive feedback loop

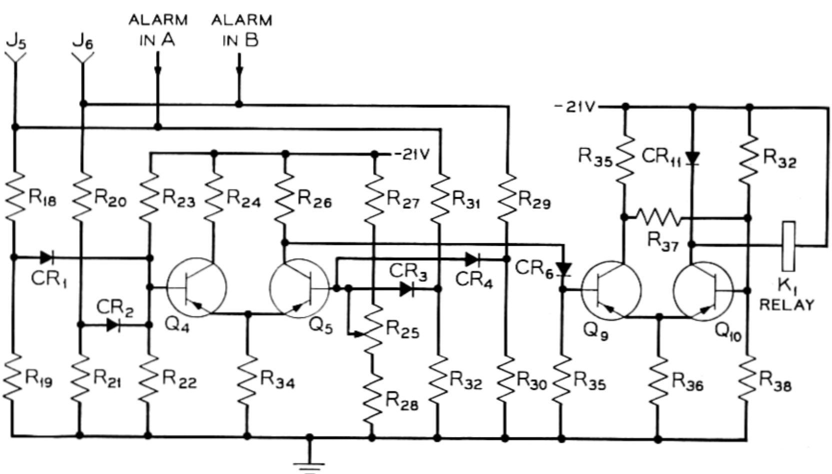

Fig. 28 — Monitoring circuit.

exceeds unity. The switching process proceeds rapidly when the threshold voltage is crossed.

XIII. PRIMARY DISTRIBUTION CIRCUIT

The distribution of carrier-frequency voltages to as many as 26 carrier terminals requires a large number of cable pairs. The number increases rapidly with the number of carrier terminals; and to achieve economy and convenience, the distribution is accomplished in two stages. A primary distribution unit which is part of the carrier supply assembly may be connected to as many as 13 secondary distribution units. One secondary distribution panel is furnished for every two terminals, and it supplies all of the carrier voltages needed. The 16 carrier frequencies are fed to each secondary distribution panel on 19 pairs in an interconnecting cable. Two pairs are used for each of the two channel group carriers and for the group carrier. One pair is used for each of the 12 channel carriers and for the N3 to L translation carrier. An adjustable pad is provided at each of the 19 inputs to the secondary distribution unit. These pads provide a means for compensating for the losses in the interconnecting cable which may vary in length from a few feet to a maximum of 700 feet.

The primary distribution panel provides means for connecting 13 secondary distribution units to the carrier supply. The circuit includes 16 bandpass filters, one being used for each carrier frequency. Each filter suppresses the unwanted harmonics generated in the regulating amplifier and delivers a sinusoidal wave form having the wanted carrier frequency to a multiplicity of resistance loads. The resistance loads are connected through capacitors that are part of the filter structure. A simplified schematic circuit for the primary distribution of one of the 16 carrier frequencies is shown in Fig. 29.

The principal function of each filter is to suppress harmonics, and a low-pass filter would be adequate for this purpose. However, the net-

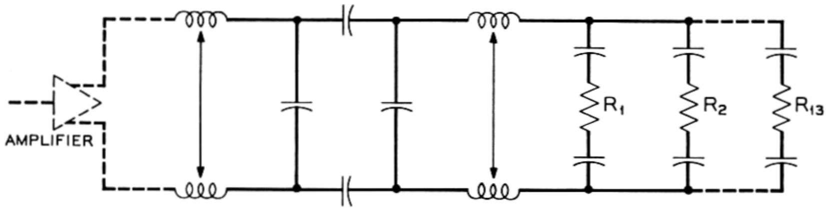

Fig. 29 — Primary distribution circuit.

work used is an impedance transforming bandpass filter designed for insertion between a source impedance, R, and an impedance, R/N, which represents N loads connected in parallel. The output loads are independent circuits, and it is important to provide isolation between them so that one will not react upon another. This has been accomplished by placing a capacitor in series with each load. By designing the filter to include the capacitor, sufficient isolation is achieved without loss of power. The filter is adjusted to present a resistive termination of 115 ohms to the limiting amplifier when each output load is 115 ohms. All of the outputs are terminated in either a cable pair having a 115-ohm load at the far end or with a 115-ohm resistor which is furnished with the unit. These resistors are removed by cutting leads when a cable is connected.

XIV. SECONDARY DISTRIBUTION CIRCUIT

Although only 16 different carrier frequencies are needed by each carrier terminal, many different voltages are required for the circuits in each terminal. A fully-loaded carrier frequency supply and the 26 carrier terminals that it serves would require 1482 interconnecting pairs. By locating a secondary distribution unit in each terminal bay the lengths of the interconnecting cable pairs are minimized. Arranging the distribution system in two stages is economical and also provides flexibility in locating the carrier terminals.

Each secondary distribution unit receives inputs from 19 pairs which connect it to the primary distribution panel of the common carrier supply. Two N3 terminals are connected to a secondary distribution panel with a total of 114 pairs. Fig. 30 shows the plan for the secondary distribution circuits.

As shown in Fig. 30, each of the 19 incoming cable pairs is connected to an attenuator. These pads are adjustable in 0.5 dB steps and are used to compensate for variations in losses in the cable between the primary distribution panel and the secondary distribution panel. The output distribution networks are designed to provide isolation between the outputs. Six carrier regulator circuits are used to control accurately the amplitudes of the six transmitted carrier frequencies. These regulators are similar to the output stage of the regulating amplifier shown in Fig. 26.

XV. SWITCHING AND ALARM CIRCUIT

As the number of carrier terminals connected to a common carrier supply increases, it becomes important to minimize the possibility of service interruptions. The more vulnerable components of the N3

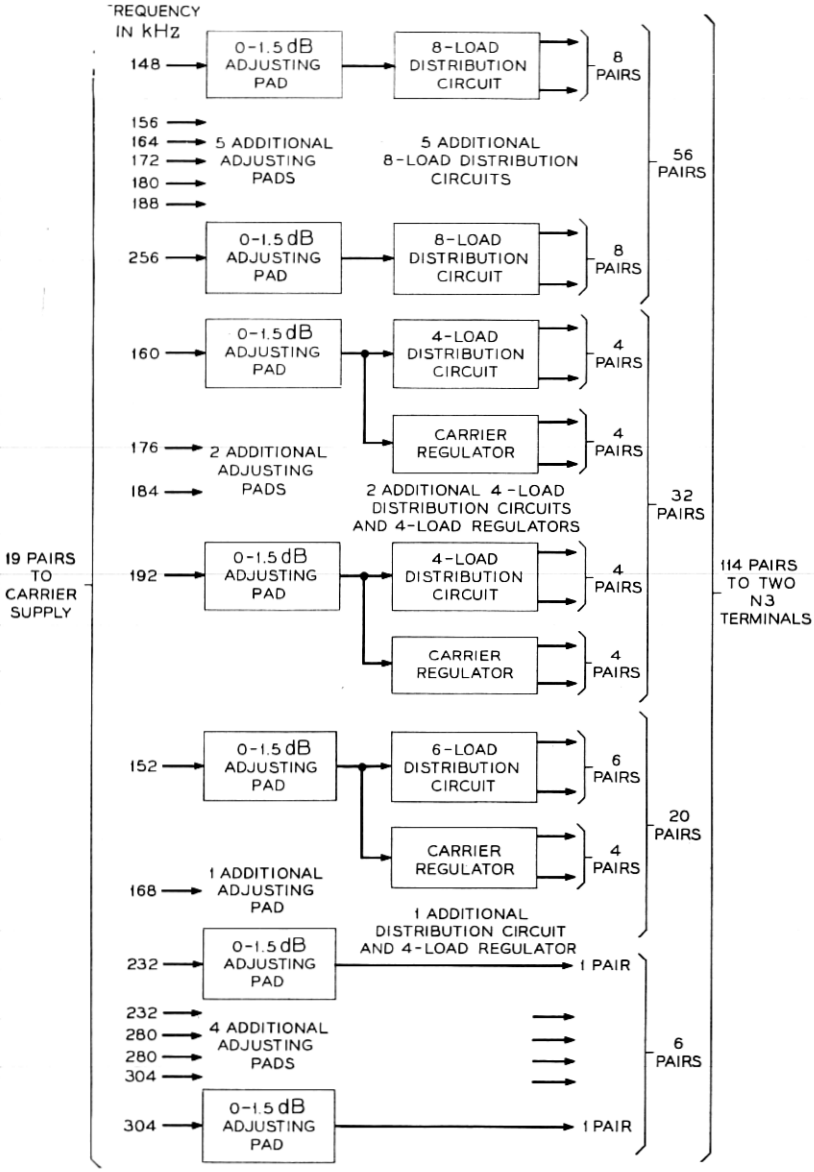

Fig. 30 — Secondary carrier distribution circuit.

carrier supply have been assembled as plug-in units that can be replaced easily. Also, the shelves on the bay frame have been equipped with pairs of receptacles wired so that plug-in components can be used in duplicate pairs to provide standby protection.

If duplicate units are provided, both the regular and the alternate units are maintained in an operating condition and their outputs are monitored at all times. Automatic detection and switching facilities select from each pair and connect into the system one unit whose output is within specified limits. Manual switches for producing a transfer are provided as an aid in maintenance. A trouble indicating lamp near each unit is lighted if the output is not within prescribed limits. Simultaneously, the appropriate major or minor alarm is initiated.

The principal function of the automatic switching circuit is to maintain continuity of service by transferring the load to a standby unit whenever a regular unit becomes defective. Another important function is to aid maintenance and supervision of the carrier supply by providing means for making a manual transfer from one unit to the other. The schematic diagram for the configuration of the contact network in the control path for a typical transfer relay is shown in Fig. 31.

The input conditions that initiate and control the action of the transfer relay are derived from the relays in the monitoring circuits on the regular unit (designated R), and the alternate unit (designated A), and a manual key on the switching and alarm panel (designated S). The schematic diagram represents normally open contacts by crosses and normally closed contact by bars. The R and A relays are in the normal released state when the units are within limits. As shown in the diagram, the S switch is selecting the regular unit, both the regular and the alternate units are within limits, the transfer relay is released, and the load is connected to the regular unit. Current

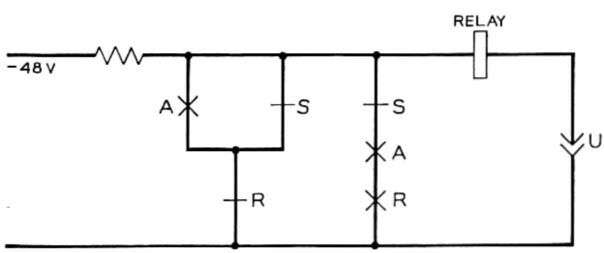

Fig. 31 — Relay control circuit.

flows through the closed R and S contacts in the left-hand path and the relay is prevented from operating. If the R unit fails, this shunt path is opened, and the relay operates to transfer the load to the A unit. If the S switch is turned to the alternate position, the shunt path is opened and a manual transfer is completed when the transfer relay operates.

The contact designated U is a link through the connector to the plug-in assembly. It is closed when the alternate unit is inserted. This interlock circuit inhibits either automatic or manual transfers whenever the carrier supply is not equipped with an alternate unit.

The right-hand path becomes effective whenever both units are out of limits. The key can be used to select either unit. This feature is desirable since the system may still be usable (with impaired performance) if one of the units is not too far out of limits.

Both the major and the minor alarm systems include a relay operated by a flip-flop circuit and means for generating a driving pulse whenever a monitoring relay operates in any of the protected units. After the alarm circuit has been operated by a pulse, the flip-flop circuit can be reset by using the reset button. Thus, a second pulse will produce a second alarm even though the first trouble has not been cleared.

The minor alarm is activated whenever either an R or an A relay operates on one of the plug-in units. The major alarm is activated whenever both the R and the A relays operate on any pair of plug-in units. Thus, a minor alarm means that at least one unit is working without standby protection. A major alarm means that at least one of the carrier frequencies is out of limits. When an alarm occurs, the lamps associated with the separate units indicate which units are out of limits. Replacement of a defective unit restores the system to the normal condition.

XVI. PRIMARY SOURCE OF POWER

The primary source of power for the carrier supply is the −48 volt plant battery. Since the types of transistors selected for the amplifiers cannot be operated efficiently with supply voltages much greater than 20 volts, a dc-to-dc converter is used to provide an efficient internal −21 volt source. Regulation and voltage transformation are accomplished by using a transistor as a switch. A control circuit causes a transistor to conduct and to be cut off periodically at a nominal switching rate of 10 kiloHertz per second. The output voltage is determined by the fraction of the total cycle during which the transistor is conducting. A large smoothing capacitor is charged by the current pulses; and the dc output voltage is proportional to the area of the pulses. The regulator circuit compares a fraction of the output voltage with a reference voltage provided by an avalanche diode. The comparison circuit changes the current pulse duration so that the desired voltage is maintained. The voltage is adjusted initially and is maintained thereafter within the range -21.0 ± 0.1 volts. Since the carrier voltages delivered to the primary distribution system are proportional to the voltage of this -21 volt supply, precise regulation is required. Both high-voltage and low-voltage alarms are provided. This is the same power supply used in the N3 terminal.

XVII. SUMMARY

A new 24-channel single-sideband terminal has been developed to supersede the existing ON terminal. The N3 terminal employs such new circuits as the common carrier supply and the frequency correction circuits to achieve its excellent performance. Full use has been made of the advances in the solid-state art, crystal filter design techniques, and high-performance miniature transformers. The N3 system performs significantly better than ON while being easier to install and maintain. It has been designed with a potential for full flexibility with the long-haul systems.

The first N3 terminals were placed into operation between Texarkana and Dallas, Texas on December 6, 1964.

XVIII. ACKNOWLEDGMENT

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