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The N2 Carrier Terminal — Objectives and Analysis

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The N2 carrier terminal, a 12-channel, double-sideband, amplitude modulated multiplex, is the first of a new family of short-haul carrier facilities. The new carrier family is designed to take advantage of improvements possible with solid-state technology and to meet changing needs of the growing Bell System toll network. Increased demands on the short-haul trunks have resulted from the growth of voice and nonvoice services on the DDD network, tightening requirements such as those for over-all net loss variations between channels and gain variations across the channel frequency band. Maintenance and operational features of short-haul facilities also are affected by the increase in complexity and size of the Bell System carrier network: newer equipment must have fewer adjustments, and the design must provide built-in margins to permit longer maintenance intervals and more effective alarm and trunk processing features in case of failure. The new carrier family must compete economically with existing short-haul systems, yet work with in-place carrier systems and facilities.

The new terminal meets the above objectives. In addition, improvements in the performance of N-carrier repeatered lines are indicated as a result of the systems analysis of short-haul carrier systems which led to the requirements for the N2 terminal.

I. INTRODUCTION

A comprehensive development program is in progress to provide a new family of solid-state terminal and repeatered line equipment for short-haul carrier systems. Each unit will meet modern requirements imposed by the long distance Bell System network for the transmission of voice, data, and other special services. The new short-haul family includes:

— a 12-channel double-sideband N2 terminal to replace the N1 terminal
— a 24-channel single-sideband N3 terminal to replace the ON2 terminal
— an N2 repeatered line and its adjuncts to replace the N1 repeatered line.

The members of the family are being designed so that they will be compatible with each other and with their existing short-haul counterparts. Thus N1, ON, N2, or N3 terminals can provide the frequency division multiplexing for the N1 or N2 repeatered carrier lines.

This paper describes the N2 terminal, which is the first member of the new family. Included are the reasons for its development and its important objectives and requirements, system characteristics, and performance. Included also is a discussion of the over-all N system made up of the N2 terminal and the N repeatered line. Companion papers will cover the N2 circuitry in detail and discuss the terminal equipment features.[1,2] The other members of the new short-haul carrier family will be described in subsequent series of papers.

The operating telephone companies began using N2 terminals at the end of 1962 to provide telephone and special-service channels in a number of locations. In 1964 over 9600 N2 terminals were produced by the Western Electric Company. The first use of N3 terminals began in late 1964. The N2 repeatered line equipment is being developed on schedules that will make initial production units available in quantity from Western Electric early in 1966.

II. BACKGROUND FOR NEW SHORT-HAUL CARRIER FAMILY

The new solid-state short-haul carrier family is being developed to meet the changing needs of the growing Bell System network. In the late 1940's Bell Laboratories engineers developed the first short-haul system, the type N1 carrier.[3,4] The N1 channels were designed to provide short-haul toll and exchange trunks up to 200 miles long and the toll connecting trunks used as the end links in a switched, multilink connection. Initially the N1 short-haul carrier system was designed to provide only voice transmission channels. Other channel arrangements were developed in the years that followed. In addition, a number of related systems, including O, ON and ON/K carrier, and the ON radio multiplex, were developed subsequently to meet comparable needs.[5]

As use of direct distance dialing (DDD) has grown in the Bell System, the increasing complexity of the hierarchal switching network with automatic alternate routing has in turn increased the number of trunks that may be switched in tandem. The number of short-haul carrier trunks in a typical switched connection has increased to as many as 4 or 5. In addition, the trunk layout has grown more complex. A short-haul channel may be wired in tandem with a long-haul carrier channel to make a single trunk. Finally, short-haul carrier channels may be a part of one or more of the links in a switched connection spanning intercontinental distances. The growing use of submarine cables and the potential use of satellites increases the likelihood of such connections.

In addition to its predominant use for voice channels, the Bell System network is being used to transmit a growing variety of nonvoice services. One or several teletype or digital data circuits can be transmitted over a short-haul carrier channel of voice-frequency bandwidth (200–3000 cps). In addition, all or part of the 96-kc N-carrier band has been used to transmit wideband services, including high-speed digital data.

These changes in the Bell System environment have imposed more severe requirements on the individual short-haul channels than can be met by the performance capabilities designed into the original short-haul systems. In the switched message network, the possibility of more links in tandem has tightened the requirements on the performance of each link. The variations in over-all net loss of existing channels must be reduced materially. This applies both to long-term variations due to aging, changes in temperature, and office battery voltage variations and to short-term variations such as cyclic changes in net loss, called "beats." The bandwidth provided by a channel must be increased, and the variations in gain across the band reduced. The crosstalk coupling between channels within a system must be reduced by controlling the sources of coupling within the terminals and repeaters. The background noise contributions of the terminals and the repeatered line must be reduced.

The increasing number of links in tandem, carrying both voice and nonvoice services also has imposed new requirements on the control of impulse noise and envelope delay distortion. Consistent with economic limitations, both should be controlled in the basic terminals and also in the repeatered line. Where necessary, additional equalization may be provided as required for specific voice-band or wideband services.

These new requirements have been important in the design of the new N2 terminal. In addition, it will be necessary to correct deficiencies in the performance of the existing short-haul carrier channels to meet as many of these up-to-date objectives as economically practical. At the end of 1961, the N1 and ON channels in service provided about 55 per cent of the carrier channels in the Bell System plant. Techniques developed for the N2 terminal have indicated improvements that are being incorporated into existing N1 and ON terminals, and this modernization program will continue.

The increase in complexity and sheer size of the Bell System carrier network has also focused attention on the maintenance and operational features of the N2 terminal. One important implication is that the design should have a minimum number of adjustments. Design margins have to be increased to permit longer intervals between adjustments. Also needed are more effective alarm and trunk processing features which operate when the system fails, including automatic restoral to service when the carrier system again has been made satisfactory for commercial service.

Finally, development of a modern family of short-haul carrier units will provide other benefits to Western Electric and the operating telephone companies. An up-to-date design taking advantage of new solid-state and ferrite components, modern design, and new manufacturing techniques will be easier to manufacture and operate in the long run than existing short-haul equipment.

III. BROAD OBJECTIVES

The basic objective for the new family of short-haul carrier systems is implied by the preceding section, which gave the reasons for undertaking the development program. That is, the new systems must meet the requirements imposed by the changing Bell System environment. In addition, however, there are certain other broad objectives which have had a major influence on the development of the new units.

One objective is that the members of the new short-haul family must be competitive in cost with their existing counterparts. Improvements in performance were expected to increase the basic costs of the equipment itself. These increases must be offset by savings in the first cost of dc power in central offices, due to the lower dc power drains of transistor circuitry vs electron tubes and the related use of lower, more economical central office battery voltages. Other savings can be expected from the smaller size of the equipment and from the substantially simpler engineering and installation and maintenance effort.

Another objective applying to all of the new carrier units is that each must be compatible with the transmission plan for existing short-haul systems. The carrier frequencies, signal powers, and transmission levels must match. By doing so, it will be possible to operate the different terminals on repeatered lines in the same cable. The different repeaters must provide compatible carrier lines in a cable or work in tandem on a given line.

One important reservation has been applied to this desirable compatibility. An N2 terminal operated at one end of a repeatered line with an N1 terminal at the other end would restrict the performance improvements provided by the N2 terminal. Therefore, N1-N2 terminal compatibility was not taken as an objective for the project. This reservation was justified on two bases. One is the high rate of growth in new short haul carrier channels. The other is the anticipated low level of N1 terminal reassignments that might lead to the desire to have N1 and N2 terminals work together. The combined growth of short haul channels has been equal to or greater than 20 per cent per year, and in 1965 there will be equal numbers of N1 and N2 terminals in the plant.

A further objective is that the N2 terminal would not use the built-in, 3700-cycle signaling system designed for N1, O, and ON terminals. In its place, the existing, in-band, single-frequency (SF) signaling system should be used.[6] With this change, all of the signaling options of the modern Type E SF signaling system can be used without any changes in the N2 channels. The need for this change has grown out of the increasing complexity of the Bell System trunk network. Many of the trunks made up of two or more carrier channels wired in tandem now include one short-haul carrier channel. For a trunk including two channels in tandem, with in-band tones used for signaling, only one set of signaling terminals is required, with none at the junction of the two channels. This saving of in-band equipment offsets the lower costs that might have been achieved with built-in, out-of-band signaling.

The use of SF signaling with N2 channels has led to the need to integrate the system failure indications provided by the N2 terminal and the appropriate signaling information provided by the SF units to condition properly the derived trunks in the event of carrier failure. System failure alarms in the N2 terminal should be similar to those now a part of N1 and ON terminals. In addition, during a system failure, the N2 terminal and SF units must have features like those in N1 or ON terminals that permit the customer to disconnect himself or be disconnected. The processing equipment must then make the trunks appear busy so they will not be seized when they are not usable. In addition, an objective for the N2 terminal is that its system failure processing equipment should be able to restore the trunks automatically to an operating condition when the N2 system is properly restored to a condition suitable for commercial service. This objective poses the dual requirements of having the N system, including the associated SF units, first test itself to determine when transmission becomes satisfactory after a failure and then provide signals to process each of the trunks so that it will be ready to accept calls again. These objectives imply that a universal trunk processing arrangement be provided for all E-type signaling units connected to E and M, loop, or revertive trunk circuits.

IV. DESCRIPTION OF N2 CARRIER SYSTEM

Although the subject of this paper is the N2 carrier terminal, this section and the next will deal more generally with the N2 carrier system. That is, they will cover both the N2 terminal and the N repeatered line. This broader perspective will make it possible to point out similarities and differences between the N1 and N2 system philosophies and requirements. The perspective will also help to clarify the transition from over-all system objectives to requirements for the N2 terminal and N repeatered line.

As in N1 systems, the N2 terminal is a 12-channel, double-sideband, amplitude-modulated multiplex for N-carrier repeatered lines. The voice-frequency channels derived by the N systems are used by the operating telephone companies to provide direct, toll-connecting, and intertoll trunks up to about 200 miles long on paired cables. The cables are of both low-capacitance (0.066 mf/mile) toll and high-capacitance (0.085 mf/mile) exchange types. As an indication of the range of system lengths in the N family, Fig. 1 shows two length distributions: one for systems multiplexed with N1 or N2 terminals and one for those multiplexed with ON or N3 terminals. The curves are based on samples of system lengths existing and estimated through 1965 by the Bell System operating companies.

4.1 *Frequency Allocation*

Fig. 2 shows the frequency allocation for the N1 and N2 carrier terminals. Twelve N2 carrier channel modems amplitude modulate the voice-frequency input signals into double sidebands along with their modulating carrier in the high group, generally using the channel 2 through 13 assignments. Channel 1 can be used as a spare, or as a replacement in case unavoidable carrier-frequency interference is present in another channel assignment. However, the use of channel 1 is not preferred due to the relatively high delay distortion encountered on long N repeatered lines. The high group is applied to the repeatered line or

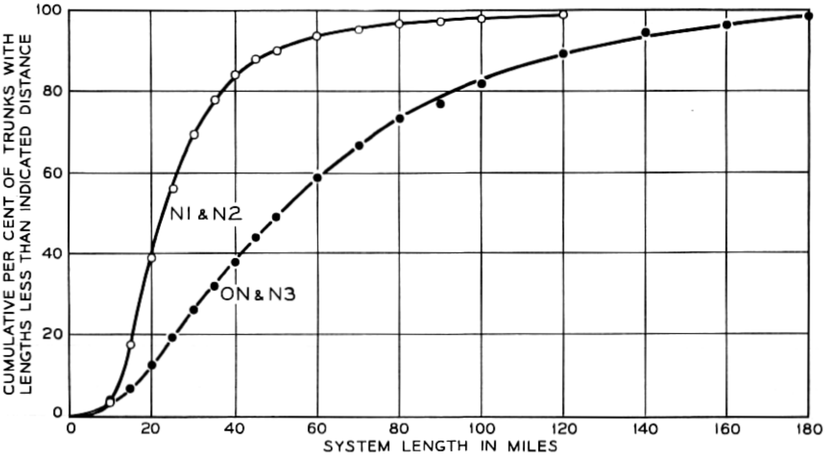


Fig. 1 — Distribution of lengths of typical short-haul carrier systems.

modulated into the low-group allocation, which is then applied to the line.

4.2 *N System Transmission Plan*

Fig. 3 shows one combination of transmitting and receiving groups. The figure illustrates that both groups are used in each repeater section, one for each direction of transmission. Fig. 3 also shows the frequency inversion, or "frogging," used at each repeater. The group received at the repeater is modulated with 304 kc into the other group and transmitted to the next repeater section. The frequency separation between the input and output groups at a terminal or repeater greatly simplifies the control of the effects of near-end crosstalk and of near-end interaction crosstalk between cable pairs adjacent to the repeaters. The frogging of the two groups also improves far-end crosstalk. For a given direction of transmission for the high-group frequencies where crosstalk is poorer, the total length of exposure is cut in half between parallel systems in the same cable.

Frequency frogging of the two groups also provides first-order equalization for the variation of line loss with frequency. The slope of line loss encountered, for example, across the high group band in one line section is nearly offset by the opposite slope in the loss of the low group in the next line section, after the group is inverted by the frogging repeater. This compensation and the slope equalization provided in the repeaters and terminals are discussed further later in this section.

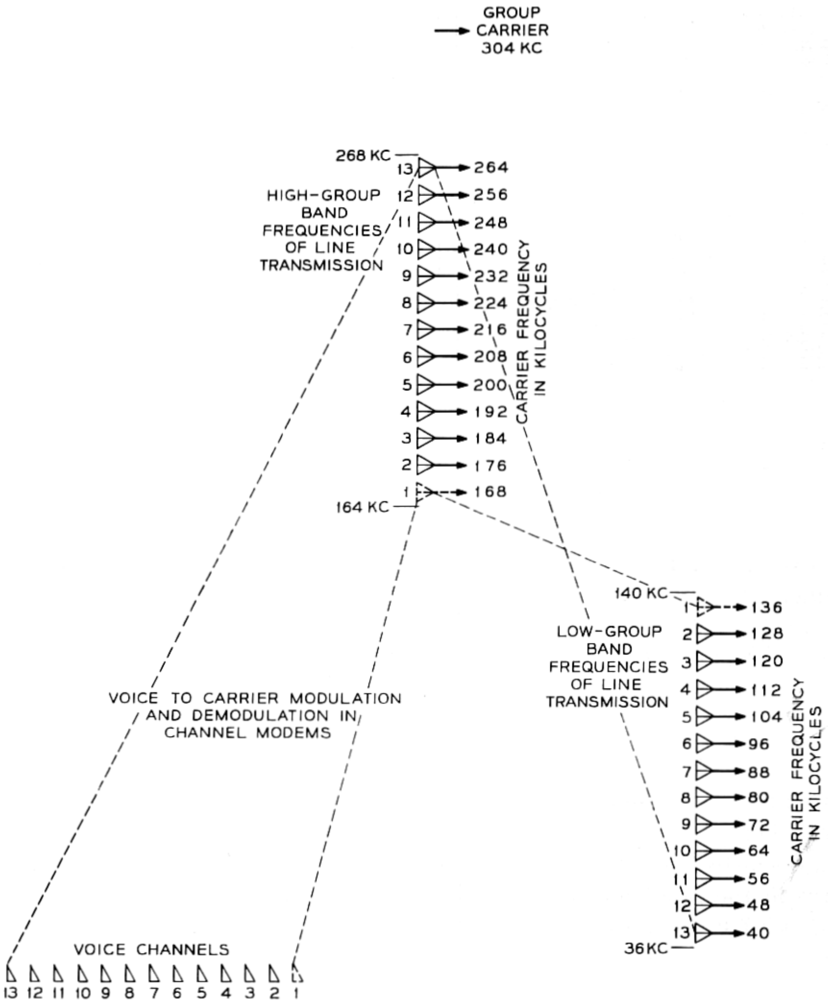


Fig. 2 — Frequency allocation for N terminals.

Fig. 4 summarizes the important transmission level points for the major functional transmission units in an N2 system. The values for message power on the line side of the channel modulator and demodulator are the power which would be measured in one of the sidebands of a carrier channel if a 0-dbm one thousand-cycle sine wave were applied at a 0-db system level (SL) point (see Appendix of Ref. 1) on the voice-frequency input leads. The message power on the line for that (compressed) tone is 12.5 db below the channel carrier power.

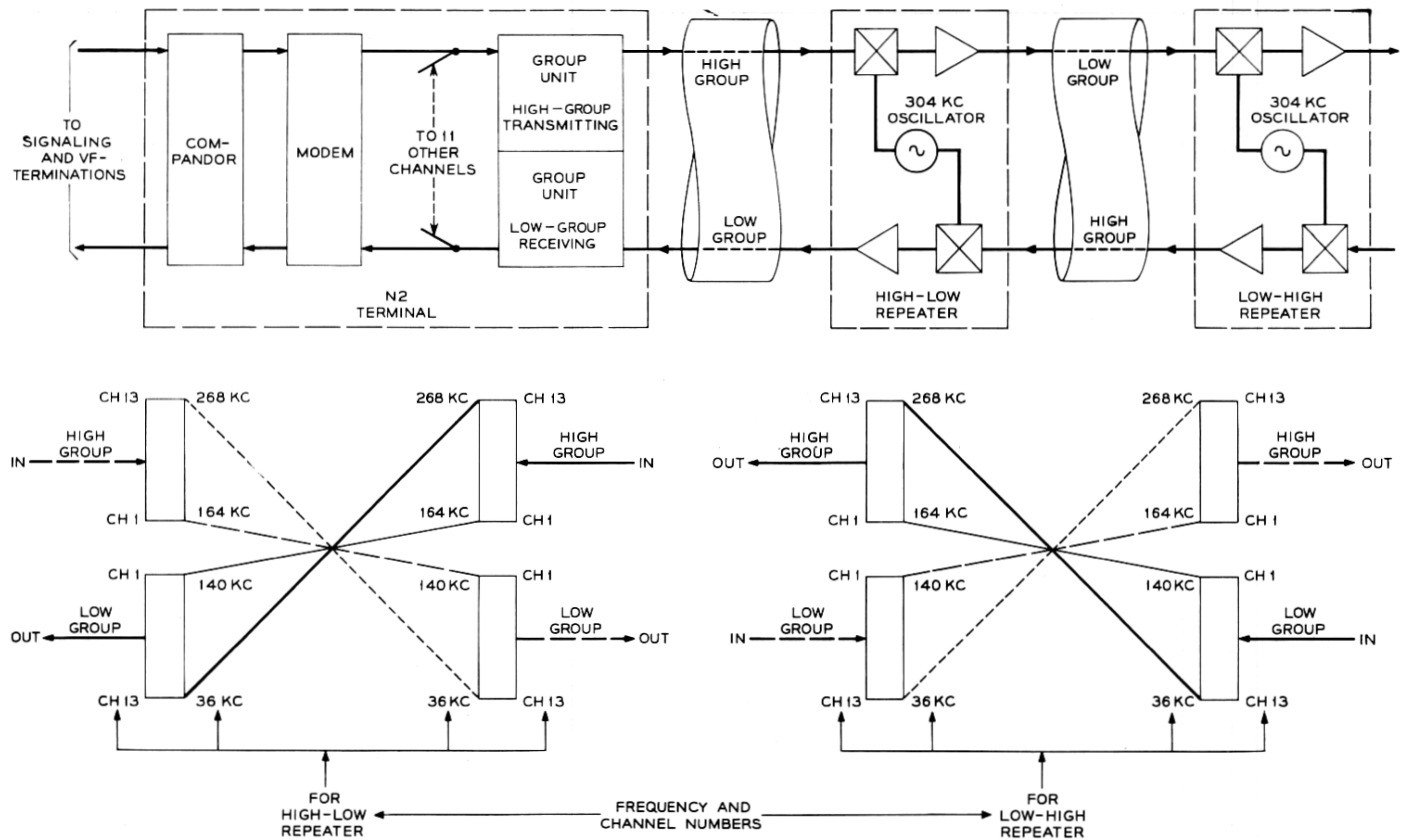


Fig. 3 — N-carrier line transmission plan.

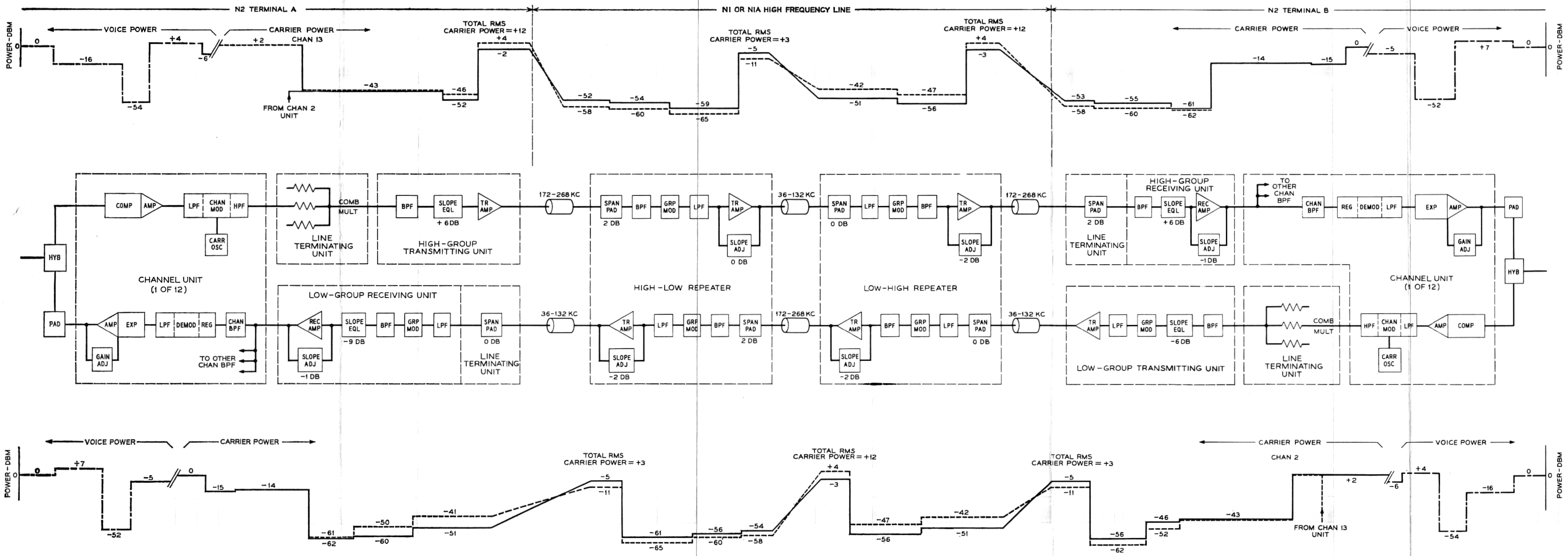
In the earlier paper on the N1 system,[3] values were also given for "message level," which represented a fictitious set of levels in the terminal and on the line. They were powers for a 0-dbm at 0-SL one thousand-cycle input wave if it were not compressed in the compressor. The message levels could be used along with an appropriate expandor advantage to calculate the output power of noise or other interferences on N lines. The message level for an uncompressed 0-dbm at 0-SL tone in a single sideband in the carrier portion of the N system would be 15 db below the carrier. Message levels have been omitted from Fig. 4 for simplification.

The carrier-to-sideband ratios mentioned above are those used in both the N1 and N2 systems. This is necessary to simplify operation of N1 and N2 terminals in a telephone office and of N1 and N2 systems in the same cable. The ratios were chosen so that, for even the highest speech volumes, the index of modulation would not exceed 100 per cent.

The power of the channel carrier is used to define the transmission level of the channel signals in the carrier portion of the N system. Thus, the carrier must represent that level without significant interference from the sidebands. The over-all net gain of the channel is regulated by the receiving channel regulator, indicated as "REG" in the channel unit in Fig. 4, which operates on the amplitude of the received carrier signal. This is necessary because the receiving amplifiers in the receiving group units and their counterparts in the repeater all regulate the total group power at their outputs, which essentially consists of the channel carriers.

4.3 *N-Carrier Line Engineering and Equalization*

The carrier powers shown on the carrier line in Fig. 4 were set by the practical need to have N2 terminals work on N1 and N1A repeatered lines. The total powers of the high-group or low-group carriers transmitted to the carrier line are the same as those for the comparable groups at N1 terminals or the appropriate N repeaters. However, the slope of the carrier powers is used as a flexible parameter in engineering modern N lines, and the N2 terminal provides slope equalization in a much wider range than does the N1 terminal. Slope is defined for a terminal or repeater as the difference in power output, or gain, for Channel 13 with respect to Channel 2, being positive when Channel 13 has greater power or gain. The block shown in Fig. 4 for slope equalization in the N2 terminal is provided by plug-in networks available in 3-db steps from +9 to −9 db supplemented by mop-up switched equalization in three 1-db steps in the receiving terminal.



ABBREVIATIONS:

ADJ = ADJUSTMENT
AMP = AMPLIFIER
BPF = BANDPASS FILTER
CARR OSC = CARRIER OSCILLATOR
CHAN = CHANNEL
COMB MULT = COMBINING MULTIPLE
COMP = COMPRESSOR
DEMOD = DEMODULATOR
EQL = EQUALIZER
EXP = EXPANDOR
HPF = HIGH-PASS FILTER
HYB = HYBRID
LPF = LOW-PASS FILTER
MOD = MODULATOR

INDEX:

—·—·— MESSAGE POWER (ALL CHANNELS ALIKE)
——— CARRIER POWER (CHANNEL 2)
- - - - CARRIER POWER (CHANNEL 13)

NOTE:

1. SINGLE SIDEBAND MESSAGE POWER IS 12.5 DB BELOW CARRIER
2. ASSUMED:
   GROUP MOD PLUS FILTER LOSS:
   LGR = 9 DB
   LGT = 10 DB
   REPEATER MOD = 5 DB
3. FREQUENCIES SHOWN BETWEEN TERMINALS ARE FOR CHANNELS 2 AND 13

Fig. 4 — N2 carrier power level.

The slope of the carrier powers — and indeed the layout of the entire carrier line including line losses, repeater and terminal gains, and the use of equalizers — is aimed at controlling the slope and signal magnitudes of the channel carriers and the accompanying sidebands. That control has several objectives:

(1) to control over-all channel noise by keeping the channel carriers and sidebands above the noise present on the line

(2) to control crosstalk between systems by keeping the powers of each carrier in one system close to the powers of the corresponding carriers of other systems in the same cable

(3) to keep the slope linear across both sidebands of a given channel so that the two sidebands will add in the channel demodulator without distorting the channel gain-frequency response.

In meeting the above objectives, the philosophy used in engineering the N line has changed over the years. Originally, all N lines were laid out so that there would be a nominal 14-db total slope in the cable loss between repeaters. For shorter repeater sections, the loss was built out with flat loss span pads and the slope made up by one of the three steps of slope equalization built into the N1 and N1A repeaters. For quite short repeater sections, the pads were supplemented by artificial cable networks roughly simulating the loss and slope of one or two miles of 19-gauge low-capacitance cable. For any length repeater section, the transmitted signal was pre-equalized to a 7-db slope, one-half of the expected nominal slope of the cable loss in a repeater section. The pre-equalization was necessary so that the frequency-frogging at the repeaters could equalize adjacent line slopes. However, the pre- and post-equalization also helped minimize the noise produced by misalignment and imperfections in equalization.

The original layout philosophy has been changed for several reasons that arise from the need to control the interference that external impulse noise produces in both voice and nonvoice signals which must be transmitted over N systems. N repeater spacings have been shortened for repeater sections adjacent to telephone central offices which are sources of impulse noise. For 19-gauge cable, sections of 3 to 5 miles are now prevalent, compared to the 7- to 8-mile sections used in early N systems. Use of the original N line engineering philosophy for short sections required use of large numbers of sloped line buildout units. The only such buildout units generally available until recently were the one- or two-mile artificial cable networks. These networks do not provide a good match for the loss of modern polyethylene insulated cable (PIC). The mismatch shows up as a bulge in the carrier frequency characteristic across an N group. The result penalizes the channels in the center of the group band. As a means of controlling impulse noise in sections with severe exposures, it is advantageous to have all carriers received at the same power at a terminal or repeater rather than with a slope across the group, thus not forcing a few of the channels farther down into the noise than the others.

All of the above influences resulted in a change to a new philosophy of N line engineering termed "natural-slope" engineering. The basis of the philosophy is that any value of slope within wide limits is permitted at repeater or terminal outputs. That is, the loss slope "naturally" contributed by the line section is acceptable and should not be supplemented by artificial lines to obtain the fixed 7-db slope previously required at all repeater outputs. This degree of freedom facilitates obtaining zero slope when required at terminals at locations of severe noise induction. Occasionally, when the range of slope adjustments within the repeater is inadequate, fixed slope equalizers may be required.

The examples of slopes shown in Fig. 4 illustrate a variety of slopes of line loss and carrier powers at terminal or repeater outputs. Actual values on practical N lines may differ very widely from those shown.

4.4 *N2 Terminal Levels*

Most of the signal levels in the N2 terminal shown in Fig. 4 were determined by noise and crosstalk considerations. The minimum levels were chosen as a compromise between levels high enough to keep above noise sources and low enough to keep from producing distortion in nonlinear circuits or circuit elements.

The noise sources in the terminal include first circuit noise in the amplifiers and external interference. An example of the latter which posed a problem was magnetic pick-up of 60-cps energy within the expandor. As shown in Fig. 4, a very low level for voice frequencies exists in the expandor at the output of the variolosser and input of the amplifier. Until proper shielding was provided for the expandor amplifier input transformer, the 60-cps interference substantially exceeded the noise objective for program channels.

The primary sources of nonlinear distortion within the voice-frequency portion of the terminal are the variable loss ("variolosser") elements in the compressor and expandor. In the carrier portion of the terminal, nonlinear distortion occurs in the group amplifier and group modulator and demodulator resulting in the generation of unwanted modulation products. Such distortion shows up as intermodulation crosstalk between channels in the group. The carrier levels were chosen so that the intermodulation crosstalk arising in an N2 terminal does not contribute materially to the total interchannel crosstalk in an N system. Interchannel crosstalk in the terminal is primarily leakover from adjacent channels through the receiving channel band filters.

The maximum levels in the terminal were determined by two considerations. In the receiving channel portion of the terminal, enough carrier power was needed to ensure that the envelope detector operates properly as a demodulator. High carrier power at that point also minimized the dc gain needed in the channel regulator control loop. The carrier power needed at the regulator and demodulator, taking into account the in-band loss of the channel band filter, determined the output power of the amplifier in the receiving group unit.

The maximum terminal power is at the output of the transmitting group amplifier. It is desirable to transmit as much power as feasible from the terminal to the line to permit the maximum cable loss to be spanned in the face of external noise and interference. That power was limited by the transmission plan of the N line. However, even within that constraint, an amplifier transmitting a total of +12 dbm (rms) with the tight intermodulation requirements imposed by crosstalk objectives posed a design challenge. The slope equalizer was put ahead of the amplifier so that the amplifier output power would not be reduced before it was applied to the line.

4.5 *Terminal Net-Loss Stability*

As discussed in earlier sections, the N2 terminal must meet exacting requirements on its net-loss stability. The carrier-to-sideband ratio established in the transmitting terminal must be determined precisely and held constant over the life of the channel modem. In addition, the voice-frequency transmission levels must not vary significantly. Both precision and stability are provided by large amounts of feedback in the voice-frequency amplifiers and by a precision channel modulator. The carrier-to-sideband ratio, i.e., the index of modulation, is carefully controlled by fixed voice-frequency gain ahead of the modulator and by built-in bias on the modulator. The receiving terminal channel regulator provides very tight regulation of the carrier, unaffected by sideband power.

4.6 *Special-Service N2 Terminal Units*

In addition to the terminal units which provide the message channels described thus far, other channel options are available for use in the N2 terminal. A VF amplifier can replace the compandor unit when non-compandored operation is desired for voice-band data transmission on private lines. Two VF amplifier units can be used at the junction of two N2 compandored channels which are wired together to form one derived circuit. By that means, only one compressor and one expandor are needed at the ends of the circuit rather than using two complete compandors in tandem. A Schedule C and D program channel modem can be used to replace any of the normal message channel modems for channels 3 through 7 to meet the more stringent program requirements for the channel gain-frequency characteristic. Finally, plug-in modems can replace the plug-in units for channels 5 through 11 to provide a wideband channel to transmit 40.8-kilobit synchronous data over part of the N carrier frequency band.

4.7 *N2 Terminal Alarm Arrangements*

In the N2 terminal, a number of alarm functions are carried out automatically if either the carrier line or the terminal common equipment fail. The alarm arrangements:

(1) keep customers from being charged falsely for a call in progress when service has failed,

(2) keep the failed trunks from being seized by the switching machine, and

(3) restore the system automatically when the failed portion is made good so that the derived trunks can be used without delay.

The functional alarm units include the terminal alarm unit and an external carrier group alarm (CGA) panel through which pass all the derived voice channels as well as the supervisory signaling leads. The operation of the alarm system is described in a companion paper.[2]

A special feature of the alarm system is necessary for automatic restoration. When an N line fails, the many N repeaters in tandem will increase their gain as their built-in regulators regulate on the power of the noise and crosstalk present in the failed line. The receiving channel regulators do likewise. This regulation provides enough extra gain so that the total interference power is usually equal to the normal total carrier power. The excess gain is enough so that when carrier transmission is restored the net gain of the individual channels will be many db too high, often to the point where the trunks will sing. In addition, the channels will be very noisy. The many regulators in tandem will gradually return to their proper operating points, but only after that time has elapsed will the channels be suitable for service. Therefore, the alarm system includes a means of assuring that transmission is satisfactory on the restored channels before they are returned to service.

4.8 *Summary of N System Features*

Table I summarizes a number of the features of N systems discussed in Section IV. It highlights features common to both N1 and N2 terminals. In addition, it points out those features of the N2 terminal which are an improvement over the N1 terminal. The quantitative value of some of those improvements are discussed further in Section VI.

TABLE I — SUMMARY OF N SYSTEM FEATURES

Features *Common* to N1 and N2 Terminals	N2 Terminal Features *Improved* over N1
Transmission plan Frequencies, powers, levels, and type of modulation Built-in compandors, and channel and group regulation Frequency frogging of high and low groups Separate, single-frequency, in-band signaling (N1 also provides built-in out-of-band signaling) Layout flexibility of repeatered line Repeater spacings up to 7 miles Control of impulse noise Power feed over line to remote repeaters Variety of plug-in units Message (compandored) Noncompandored Schedule C and D program Small, lightweight, portable test equipment Sets for in-service switching of group units Simple order wire and alarm system	Wider channel gain-frequency response Smaller long- and short-term net-loss variations Closer to ideal compandor tracking Greater channel overload capacity Tighter channel and group regulation Reduced intrasystem crosstalk Solid state components instead of electron tubes Built-in carrier failure alarm with automatic restoration Built-in power supply for −48-volt operation with filtering and regulation for improved stability In-service, hit-free switching of power unit (Not required for N1) Simplified maintenance Packaged bay including signaling

V. SYSTEM DESIGN ANALYSIS

5.1 *Over-All Transmission Requirements*

The terminals for the N2 carrier system have been designed to meet the performance objectives that apply for transmission of message, program, data and other special services on intertoll trunks. Table II summarizes the over-all transmission requirements on a four-wire voice-frequency channel which were established for this system.

TABLE II — N2 CARRIER SYSTEM: OVER-ALL TRANSMISSION REQUIREMENTS

Channel gain-frequency response (3-db points)	200–3400 cps
Net-loss stability	
Long-term stability vs time and temperature	$\sigma = 0.5$ db
Short-term variations from intrasystem sources ("beats")	0.1 db peak-to-peak
Compandor tracking and load capacity	±1.0 db for inputs +8 to −40 dbm0; ±2.0 db for inputs +10 to −52 dbm0
Compandor advantage (measured)*	28 db minimum 30 db average
Channel noise referred to 0 db SL	
Terminals	16 dbrnc
Over-all System:	
Measured	26 dbrnc
Effective	31 dbrnc
Channel crosstalk from intrasystem sources (equal level coupling loss)	70 db loss for all terminal sources
Channel intermodulation distortion	30 db average for one second- or third-order type product below either one of two simultaneous fundamentals of 0 dbm0

* The effective advantage is usually considered to be about 5 db less than the measured advantage due to the effect of increased noise present along with the syllabic speech spurts.

5.2 *Derived Transmission Requirements*

Based on over-all transmission objectives such as those given in Table II, analytical studies were made leading to the derivation of detailed technical requirements for the functional blocks of the N2 terminal. Since the overall performance of the N2 system is controlled by both the terminals and the repeatered line, it was necessary to develop requirements for the new N2 repeater as part of this study. The analysis involved the quantitative study and evaluation of all significant transmission and interference mechanisms, for the purpose of translating objectives into specific circuit design requirements (e.g., required filter suppression, modulator balance, repeater linearity or crosstalk). Table III lists some of the N2 circuit units for which detailed technical requirements were derived from system design studies.

5.3 *Example of System Analysis*

To illustrate a typical system analysis study, this section describes a problem concerned with the control of short-term net-loss variations, or beats, in short-haul carrier systems. The problem is important because interference mechanisms causing beats of as much as several db characterized N1 and ON systems operating in the field. The following discussion describes the quantitative analysis of the important interference mechanisms producing beats, and shows how detailed technical requirements on the appropriate circuit blocks were derived. The analysis has been applied to the solution of the present beat problem in existing N1 repeatered lines, and to the design of circuits for the N2 carrier terminal and the new N2 repeater.

5.3.1 *Sources of Short-Term Net-Loss Variations (Beats)*

Nominal carrier and sideband power relationships of the transmitted signal may be modified by interferences that originate along the high-frequency line of an N2 system. Such interferences can cause beats, due to small frequency differences between the wanted and interfering signals. These frequency shifts occur because group frequencies in a given N system are not synchronized from one repeater section to the next, as they are frequency-frogged by a separate 304-kc oscillator in each repeater along an N line. It also follows that group frequencies are not synchronized among the different systems operating on a common cable.

Beat interference may originate from two sources: (1) intrasystem sources, which are subject to design control within the system itself, and (2) intersystem sources which are independent of internal system characteristics. To keep beats within desirable over-all limits, a total

TABLE III — DERIVED REQUIREMENTS AND INTERFERENCE CHARACTERISTICS

	Circuit Unit	Derived Requirement	Interference Characteristic
Terminals	receiving channel band filter	out-of-band suppression	system noise and interchannel crosstalk
	receiving channel low pass filter	out-of-band suppression	system noise and interchannel crosstalk
	group unit filters	out-of-band suppression	beats
Line repeaters	amplifier modulator output coupling networks	modulation performance and crosstalk between opposite directions of transmission	beats and intelligible crosstalk
	group bandpass and low-pass filters	out-of-band suppression	beats and system noise

TABLE IV — ALLOCATION OF 51-db S/I INTRASYSTEM LINE BEAT OBJECTIVE

Type of Interference	Allocation of S/I Objective
Crosstalk coupling between repeater halves	54 db
Low-high repeater image frequencies (344–432 kc)	58 db
Second- and third-order line repeater modulation products	58 db
Crosstalk coupling between transmit and receive terminal units	60 db
Total objective	51 db

high-frequency line objective of 0.1 db peak-to-peak allowable variation in transmitted carrier power was specified. Assuming that the total line objective was allocated equally between internal and external sources, the allowable peak-to-peak carrier variation for all intrasystem sources is 0.05 db. This can be translated to a signal-to-interference (S/I) ratio of 51 db for the high-frequency line. This also corresponds to a voice-frequency variation of 0.1 db peak-to-peak at the channel output because of the doubling action of the N2 expandor. The allocation of 51 db to external sources is in keeping with objectives for intelligible crosstalk from other short-haul systems in the same cable.

Within an N2 system, there are five independent mechanisms that can produce beats. Of these, four are allocated a significant share of the 51-db objective. The fifth mechanism, input leak through low-high repeaters, is so easily controlled through group filter suppression that it can be assigned a negligible portion of the 51-db requirement. The allocation of this requirement among the four significant sources is given in Table IV, assuming independent mechanisms which add in random phase. The allocation shown reflects the relative difficulty of controlling each type of interference.

5.3.2 *Derivation of Technical Requirements*

Based on the allocations given above, specific technical requirements were derived for individual parts of the system. In the allocation diagram of Fig. 5, for example, the repeater crosstalk objective of 54 db is equally divided among 40 repeaters of a long system to derive a per-repeater crosstalk objective of $54 + 10 \log 40 = 70$ db.

Similarly, the 58-db allocation to the low-high repeater image band leads to an allocation of $58 + 10 \log 20 = 71$ db per pair of repeaters. Meeting this objective assures that frequencies in the unwanted image band from 344 to 432 kc generated in the low-high repeater are ade-

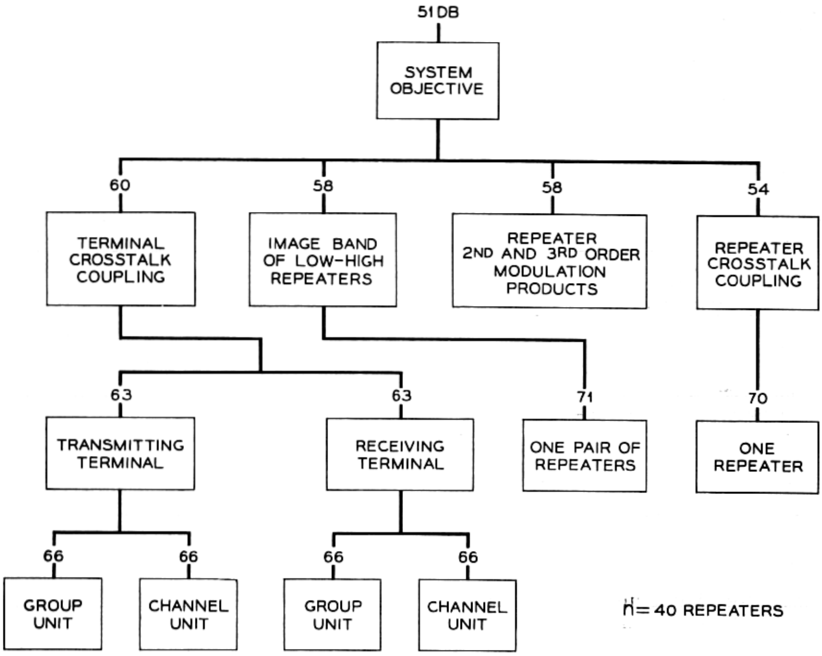


Fig. 5 — Allocation of beat objectives.

quately suppressed before reaching the next repeater, where modulation of the image band causes it to disturb the low-group band at the modulator output of the high-low repeater. From the stated 71-db objective, image band suppression requirements on the two filters which control this interference mechanism are readily derived. Fig. 6 shows minimum suppression requirements in the low-high repeater image frequency range which the low-high repeater output filter and the high-low repeater input filter taken together must provide.

This figure also shows the required combined suppression from the same pair of filters over the low-high repeater leak-through range of 36–140 kc. In this instance, an unwanted band of signals at low-group frequencies "leaks through" the low-high repeater modulator, is transmitted over the line and in turn leaks through the following high-low repeater modulator, where it disturbs the wanted low-group band of frequencies.

Similar image and leak-through bands of frequencies occur in the high-low repeater. Suppression requirements in the 468- to 572-kc

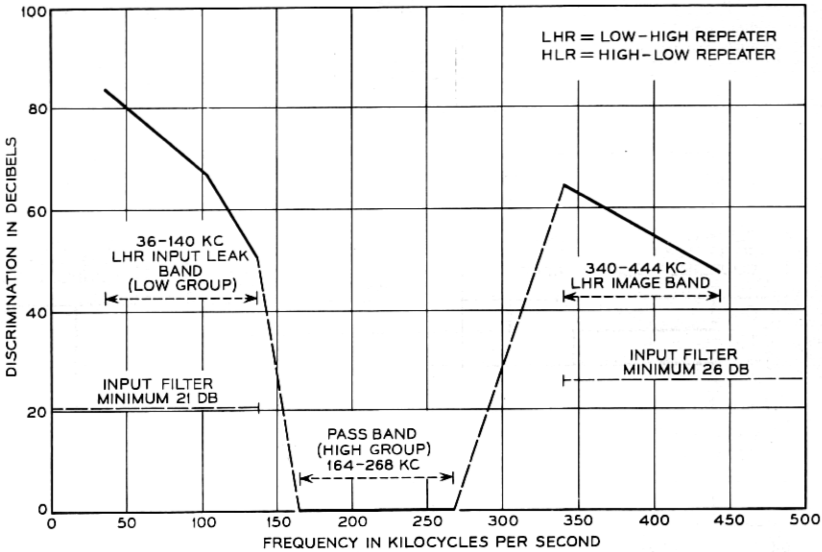


Fig. 6 — Minimum discrimination requirements of HL repeater input plus LH repeater output filters.

image band and the 164- to 268-kc leak-through bands necessary to reduce to acceptable limits the interferences from these sources are shown in Fig. 7.

The third item in the allocation table above provides for beats due to modulation products generated along the repeatered line. On the basis of a detailed analysis of all second- and third-order products generated in a 40-repeater system, it was concluded that significant improvement is needed in repeater linearity over that of the N1 repeaters to meet the beat objective of 58 db allocated to modulation sources. Table V summarizes these conclusions, indicates the required N2 repeater modulation coefficients, and compares them with the corresponding N1 performance.

Terminal crosstalk coupling, the final item in the allocation table, is allocated an objective of 60 db. This relatively severe objective reflects the fact that there are only two sets of terminal contributors per system and the expectation that terminal crosstalk should be more easily controlled than crosstalk along the repeatered line. As Fig. 5 shows, each terminal is allocated one half of the terminal objective, or 63 db. A further suballocation of 66 db is made within each terminal to each channel unit and group unit, respectively.

To summarize this illustrative example of the system analysis, in-

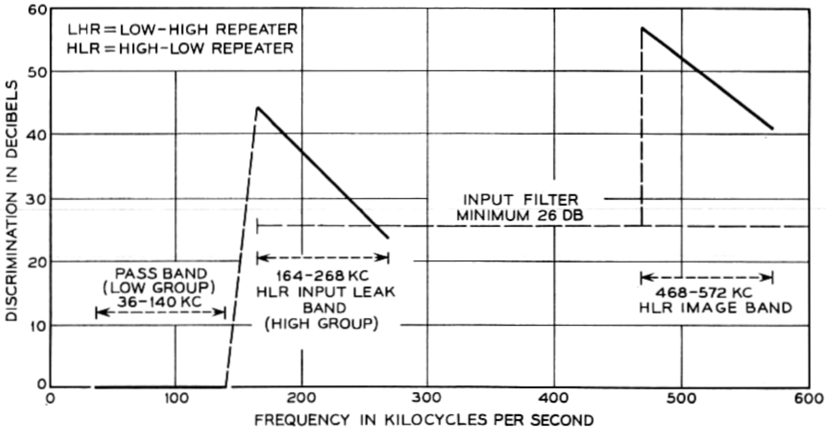


Fig. 7 — Minimum discrimination requirements of LH repeater input plus HL repeater output filters.

dividual circuits which meet the derived transmission objectives described above will assure that short-term net-loss variations from internal system sources will meet the over-all line beat objective of 51 db for systems of up to 40 repeaters. As a result, short-term net-loss stability in N2 systems will be governed by external sources of interference.

5.3.3 *Application of System Analysis of "Beats" to Type N Repeatered Lines*

The analysis described in the preceding sections has been applied to the problem of beats in existing N repeatered lines. On the basis of this analysis, it was possible to identify the dominant source of intrasystem beats in these systems as unwanted low-high repeater image band energy. The next step was to specify the design of a new high-low repeater input filter to control beats generated by this mechanism. Field tests of the new design demonstrated that the new filter virtually eliminated all intrasystem beats from this source generated on an N-repeatered line. The new filter is included in all current N1 and N1A repeater production, and is being installed widely on a replacement basis on existing N repeatered lines.

VI. N2 TERMINAL PERFORMANCE

This section summarizes the measured over-all performance of N2 terminals connected on a back-to-back basis. The performance is given

TABLE V — COMPARISON OF N1 AND N2 REPEATER MODULATION COEFFICIENTS

Product Magnitudes are Referred to 0 dbm Fundamental Power at Repeater Output.

Repeater	N1	Required N2
L-H	M2A = −75 dbm	M2A = −91 dbm
L-H	M2A-B = −99 dbm	M2A-B = −99.4 dbm
H-L	M2A = −71.5 dbm	M2A = −84.5 dbm
H-L	M2A-B = −86 dbm	M2A-B = −87.4 dbm

in terms of the characteristics of the over-all derived four-wire voice-frequency channel. Included are results of measurements of the channel gain frequency characteristic, compandor tracking, channel intermodulation, noise, crosstalk, and carrier failure arrangements. More detailed information on the performance of the functional circuit units is given in a companion paper.[1]

6.1 *Channel Frequency Characteristics*

Fig. 8 shows the gain frequency characteristics for typical N2 channels. The curve labeled "average" represents typical performance of N2 channels using the channel band filters incorporating quartz crystals. These filters have been in production since the fall of 1964. They replace an earlier design which was based on high-Q ferrite inductors. The performance of the channels with both types of filters is summarized in Table VI, which compares the frequencies at which the average channel gain is 3 db down from the gain at 1000 cps for N2 channels and for the A5 channel banks used to provide Bell System long-haul channels. It is expected that even the worst N2 channels with ferrite filters will provide a 3-db point at the high end of the channel characteristic whose frequency is greater than 3000 cycles.

A typical envelope delay distortion characteristic for N2 channels is shown in Fig. 9. The curve applies to channels with crystal filters. The bar values represent the standard deviation of the values measured at the indicated frequencies. The points represent average values for N2 channels with ferrite filters.

6.2 *Channel Net-Loss Stability*

Measurements have been made of the over-all net loss of N2 channels provided by two back-to-back N2 terminals installed at the Bell

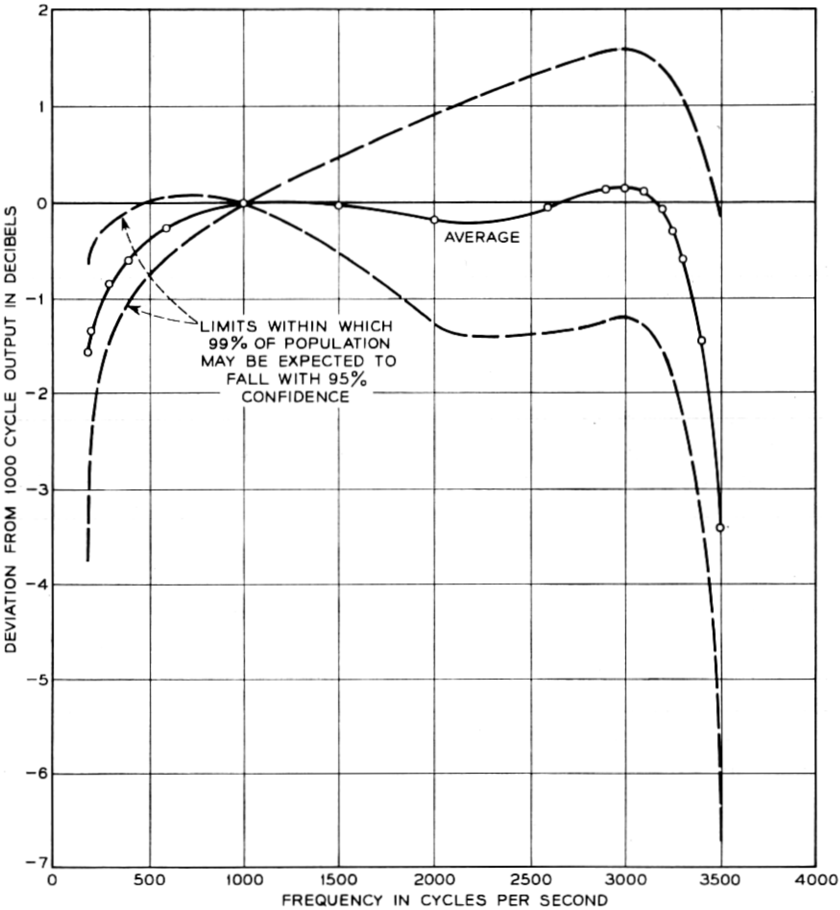


Fig. 8 — Typical over-all channel frequency characteristics provided by N2 terminals.

Laboratories field trial site in Virginia. (The over-all channel actually provides a net gain of 23 db between the −16-db input system level point and the +7-db output system level point. However, stability of the transmission of the channel is generally referred to in terms of the net loss of the derived trunk. Thus loss is used in this and following sections for convenience of association.) After six months without adjustment of over-all loss, the distribution of channel net losses had an average which deviated from nominal loss by 0.1 db and a standard devia-

TABLE VI — CHANNEL GAIN-FREQUENCY CHARACTERISTIC

Type of Channel	Frequencies in cps for Average Gain 3-db Down	
	Lower End	Upper End
N2 with crystal filters	100	3480
N2 with ferrite filters	100	3200
A5 channel bank	140	3370

tion of 0.3 db. Variation of net loss with changes in ambient temperature would increase those values by only small amounts.

6.3 *Compandor Tracking Performance*

The compressor and expandor which make up the compandor in an N2 channel must track each other, both statically and dynamically. The over-all input-output static characteristic of the compandor must minimize the changes in over-all channel net loss introduced for different powers of input signal within the design range. The input-output tracking of compressor and expandor separately and the dynamic tracking performance of the N2 compandor for step changes in input power are discussed in a companion paper.[1] Regarding the dynamic tracking, suffice it to say here that the N2 compandor has essentially no effect on the wave shape of signals for step changes in the input signal power.

The over-all compandor tracking performance for N2 channels versus input power is summarized in Fig. 10. The center curve represents the average deviations from the channel net gain measured for an input power of 0 dbm at 0 system level. A perfect tracking characteristic would have no deviation for any input power up to the point at which the channel overloads. The upper and lower curves show the limits within which 99 per cent of the compandor tracking characteristics may be expected to fall. For perspective, the shaded areas show the limits for tracking characteristics given in Section 5.1 and also those being proposed by the CCITT* for compandors to be used on long intercontinental circuits. The overload characteristic of the compandors shown in Fig. 10 is comparable to the performance of A5 channel banks.

The compandor tracking performance was measured at room temperature (26°C). If either the compressor or the expandor is operated at higher temperatures, there will be changes in the deviations from nominal. These changes are summarized in Table VII for a typical channel.

* International Telegraph and Telephone Consultative Committee.

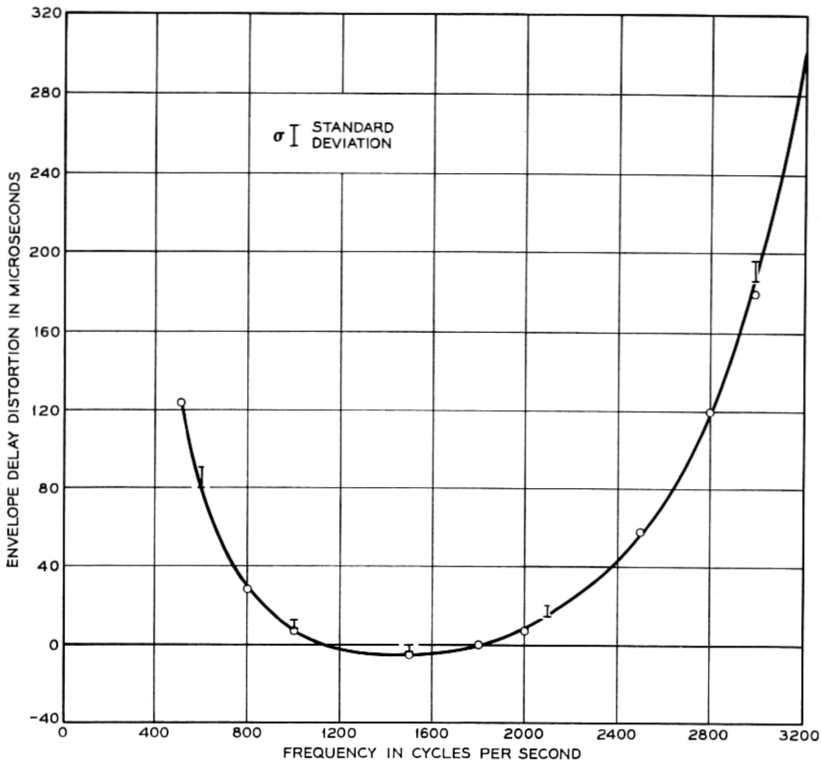


Fig. 9 — Typical envelope delay distortion characteristic provided by N2 channels.

These changes with temperature are not corrected by the channel regulator. However, they are small enough to allow the over-all channel to meet the requirements on tracking and net loss stability set forth in Section 5.1. The latter requirement may be interpreted as meaning that the distribution of net loss over a 6 month period for a given channel should have a standard deviation less than 0.5 db.

6.4 *Channel Distortion*

The distortion introduced by an N2 channel is an indication of the fidelity with which the channel can transmit voice signals, signaling tones such as multifrequency key pulsing, and voice-band data signals. The distortion can be characterized by measuring intermodulation products formed when two sine waves are transmitted over the

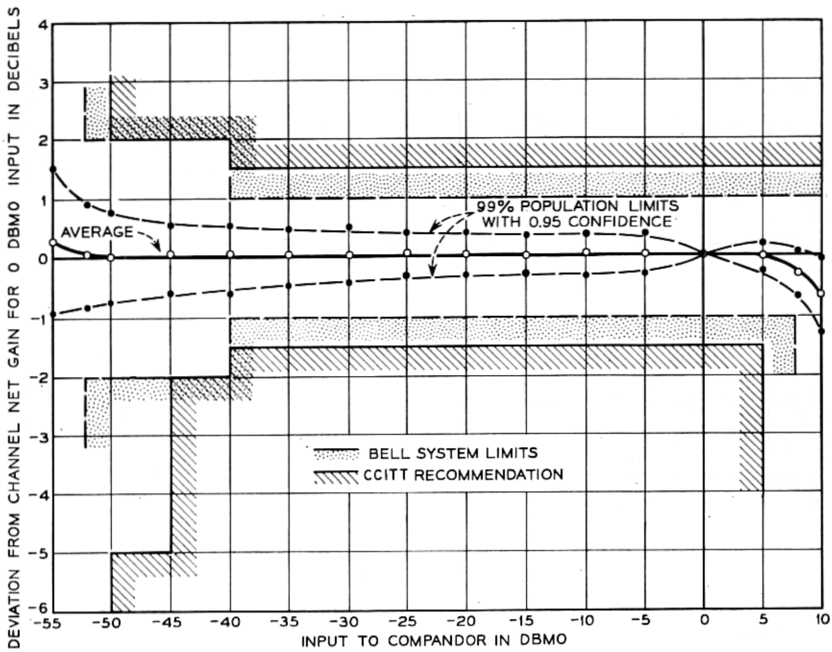


Fig. 10 — N2 carrier compandor tracking.

channel. The two frequencies used, 740 and 1250 cps, were chosen so that the important second-order products of the $f_1 \pm f_2$ type and third-order products of the $2f_1 \pm f_2$ type would fall within the transmitted voice band. Each of the two input signals was introduced at 0 dbm at 0 system level. The measured performance of recently manufactured compandors is summarized in Table VIII. Present indications are that the performance will be entirely satisfactory for transmission of one of the most critical signals, multifrequency key pulsing.

TABLE VII — COMPANDOR TRACKING VS TEMPERATURE

Deviations from Ideal Net Loss in db for Inputs from +8 to −52 dbm at 0 SL.

Temperature of		Max Deviation (Over Range of Input)	Max Change in Channel Net Loss (for 0 dbm at 0 SL Input)
Compressor	Expandor		
26°C	26°C	+0.2	0.0 (reference)
50°C	26°C	+0.4	0.0
26°C	50°C	+0.3	+0.2

TABLE VIII—DISTORTION FOR COMPANDORED N2 CHANNELS

Type of Product	Modulation Product — db Down on One Fundamental	
	Average	Worst
Second-order ($f_1 \pm f_2$)	44	35
Third-order ($2f_1 \pm f_2$)	36	31

6.5 *Channel Noise*

The back-to-back terminal noise performance of N2 channels is summarized in Table IX below. The performance of the channels was well within the objective of 16 dbrnC at 0 system level for the compandored channels. The noise measured on a noncompandored basis meets the objective of 48 dbrnC at 0 system level for voice-band special services provided on a private line basis.

An expandor advantage which averaged 30 db, with values ranging from 29.0 to 32.8 db, was provided by the N2 channels for noise from the carrier line and most of the carrier line terminal circuitry. The advantage is reduced by an average of 5 db when speech is present. The reduction results from the smaller expandor advantage during syllabic speech spurts and the consequently higher noise present during the speech spurt.

The background noise discussed thus far, however, is only part of the total noise which may be present in N2 channels. Babble noise will result from the multiplicity of small intrasystem crosstalk sources within the terminals, which will contribute both intelligible and unintelligible crosstalk. As a measure of such noise, several of the channels in an N2 terminal were loaded with white noise shaped to simulate speech, and the total noise was measured in the other channels. The total noise was separated into the noise power contributed by background noise and by crosstalk babble. Each of the contributions is summarized in Table X. The performance indicated in Table X con-

TABLE IX—BACKGROUND CHANNEL NOISE IN dbrnC AT 0 SL

Type of Channel	Channel Noise in dbrnC C at 0 SL	
	C Message Weighting	Flat Weighting
Compandored Channels	7–14	10–17
Noncompandored Channels (Private line data line-up)	25–27	26–37

TABLE X — MEDIAN CHANNEL NOISE IN dbrnC AT 0 SL DUE TO SYSTEM LOADING

(40 per cent of channels loaded with F1-shaped white noise at 88 dbrnC at 0 SL.)

Background noise	10
Babble noise	
in channels adjacent to loaded channels	13
in channels not adjacent to loaded channels	10

firmed the expectation that leak-over from adjacent channels through the receiving channel band filters would be the prime source of intra-system crosstalk. The value of 13 dbrn C at 0 system level implies an equal-level coupling loss of 75 db, which is 5 db better than the system design objective given in Section 5.1. It should be emphasized that this performance was achieved in the face of a stringent 40 per cent system loading with noise simulating loading of 0 vu at 0 system level in each active channel.

6.6 *Crosstalk*

The babble noise discussed in the preceding section is one form of crosstalk between channels within an N system which arises in the N2 terminal. Other forms of interchannel crosstalk were measured by using simulated speech as a disturbing signal in one channel and measuring total noise in the disturbed channel. The results are summarized in Table XI in terms of equal level coupling loss between channels. Even the worst coupling loss more than meets the 70-db system objective for crosstalk, with margin left for contributions from the repeatered line.

6.7 *Failure Alarm and Automatic Restoration*

Comprehensive tests of the N2 terminal in conjunction with its carrier group alarm (CGA) panel have demonstrated that the channels will provide satisfactory alarms and trunk processing in the event of transmission failure and satisfactory channel performance upon automatic restoration to service. The measured channel noise will come down

TABLE XI — FAR-END EQUAL LEVEL COUPLING LOSS IN db FOR WEIGHTED NOISE AS DISTURBER

Average	Range
77	74 to 84

from values which can exceed 90 dbnC at 0 system level during failure to values of about 30 dbrnC0 at 0 system level before the CGA circuitry will restore the channels to service.

VII. ACKNOWLEDGMENT

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