The N2 Carrier Terminal — Circuit Design

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(Manuscript received December 7, 1964)

The N2 carrier circuit design takes advantage of solid-state technology to provide economies in power consumption and space requirements over earlier N-carrier equipment. At the same time, improvements in performance have been obtained in the areas of noise, signal distortion, and net loss stability. The last two are obtained through the extensive use of negative feedback in amplifiers and regulators and the use of variolosser diodes in the compandor which are stable over a wide operating range. Wider effective channel bandwidths have been attained. Where the terminal is used for nonvoice services, the resulting decrease in delay distortion is significant. Maintenance and testing on an in-service basis have been provided, including in-service switching of group units and power supplies.

I. INTRODUCTION

During the early 1950's there began to appear a series of carrier telephone systems intended for short-haul use. The first of these was N1,[1] a 12-channel double-sideband system for single-cable application. The rapid growth of the telephone plant resulted in large demands for these systems. Advances in the art, particularly those associated with the transistor and other solid-state devices, have made possible an improved design of the N system terminal. The circuits used in the new N2 terminal are described in this paper.

The N2 carrier system functions primarily as a connecting link over moderate distances for four-wire voice-frequency circuits. Basic considerations affecting the system layout are covered in a companion paper.[2] The principal features of the earlier N1 system are retained, including the use of compandors, double-sideband modulation and detection, and gain regulation on both a group and an individual channel basis, as well as provision for slope and flat gain adjustment of

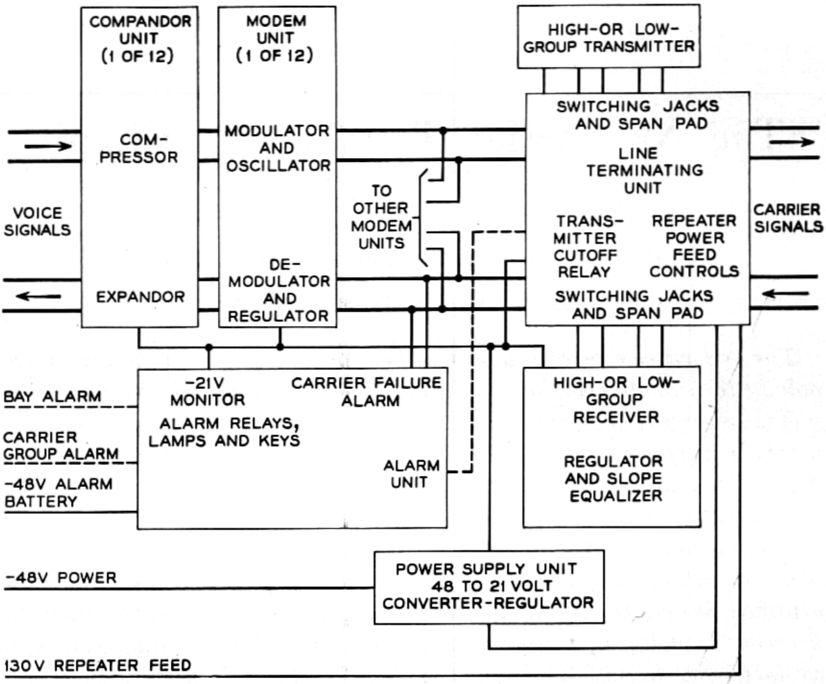

Fig. 1 — N2 carrier terminal.

levels at both ends of the line. Channel frequency assignments are unchanged.

Fig. 1 is a block diagram indicating the over-all circuit arrangement of the N2 terminal. The first step in preparing a signal for transmission over the N carrier system is to compress the volume range. Voice signals arriving at the carrier terminal may have a volume range as large as 60 db. For optimum system performance it is necessary to reduce this volume range to 30 db. This is accomplished by a compressor circuit which operates on a logarithmic basis. Each change of 2 db in the incoming signal is reduced to a variation of only 1 db in the outgoing signal. This increases the level of the lowest-volume signals by approximately 30 db, to a point where they are much less susceptible to noise interference which may be picked up in subsequent transmission over the line. The compressed signal is applied to a modulator where, after going through a band-limiting filter, it is modulated and added to a carrier frequency of accurately controlled amplitude. This fixes the carrier-to-sideband ratio of the signal transmitted over the carrier line. The carrier frequency is generated by a crystal-controlled oscillator which is an integral part of the modulator unit. The modulator output is a double-sideband modulated signal. This is delivered to a summing circuit where it is combined with similar outputs from 11 other compandor and modulator circuits.

The carriers are spaced 8 kc apart, and both sidebands can be transmitted over the N line without interference between channels. The composite signal arriving at the summing point occupies the frequency band 172 to 268 kc. This is referred to as the high-group frequency band. Signals are transmitted over the line both in this frequency range and in another range commonly referred to as the low group. The low-group frequencies are from 36–132 kc.

The 12-channel composite signal is at a low level when it leaves the summing circuit. It also contains a large number of unwanted modulation products. These deficiencies are eliminated in the group transmitter. Two types of group transmitter are available. If transmission is to be in the high-group band, then a simple filter to select this band and a power amplifier to raise the levels to those desired on the line will be sufficient. On the other hand, if low-group transmission is desired, it will first be necessary to select the desired frequencies, modulate them with a carrier frequency of 304 kc, select the lower sideband resulting from this modulation step and amplify it to the desired line transmitting levels. In either case, the input and output of the group transmitter are wired through a line terminating unit which serves several functions in addition to the obvious one of connecting the carrier frequency signals to the line. First of all it provides access points for making in-service tests on the group transmitters and also for making in-service switches for maintenance purposes. In addition, the line terminating unit contains lightning protection devices and means for feeding simplex power over the lines to provide the energy required by remotely located repeaters.

Although the carrier line signals are transmitted and received over separate cable pairs, they are separated further by being placed in different frequency bands to simplify crosstalk suppression problems. Thus a particular terminal may be receiving high-group and transmitting low-group signals or vice versa. Except for this distinction and the obvious level differences, signals arriving at the carrier terminal from a distant repeater are treated in a manner inverse to that accorded to the outgoing signals. The 12-channel composite signal enters the line terminating unit with its protection and power supply features. Provision is also made for adding loss to the circuit in cases where the distance from the nearest repeater is relatively short. This loss brings the signal levels within operating range of the regulation circuit in the group receiver. Two designs of group receiver are available. If the received signals are in the high-group band, then the unit known as the high-group receiver will select the desired frequency band and amplify the signals to the desired output level. If the incoming signals are in the low-group band, then the group receiver will select this band, perform a modulation process to convert these to the high-group frequency band, equalize for line slope, amplify the resultant signal and regulate its level. Therefore the signals coming out of a group receiver are always in the high-group frequency range. Regulation is on a total power basis, so that any errors in line equalization must be further compensated by regulation in the channel receiving units.

The channel demodulator contains a highly selective bandpass filter which selects one of the 12 channels available at this point. Since this is a carrier-transmitted system, a simple full-wave rectifier is adequate for demodulation purposes. Moreover, the carrier is transmitted at a known level relative to the sidebands, and this information can be used for regulating the voice-frequency output level. The resultant signal is passed to an expandor circuit which inverts the operation performed at the far end by a compressor. Each change of 1 db in the input signal to the expandor appears as a 2-db change in the level of the signal coming out of the expandor. Thus the received signal is restored to the full 60-db volume range it had when it arrived at the transmitting N carrier terminal.

Power for the N2 carrier terminal is obtained from the 48-volt office battery. However, substantial economies are obtained by interposing a dc-dc converter between this battery and the active circuits of the N2 terminal. By doing this, a tightly regulated power supply is obtained which is quite free of the usual types of noise encountered in battery supplies. The output of the converter is regulated to 21 volts $\pm$ 1 per cent for input voltage variations of 10 per cent or less. Both the lower voltage and the tight regulation make possible greater efficiency in the choice of bias conditions for the transistors. The power supply itself has an over-all efficiency of better than 85 per cent.

The state of the terminal is continually monitored by an alarm unit. One function of this unit is to maintain a check on the power supply and to provide a warning in case the 21-volt output goes outside working limits. Another function is to monitor the received carriers and to provide a warning whenever their level changes significantly from the normal value. In case there is a total failure of the received carriers such as would happen in the case of a line break, a processing circuit takes over and initiates certain alarm and checking conditions which take the system out of service until normal operation has been restored. The alarm unit also contains an access jack through which terminal power may be supplied from an external source, permitting removal and replacement of the normal power supply unit in the terminal without interrupting service.

II. COMPANDOR

Each terminal contains compressor and expandor circuits, the combination being designated a compandor. Although these units are closely associated in a given terminal, it should be kept in mind that it is the performance correlation (tracking) between a compressor at one terminal and an expandor at a distant terminal which affects channel net loss.

The compression and expansion functions are performed by controlled resistance pads known as variolossers. The heart of the variolosser is a pair of diffused silicon diodes whose ac impedance is an accurately calibrated inverse function of a small dc bias current of the order of 10 to 300 microamps. Using the diode pair as a shunt element in a high-impedance circuit and making the bias current proportional to the magnitude of the compressed signal gives the desired compressor action. Using the diodes as series elements in a low-impedance circuit and making the bias current proportional to the compressed signal gives the desired expandor action. Voice currents in the diodes must be kept small relative to the bias currents to avoid harmonic distortion.

The diode bias current is obtained by rectifying the compressed voice signal. This is done in a full-wave rectifier having relatively fast response time so as to follow the syllabic variations of speech. The voltage to be rectified is obtained from a transistor amplifier.

The compressor is "backward acting," since the compressed signal required to drive its variolosser appears at its output, while the low signal levels suitable for control by the variolosser appear at its input. This creates a potential feedback path which may produce low-frequency oscillations. The present design depends on the longitudinal balance of the variolosser to give high loss in this feedback path. This requires a high degree of inherent balance in the diodes and in their individual bias currents. The amplifier must be capable of delivering 80 milliwatts to the rectifier to develop the required bias current. This is almost the total output, since only 1 mw is delivered to the channel modulator.

The expandor receives a compressed signal from the channel demodulator and hence must be "forward acting." The received voice frequency current is split, with the major part going to a control amplifier, while a small fraction is fed through the variolosser and an amplifier to the four-wire voice circuit. Both of these amplifiers are capable of delivering 80 mw to their respective loads. The output of the control amplifier is rectified and delivered as a dc bias to the variolosser diodes, with the result that for each 1 db increase in the voice signal the loss of the variolosser is reduced 1 db. This results in a 2-db increase in output to the four-wire circuit.

A schematic of the compressor circuit is shown in Fig. 2 and the expandor schematic is shown in Fig. 3.

In designing these circuits economy and compactness have been stressed. To this end semiconductor devices have been used throughout. The amplifiers use alloy junction pnp germanium transistors in the first stages and diffused silicon npn transistors in the output stage. The germanium units are Western Electric 12B transistors, which have been in production for several years. The silicon epitaxial 24B transistor was developed for this application. It operates as a linear amplifier over an extremely wide range of current and voltage swings. The higher temperature tolerable in silicon transistors permits class A operation at 340 milliwatts bias and ambient temperature of 140°F with a heat radiator of modest size.

The diffused silicon variolosser diodes also were developed for this application. They have a well-defined and stable ac impedance characteristic as a function of bias current. Variolosser action is obtained by varying this current over the range 7 to 300 microamps, corresponding to an impedance range of 7000 to 160 ohms for each diode. Diodes are used in matched pairs in order to maintain good circuit balance, low modulation distortion and, in the compressor, freedom from singing.

From the previous discussion it will be apparent that when there is no voice-frequency input signal to an N2 terminal, the compressor gain is at its maximum. Such a condition may occur during dialing and switching operations, and it is just at this time that supervisory relays associated with the trunk circuits may produce high-level transient voltages. Such voltages, if allowed to reach the compressor amplifier, would cause serious overload.

Protection against high-level transients is provided by a "click-reducer" varistor connected across the primary of the compressor input transformer. The varistor consists of two parallel silicon diodes which limit the transients to a maximum value of 0.5 volt. This limitation, coupled with the fact that the duration of the transients is less than 4 milliseconds, restricts amplifier overloading to a tolerable range. Recovery from such overloads is sufficiently rapid to permit proper transmission of signaling tones. Those same transient voltages can induce longitudinal impulse noise in voice-frequency inputs to other N2 channels. A grounded shield in the compressor input transformer blocks that source of impulse noise interference to N2 terminals.

The signal-carrying amplifiers in both compressor and expander consist of three grounded-emitter transistor stages. To bring the voice-frequency currents from the low levels necessary for satisfactory variolosser operation to the levels required at amplifier outputs requires about 60 db of voltage gain. This gain is made independent of transistor parameters and their variation by using approximately 35 db of negative feedback. The expandor control amplifier uses a grounded-collector followed by a grounded-emitter stage. Higher signal levels can be delivered to this amplifier, so that only about 20 db of voltage gain is required. Low sensitivity to parameter variations is obtained by using approximately 20 db of negative feedback.

A full-wave voltage-doubler rectifier fed by the compressed speech signal is used to derive the bias currents for the variolosser diodes. A voltage which may be anywhere between 2 and 105 volts, depending on the signal level, is coupled to the diodes through large resistances to produce bias currents proportional to the signal level. Strict proportionality is not obtained because of the finite forward voltages of both the rectifier and variolosser diodes. Because these voltages are subject to relatively wide manufacturing variations, it is necessary to provide low-level tracking adjustments.

Before discussing these adjustments it is necessary to consider the compandor characteristics shown by Fig. 4. As practical matter the 2:1 compressor characteristic can be maintained over only a limited range. This is partly due to the properties of the variolosser diodes and partly to the finite circuit impedance levels required. When the attenuation of the compressor variolosser has been reduced to its minimum value the input vs output curve has a 1:1 slope. The behavior of the N2 compressor is approximated by two solid-line

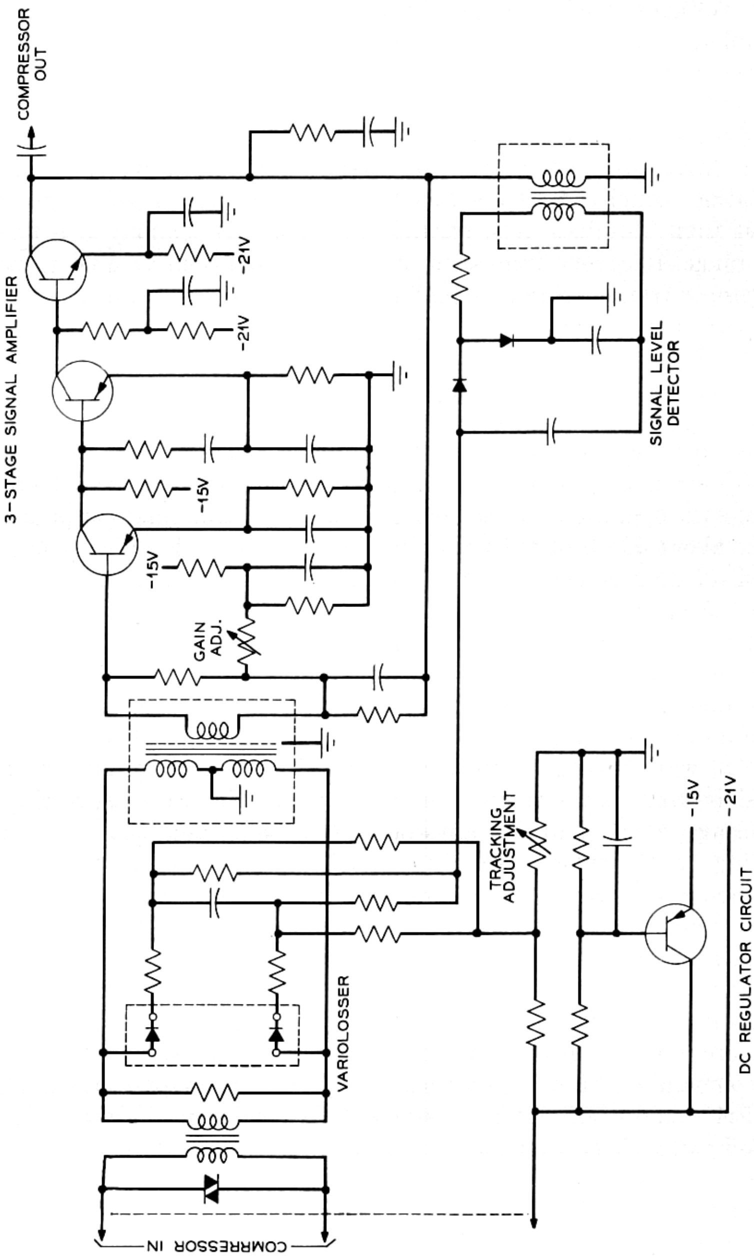

Fig. 2 — Compressor circuit schematic.

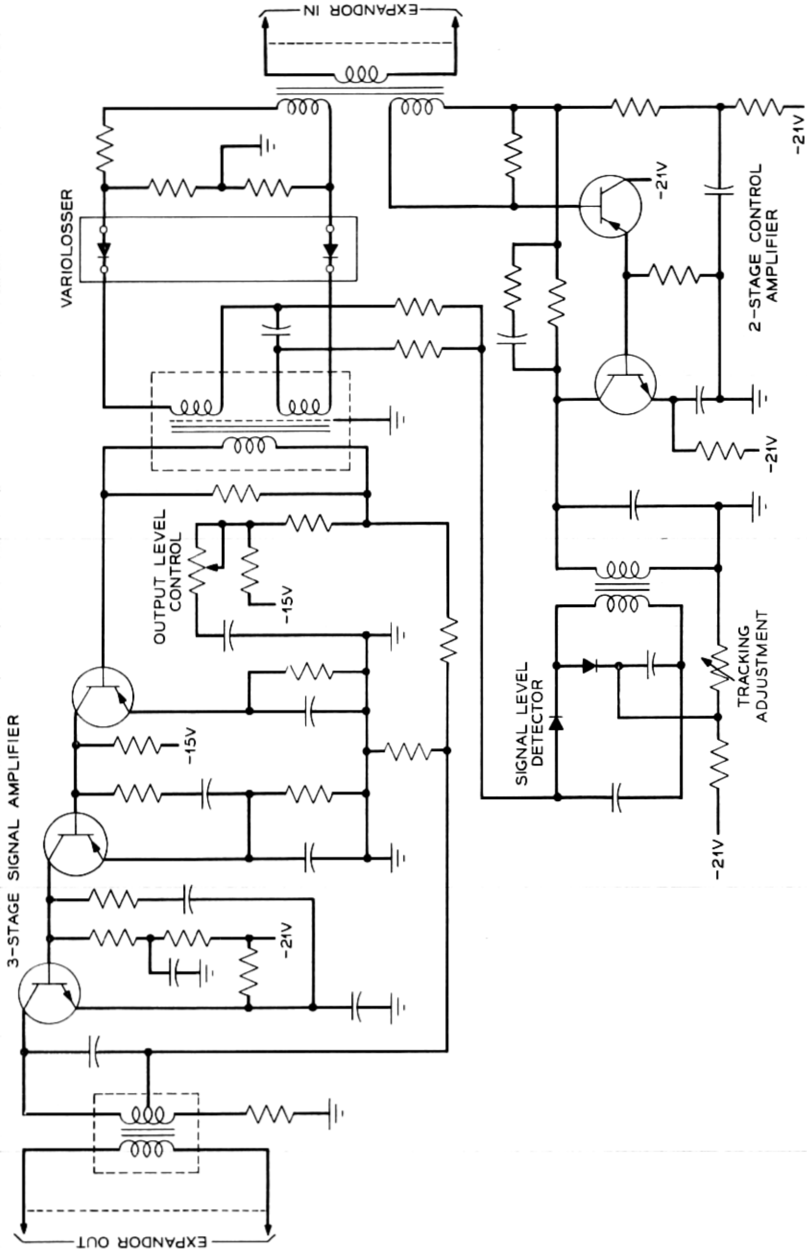

Fig. 3 — Expandor circuit schematic.

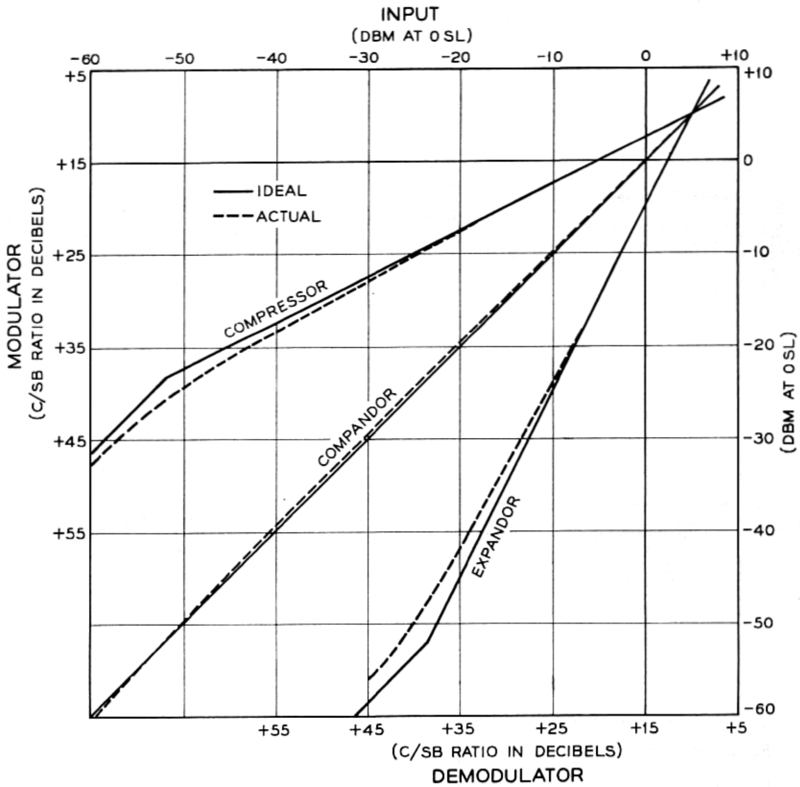

Fig. 4 — Compandor tracking characteristic.

segments, one having a 2:1 slope from +8 to −52 dbm0 and the other a 1:1 slope from −52 dmb0 through all lower values. For good compandor tracking the expandor must follow a complementary pattern, also shown by solid lines in Fig. 4. The actual performance is shown by the dashed curves.

To insure that these curves are matched exactly, so that every compressor will track every expandor, adjustments are provided. Three of these are factory set and one is available for service line-up adjustment. The gains of the amplifiers are set to give the desired outputs with 0 dbm0 input signal. Then the low-level adjustments are made with an input signal level of −52 dbm0. In the compressor the tracking adjustment furnishes a small forward bias to the variolosser diodes and hence determines the minimum loss at extremely low signal levels. There is also developed a small reverse bias on the rectifier diodes which reduces the amount of low-level noise rectified. The tracking adjustment is set to force the compressor output to be −28.5 dbm0 rather than the "ideal" value of −26 dbm0. Similarly, in the expandor the variolosser diodes are forward biased to limit their maximum loss and the rectifier diodes are forward biased to improve efficiency at low signal levels. The tracking adjustment is set to force an expandor input of −28.5 dbm0 to give an output of −52 dbm0.

The end result of these adjustments is the over-all compandor tracking characteristic shown by the central dotted curve of Fig. 4. The maximum deviation from ideal is typically less than 0.2 db and in rare cases may be as much as 0.5 db.

Another important aspect of compandor performance is the response to suddenly applied signals. For example, a 12-db increase in the input signal will appear initially as a 12-db increase in compressor output but will immediately start dropping toward its ultimate value 6 db above the original output. The converse action holds for a decrease in input signal. The rates at which such changes take place have been defined as the "attack" and "recovery" times respectively of the compressor. These times are essentially determined by the rectifier filtering. The full-wave rectifier requires only simple filtering and hence permits fast attack and recovery times.

The CCITT-proposed recommendations furnish a precise definition of these times. The test signal is a 2-kc tone and at a zero system level point its magnitude is switched between −16 dbm and −4 dbm. The envelope of the compressor output wave resulting from such an input is indicated by the solid line of Fig. 5(a), where unit voltage represents the output for a steady input of −16 dbm0. The 12-db input level change temporarily changes the output level to 4 voltage units. However, the variolosser immediately starts reducing the output toward its ultimate value of 2. Attack time, t_a, is defined as the interval between switching and the point where the output envelope reaches the value 3.

After the input signal has been held at the −4-dbm0 level long enough for the output to reach its steady-state value of 2, the input level is reduced 12 db. The envelope of the output signal follows the pattern shown at the right of Fig. 5(a). There is an instantaneous drop to 0.5 followed by a gradual increase to the steady-state value 1. Recovery time, t_r, is defined as the time required to reach the value 0.75. In the first case (attack) the variolosser must increase its loss by the ratio $4/3 = 1.33$. In the second case the variolosser must re-

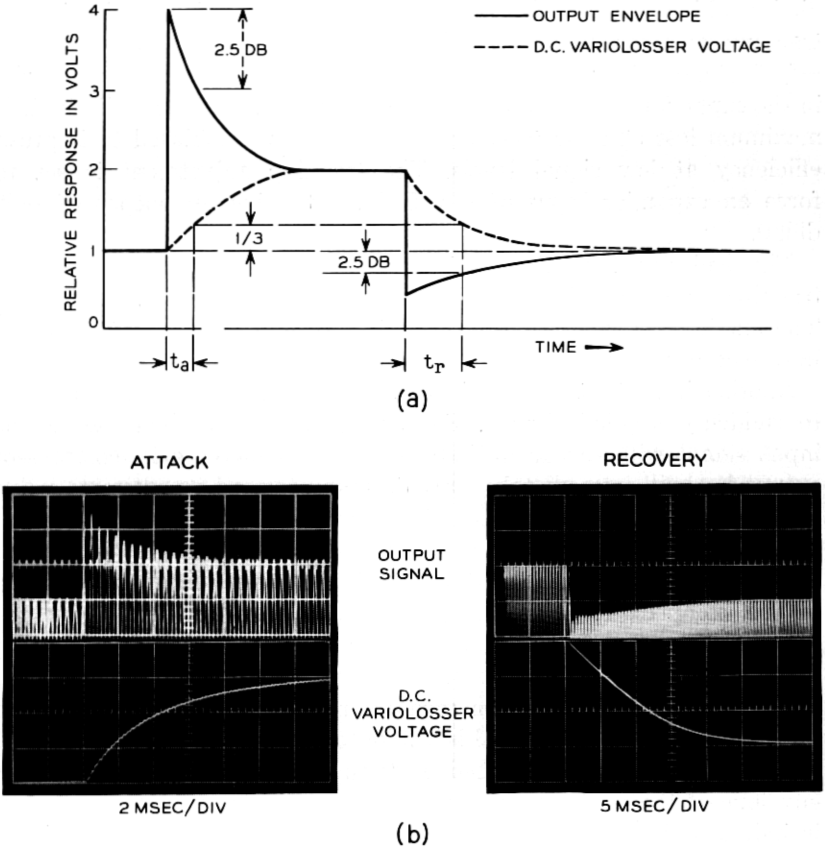

Fig. 5 — Compressor response times: (a) comparison of output voltage envelope to dc variolosser voltage; (b) oscillograms of response times with 2-kc input signal.

cover to the point where its loss is $1/0.75 = 1.33$ times its value with the low-level signal. Hence both times are measured at the instant when the loss is 2.5 db ($20 \log_{10} 1.33$) greater than its value with the steady −16-dbm0 tone.

This fact makes the measurement of the compressor response time relatively simple. The variolosser itself responds instantaneously to changes in the bias current of the diodes. To a reasonable approximation the ac impedance of the diodes is inversely proportional to the bias current and the loss is inversely proportional to the ac impedance. Hence there is a direct proportionality relation between the diode

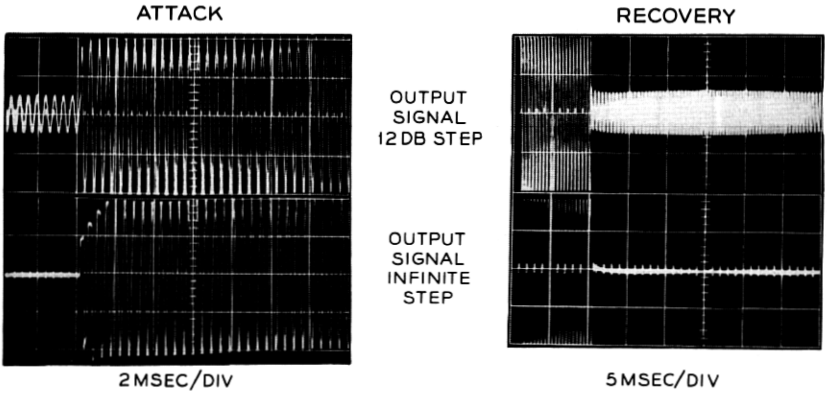

Fig. 6 — Compandor response times to step changes of 2-kc input signal amplitude.

bias current and the loss. Either may be represented by the dashed line of Fig. 5(a).

The behavior of a typical N2 compressor when tested in this way is shown in Fig. 5(b). The upper oscillogram of each pair shows the instantaneous magnitude of the 2-kc output wave and the lower shows a control voltage proportional to the diode bias current. From these it is apparent that the attack time is 1.7 and the recovery time 13 milliseconds. Tentative recommendations of CCITT are 3 ± 2 and 13.5 ± 9 milliseconds for attack and recovery time respectively. The N2 compressor meets these requirements.

In order to obtain good compandor response to stepped changes in signal level, the attack time of the expandor has been made faster than that of the compressor. The over-all result is a very rapid settling of the output signal, as shown by the oscillograms of Fig. 6.

This figure also shows the response to an "infinite" step where the input is suddenly changed from no signal to a tone level of −5 dbm0. At the start of such a tone the compressor is in its maximum gain condition and the output stage overloads. This situation lasts for about 3 cycles, or less than 2 milliseconds.

III. CHANNEL MODEM UNIT

The channel modem unit for the N2 carrier telephone terminal comprises both the transmitting modulator circuit and the receiving demodulator circuit for a particular carrier-frequency channel. Thir-

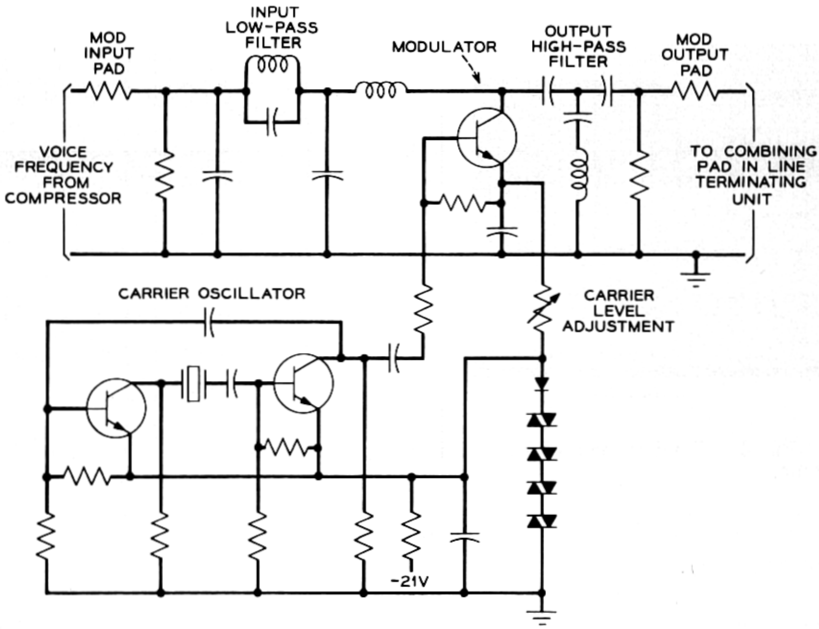

Fig. 7 — Channel modulator circuit schematic.

teen separate channel modem units are available to provide for transmission of double-sideband channels with carrier frequencies spaced at 8-kc intervals in the frequency range from 168 kc to 264 kc inclusive. A complete terminal employs 12 channels, usually channels 2 to 13 inclusive. The lowest-frequency channel (channel 1 at 168 kc) is provided as an option for use in place of any other channel which may be unavailable or unsatisfactory for use at a particular installation.

3.1 *Modulator Circuit*

The output voltage of the compressor is applied to the modulator circuit, which translates the voice-frequency input into an appropriate portion of the frequency spectrum between 164 kc and 268 kc. As shown in Fig. 7, the modulator circuit consists of input and output pads, low- and high-pass filters, a transistor switch modulator, and a crystal-controlled transistor carrier-frequency oscillator.

The input pad is designed to provide a high-impedance load (11,500 ohms) to the compressor and to terminate the transmitting low-pass filter in its design impedance of 3000 ohms. The low-pass filter band-limits the voice frequencies from the compressor, passing frequencies up to 3250 cps with minimum distortion, and suppressing frequencies above 4000 cps by at least 20 db to reduce interchannel interference.

The modulator in the N2 modem is a simple shunt modulator consisting of a transistor switch driven by a square-wave carrier-frequency generator. The transistor switch interrupts the voice-frequency voltage periodically at a carrier-frequency rate, producing upper and lower sidebands on the carrier frequency. The carrier-frequency voltage component of the modulator output is directly proportional to the dc bias voltage on the transistor switch. Since the net-loss stability of the N2 system is directly related to the carrier-frequency output stability, a special temperature-compensated diode voltage regulator is used for deriving the dc bias voltage applied to the emitter of the transistor switch. A variable resistor in the emitter circuit permits factory adjustment of the carrier output to establish a precise carrier-to-sideband ratio for a known input signal.

The output voltage of the modulator is applied to a high-pass filter which eliminates the voice-frequency component of the signal. The output pad terminates the high-pass filter and provides isolation for paralleling the 12 modulator outputs at the combining pad in the line terminating unit. Unwanted components of the modulator output voltage, composed primarily of sidebands on the harmonics of the carrier frequency, are suppressed by the bandpass filter at the input of the group transmitting unit.

The carrier-frequency generator in the modulator circuit is a two-stage multivibrator circuit with a quartz crystal unit as the frequency controlling component. This circuit provides the square-wave output for driving the transistor switch, and for manufacturing convenience permits the 13 modulator circuits to be identical except for selection of the crystal unit.

3.2 *Demodulator Circuit*

The channel demodulator circuit shown in Fig. 8 includes the channel bandpass filter, a regulating amplifier, a demodulator, and a receiving low-pass filter. The bandpass filter selects the particular channel from the output of the group receiving unit. The bandpass filter and the carrier-frequency oscillator crystal unit are at the same frequency for a given channel modem plug-in unit, and these filters and crystal units are the only differences among the 13 channel modem units.

Initial production of N2 channel modem units employed a channel

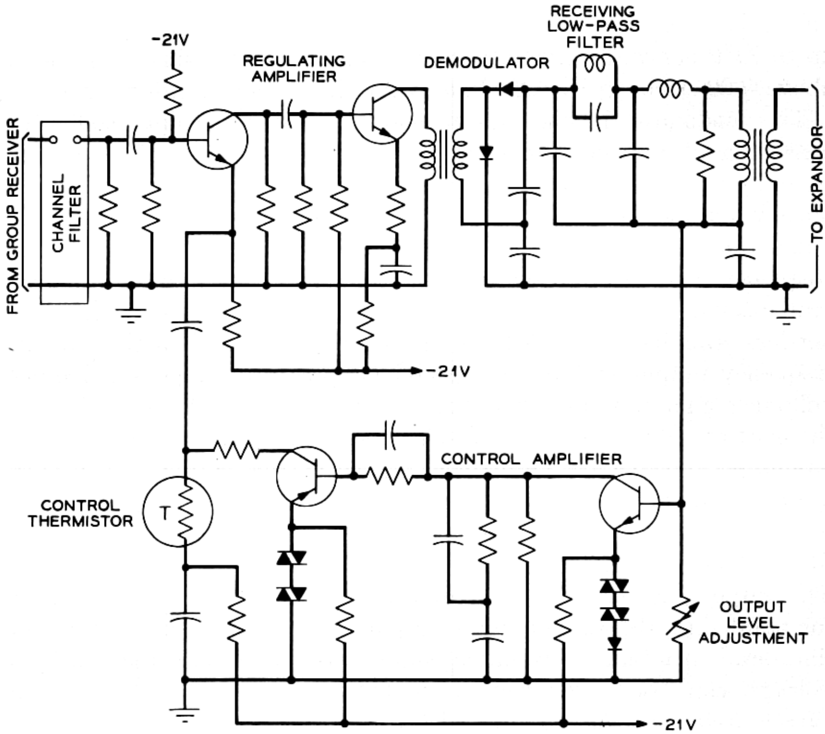

Fig. 8 — Channel demodulator circuit schematic.

filter design using ferrite inductors and capacitors. A new filter design using quartz crystal units has recently been introduced to give improved performance, particularly with regard to time and temperature stability. A typical characteristic of the crystal filter is shown in Figs. 9 and 10. As noted, the filter introduces less than 1 db distortion over the desired voice band and provides a minimum of 45 db suppression to adjacent channel carriers.

The output of the channel bandpass filter is amplified in a two-stage amplifier whose gain is regulated by a thermistor in the emitter circuit of the first stage. The output signal of the amplifier is detected by a full-wave rectifier and transmitted through a low-pass filter to the expandor. The dc component of the detected signal, obtained from carrier-frequency rectification, is compared to the voltage drop across a temperature-compensated diode voltage regulator. The difference voltage is then amplified by the dc control amplifier

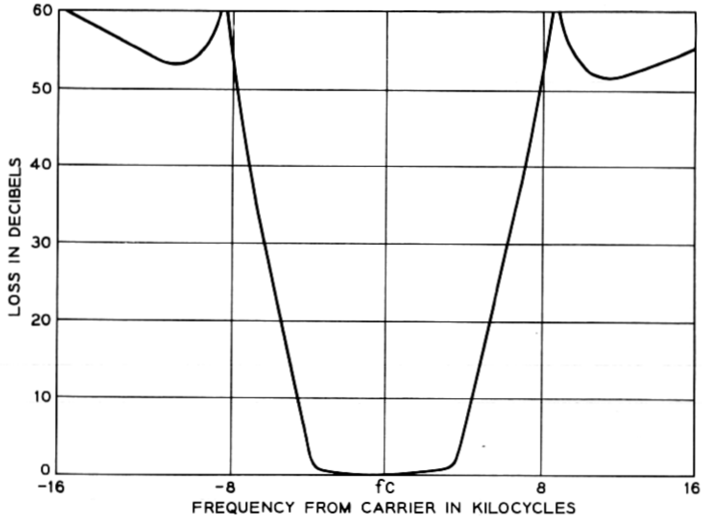

Fig. 9 — Channel bandpass filter characteristic.

and applied to the thermistor to control the gain of the regulating amplifier and maintain the carrier level input to the detector at a constant level. The regulation obtained by this arrangement is shown on Fig. 11. As noted, the variation of a 1000-cycle test tone at the voice-frequency output is less than ±0.25 db for carrier level changes of ±10 db at the input to the channel bandpass filter.

The receiving low-pass filter is designed to equalize at voice fre-

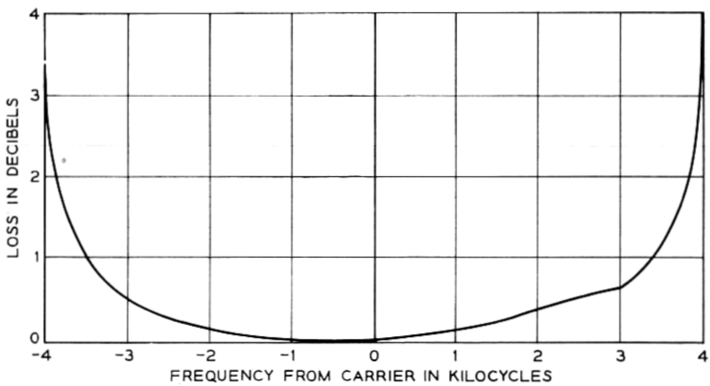

Fig. 10 — Passband distortion of typical channel filter.

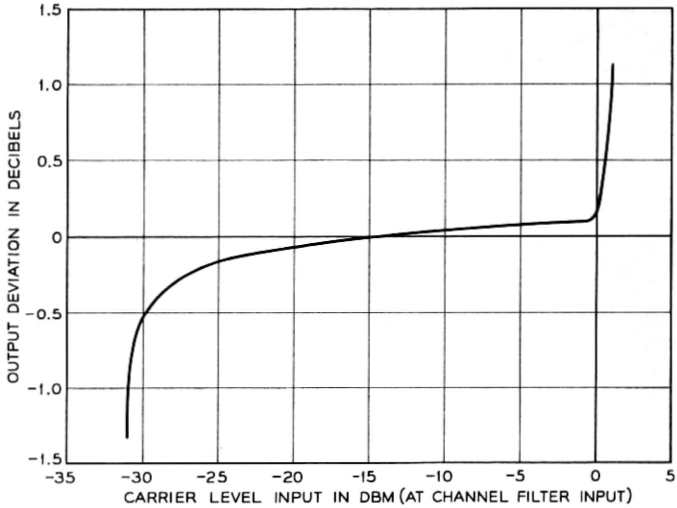

Fig. 11 — Channel modem regulator characteristic.

quencies the distortions introduced by the modulator circuit, the channel bandpass filter, and the compandor. The low distortion and reproducibility of the frequency characteristics of the above components have made possible a single fixed design of the receiving low-pass filter for all channels. The response characteristic of a typical channel for back-to-back terminal measurements is shown in Fig. 12. This figure also shows the expected 2σ limits for the manufactured product.

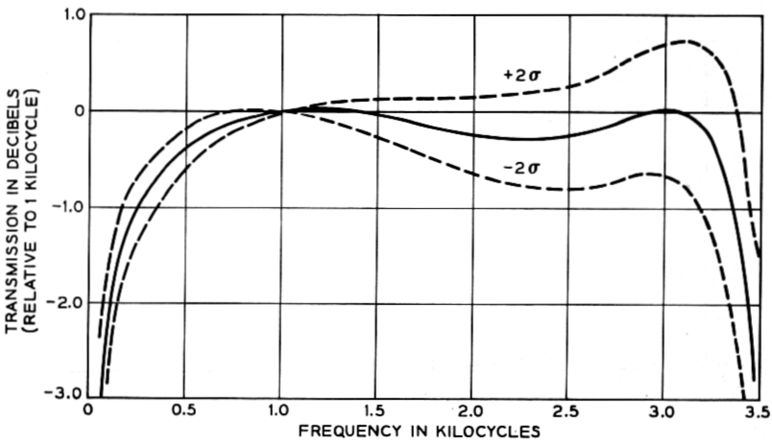

Fig. 12 — Gain-frequency characteristic of an N2 channel.

IV. GROUP UNITS

Four different group unit designs are required for complete flexibility in engineering N2 carrier systems. All of the functions performed by group units are found in the low-group receiver. Therefore a full description will be given of only this one unit, shown schematically in Fig. 13. Signals in this unit first go through a filter which selects only the low-group frequency band and rejects out-of-band noise which may have been picked up due to crosstalk or other sources in the incoming line. The wanted signals are delivered to a ring modulator consisting of a silicon diode bridge and appropriate coupling transformers. A modulating carrier frequency of 304 kc is introduced longitudinally through the transformers. This carrier frequency is obtained from a crystal-controlled oscillator and a driver stage which are integral parts of the low-group receiver. The output of the modulator consists of two sidebands and, because of transformer balance, very little carrier power. The lower of these sidebands is in the high-group frequency range and is selected by an appropriate bandpass filter.

A slope equalizer, selected to correct the attenuation distortion of the preceding line section, is inserted between the modulator and the filter. Therefore the wanted signals are essentially equal in level across the frequency band of interest at the filter output. However, the levels are quite low and amplification is required to obtain appropriate driving levels for the channel demodulators. This amplification is obtained in a three-stage transistor amplifier. To provide adequate power levels, the third stage of this amplifier uses two transistors operating in parallel. Degenerative feedback is also used to further enhance the modulation performance of the amplifier.

The feedback circuit is connected in shunt with the output transformer and to a hybrid tap on the input transformer. This provides the resistive input impedance required by the bandpass filter and a very low output impedance to drive the 12 paralleled channel bandpass filters. To make the impedance terminating the output stage substantially independent of the type and number of channel units actually in service, the output transformer is further terminated in a very low resistance.

Automatic gain control of the amplifier is obtained by including in the feedback circuit a thermistor whose impedance will depend upon the total power being delivered by the output stage. High output power will increase the energy absorbed by the thermistor, heating its internal element, thus reducing its resistance and hence reducing the

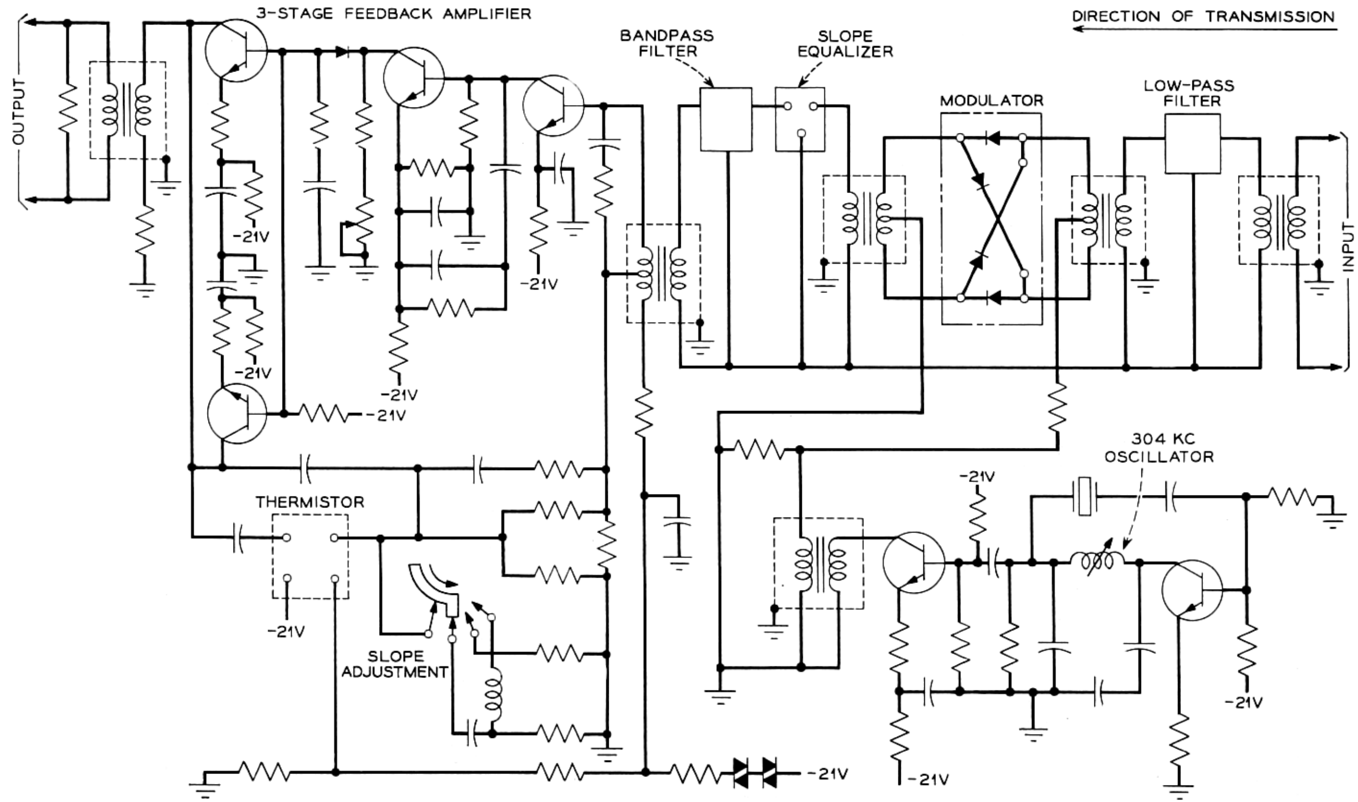

Fig. 13 — Low-group receiver schematic.

gain of the amplifier. In this manner, input level changes of ±8 db can be reduced to less than ±0.5 db. Also included in the feedback circuit are slope networks which can be used to provide fine adjustments of equalization in steps smaller than are obtainable in the slope equalizers. The desired slope network can be selected by operating a switch on the front of the unit.

The high-group receiver may be thought of as a stripped-down version of the low-group receiver. Since the signals received by it are already in the high-group range, the first selective filter, the modulator, and its associated oscillator are not required. Otherwise its performance is the same and it delivers the same signals at the same levels to the channel units. The group transmitters are simpler than the group receivers in two respects. First, since the signals delivered to them are at a constant and desired level, it is not necessary to provide gain regulation; moreover, since they are at the beginning end of a transmission circuit, the fine degree of slope equalization also is not needed. Provision is made, however, to provide some slope equalization which will act to pre-equalize the transmitted signal levels and facilitate line engineering. The low-group transmitter receives the high-group band, modulates it with the 304-kc group carrier, and selects the lower sideband for amplification and transmission to the line. The high-group transmitter does not require the modulation step and hence filters the received signal to eliminate unwanted modulation products developed in the channel modulators, amplifies the resultant signal after slope equalization and transmits this signal to the line.

V. DATA TRANSMISSION

Provision has been made for the transmission of a wideband 40.8-kilobit signal over the N2 system. This is done by removing the channel equipment associated with channels 5 through 11 and substituting equipment which has been designated as the N2WM1 wideband modem. These circuits are designed to accept signals in the band 10.2 to 51.0 kilocycles as generated by the 301B data set and modulate them into the band 203.5 to 244.3 kilocycles in the high-group N2 band. The resultant signal is summed with the six voice channels obtained by using channels 1, 2, 3, 4, 12 and 13 to give a composite signal which is delivered to the group unit and from there transmitted over the N carrier line.

The channel filters used in the wideband modem are delay equalized.

Provision is also made for additional delay equalization to compensate for high-frequency line distortion. The smallest delay equalization unit provides delay equalization for two high-frequency line repeater sections, including one high-low and one low-high repeater. Any number of delay equalization units between 1 and 18 can be obtained by selecting appropriate equalizer units and plugging them into sockets of the equalizer. Thus any number of line sections between 2 and 36 can be equalized. Since provision has not been made to equalize a single repeater section, any line involving an odd number of sections will have the delay errors associated with a single section.

VI. SPECIAL-SERVICE VOICE UNITS

Situations can arise where N2 circuits are connected together on a voice-frequency patching basis. In such cases, if standard N2 equipment were used, there would be several compandors operating in tandem on the same voice-frequency signal. This is undesirable. Therefore a special service unit has been made available which provides the necessary gains without the use of the compandor and its vario-lossers. By substituting the special unit, designated a VF amplifier, for the compandor at the intermediate points the circuit can be set up so as to operate with only one compressor at the transmitting end and one expandor at the receiving end, or the compandors may be eliminated from the circuit entirely. The latter situation is often used in transmitting certain kinds of voice-band data. In this case the signal levels used are somewhat higher than those encountered with voice signals, and therefore the VF amplifier units have been designed for such levels.

Another type of special service unit is the modem designed to handle the wider bands required to provide Schedule C & D program transmission service. These modem units are available only for channels 3 through 7. They differ from the standard units used in these channels only in their wider bandwidth. The wider band is obtained by using higher-quality transformers and improved filter designs.

VII. TESTING AND MAINTENANCE

The N2 terminal requires relatively few maintenance checks. The long life of the solid-state circuit components, adequate feedback in amplifiers and careful temperature compensation require only the simplest of maintenance measurements at intervals as infrequent as 6 or 12 months. Most of the measurements can be made on a working system by bridging conventional test gear at pin jacks located on the front of the plug-in units. A special test set is provided, separate from the N2 terminal, for making out-of-service measurements on compandors, modems or alarm units. Another special test set makes possible the in-service substitution of a stand-by unit for either the power supply or any one of the group units. This permits removal and replacement of these units without a service interruption.

Only one operating adjustment is required. This is provided by the OUTPUT ADJUST potentiometer (Fig. 3) which controls the gain of the expandor amplifier. This sets the over-all net gain of the channel and compensates for any variations from channel to channel occurring in the compressor, modulator and resulting carrier-to-sideband ratio, receiving channel band filter losses relative to its center frequency, channel regulator and expandor variolosser. In addition, the adjustment also mops up variations in the common equipment and carrier line not completely eliminated by the channel regulator. The adjustment is made by introducing a 1000-cycle tone at a standard power at the distant terminal and setting the local output power to a standard value.

VIII. SUMMARY

Circuits for the N2 Carrier System have been designed to take advantage of the special properties of semiconductor devices. The low-current, low-voltage operating points of these devices coupled with the use of a closely regulated dc-dc power supply makes possible a highly efficient design with power requirements approximately one-fourth that of the earlier N1 system.

Significant performance improvements have been achieved in freedom from signal distortion, lower noise and better net loss stability. The latter is obtained by extensive use of negative feedback in amplifiers and regulators and partiuclarly by the uniform characteristics over a wide operating range of the diodes used in the compandor variolosser.

The performance improvements and the simple maintenance procedures have made N2 a very popular system. As of the end of 1964, more than 160,000 channels of N2 equipment have been sold.

APPENDIX

Levels

The concept of "system level" provides a convenient method for keeping track of signal levels at various points in a system. The level diagram shown as Fig. 4 in the companion paper[2] is constructed by assuming 1 milliwatt of power to be injected into the system at a convenient point, which is arbitrarily designated as the zero-level point, and calculating the resultant levels at other points in the system. This is especially convenient while the signals are traveling through linear circuits where the ratio of the magnitude of the output signal to the magnitude of the input signal is totally independent of either magnitude.

However, when we consider the input-output characteristics of compressors and expandors a new dimension is added and further definition is required. Since the primary purpose of a compressor is to permit low-power message signals to produce greater carrier modulation and hence higher sideband levels than would be obtained without compression, it seems natural to define the power or "level" of the compressed signal relative to the power of the carrier signal at some arbitrary level point. The modulation ratio should be chosen as high as possible while still allowing some margin against exceeding 100 per cent modulation under extraordinary, high-power message conditions.

These considerations have led to the following definition for the N carrier systems:

After modulation, a zero system-level point (0SL) is any point where the energy in one sideband is +5 dbm when the signal producing this sideband is +5 dbm at a 0 voice level point. It is a requirement on the N2 system that the magnitude of the (unmodulated) carrier at such a point shall be +15 dbm.* The +5-dbm0 signal is thus the one which is not affected by the compressor and expandor characteristics; it is referred to as the "unaffected level" or "point of no compression" on the compandor characteristics.

The 2-db-for-1 characteristic of the compressor results in a power of +2.5 dbm for one sideband at this reference level point when the voice signal is 1 milliwatt at its 0-level point. Therefore, a test tone of 0 dbm 0 results in a carrier-to-(one)-sideband ratio of 12.5 db. Once the signal has been modulated, the broadband nature of the system insures that subsequent level changes will affect the carrier and sidebands equally. Therefore the carrier-to-sideband ratio is unchanged until the signals reach the channel demodulator.

The presentation of the compandor characteristics in Fig. 4 has

* This hypothetical point is not reached in the N2 system. In a normally operating system, the maximum level of a single carrier is nowhere greater than 4 milliwatts (+6 dbm).

been augmented by the addition of scales showing the carrier-sideband (C/SB) ratio over the appropriate range. The relation between voice frequency input and output of the compandor or either of its parts is shown by the top and right-hand scales respectively. Alternatively, the output of the compressor may be interpreted as that which will result in the carrier-to-sideband (C/SB) ratio at the modulator shown by the left-hand scale. Similarly, the input to the expandor may be interpreted as that resulting from an input signal to the modulator with the carrier-to-sideband ratio shown by the bottom scale.

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