The N3 Carrier System: Objectives and Transmission Features

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The N3 carrier system development completes the second phase of a comprehensive design program to provide a new family of short-haul carrier facilities. The system includes a 24-channel, single-sideband, amplitude modulated multiplex terminal, a common carrier supply, and an N-repeatered line. Associated development effort was directed toward the provision of a shop-wired, double-bay framework to combine the carrier terminals, voice-frequency patching jacks, signaling equipment, and automatic trunk processing facilities in one equipment package.

Design objectives were established to meet today's and future stringent transmission performance requirements for direct, toll-connecting, and intertoll trunks. Taking advantage of the rapid growth in solid-state technology, significant transmission performance improvements have been achieved over earlier vacuum tube systems. In addition, installation, operating, and maintenance procedures have all been simplified. The system can be economically applied for distances as short as 35 miles, and with satisfactory transmission performance for distances exceeding 200 miles. A feature of special note is the provision of frequency correction units within the carrier terminal which essentially eliminates the frequency shift error introduced by the N-repeatered line.

I. INTRODUCTION

The Bell System has been engaged continuously in a vigorous program of carrier telephone system development since the now obsolete Type A system was introduced in 1918. This development effort has been aimed at increasing the utilization of available bandwidth, extending the operational distance, improving transmission performance, reducing transmission facility costs (initial and operating), and investigating new methods of modulation.

Prior to the end of World War II, the expense of carrier terminals and repeaters limited their application to the longer toll trunks. The type N1 carrier system,[1] which was introduced in 1950, had the design objective of providing economical telephone trunks in the 15- to 200-mile range. The N1 carrier system derived 12 voice channels and utilized double-sideband transmission over two repeatered cable pairs. A second short-haul carrier system, the type O, was developed subsequently for open wire lines. This system derived a maximum of 16 single-sideband voice channels in four groups of four channels over a single open wire pair. Terminals of the type O carrier system and the N1 carrier line facilities were then combined to form the ON carrier system.[2] The ON2 system derived 24 single-sideband carrier channels using the same line frequency space utilized by the 12 channel N1 carrier system.

In the early 1960's, a broad program was begun to redesign these short-haul carrier systems. A comprehensive description of this program has been published,[3] so an outline of the pertinent aspects will suffice here. Several factors prompted this redesign effort. The advent of Direct Distance Dialing (DDD) demanded a higher grade of transmission performance, which has helped the growth of new services such as *Data-Phone®* service. New devices and components, notably the transistor, improved ferrite inductors and transformers, and solid tantalum capacitors, offered smaller size and less power dissipation. Continued advances in circuit and system design techniques, new component mounting and equipment packaging methods, and modern manufacturing techniques gave promise that needed transmission improvements could be accomplished at reasonable cost. Indeed, the present state of the carrier development art allows the use of complex circuit designs that give significant transmission performance improvement without space or economic penalty.

The first phase of this over-all improvement program produced the N2 carrier system. A modern solid-state 12-channel double-sideband, amplitude modulated multiplex terminal was designed for use with N-repeatered lines to replace the N1 terminal. The next phase of the redesign effort was the development and production of the N3 carrier system. Here a modern solid-state 24-channel single-sideband terminal was designed for use with N-repeatered lines. The last phase of this improvement program involves the development of the N2-repeatered line. Now going into production, the N2-repeatered line will provide a level of transmission performance commensurate with that of the N2 and N3 carrier terminals.

The system aspects of the N3 carrier terminal, a compandored 24-channel single-sideband frequency division multiplex equipment, are discussed here. The paper includes a description of the system organization, a summary of transmission objectives and a review of transmission performance. In addition, certain performance parameters within the terminal are given to serve as a foundation for terminal compatibility with other manufacturers. Companion papers cover the circuit designs[4] and equipment arrangements.[5]

II. GENERAL CONSIDERATIONS

The basic function of the N3 carrier terminal is to provide a 24-channel, single-sideband frequency division multiplex for N-repeatered lines. For analog transmission, single-sideband carrier terminals normally have an economic advantage over double-sideband terminals for distances greater than 35–50 miles. Below these distances, the lower costs of the simpler double-sideband circuits and components outweigh the higher repeatered line costs per channel.

2.1 *System Transmission Performance*

The design objectives for the N3 carrier system were established to meet not only the present transmission requirements for direct, toll-connecting, and intertoll trunks but also the anticipated requirements of the future. These objectives require that the N3 terminals provide a significant improvement in transmission performance as compared to the first short-haul carrier systems (N1, O, ON). The following improvements are of particular note: wider channel bandwidth; reduced crosstalk interference, especially at low voice frequencies; better net loss stability with temperature and supply voltage variations as well as component aging; improved compandor tracking; and greater load capacity with respect to both channel signal level and system activity.

2.2 *Repeatered Line*

Planning at the very beginning of the N3 development included use of the existing N-repeatered lines of either vacuum tube or transistorized design. Coordination with existing N1, N2, and ON2 systems was required to the limited extent that all could operate within the same cable sheath. This basically required matching of carrier frequencies and carrier transmission levels with the ON2 line signal. N3-ON2 terminal-to-terminal compatibility was not deemed essential and was not provided. This approach is justified by the high growth rate anticipated for N3 channels and the significant transmission performance improvements gained in departing from terminal compatibility.

2.3 *Equipment Arrangements*

It may appear that planned use of existing N-repeatered lines would reduce the N3 carrier development activity to effort on the carrier terminal alone. In reality, two additional phases of development were carried out simultaneously with the carrier terminal work: (*i*) the provision of a common carrier supply to provide modulating and demodulating carrier frequencies and (*ii*) the provision of an integrated equipment arrangement including carrier terminals, in-band signaling units, 4-wire voice-frequency (VF) patching facilities, and automatic trunk processing equipment.

Costs were continually reviewed throughout the development. As expected, the desired transmission improvements generally increased equipment costs. However, the packaging of the carrier terminal, 4-wire VF patching facilities, in-band signaling unit mounting arrangements, and trunk processing equipment *into an integrated shop-wired bay frame*, made it possible to more than offset the increased equipment costs by savings in floor space, engineering and installation. In addition, the solid-state circuits offer noteworthy power savings and should make possible considerable savings in maintenance expense.

2.4 *Signaling*

The modern in-band single frequency signaling family makes available the wide range of signaling options needed to provide the requisite flexibility in trunk supervision. This signaling system makes N3 channels compatible with channels or trunks provided by long-haul carrier systems. Signaling economies are achieved from this whenever a trunk is built up of two or more channels in tandem, since signaling terminals are required only at the trunk ends, and none are required at the channel junctions. Also, it was appreciated that the use of in-band signaling would ease circuit design limitations associated with providing increased channel bandwidth; the 3700-Hz out-of-band signaling tones as used in N1, O, and ON systems are necessarily transmitted at high level to insure adequate signal-to-noise performance. Since a high loss in the voice circuits is required to discriminate against the signaling frequency energy, this seriously limits the voice-frequency bandwidth that can be achieved.

2.5 *Frequency Precision*

The low frequency channel response objective and associated discrimination requirements for the channel filters dictated that the frequency shift of the sideband signal with respect to the channel filter be limited to 20 Hz. This order of precision was required since voice-frequency equalization of the channel filter band-edge roll-off was desired to improve adjacent channel suppression. If effective voice-frequency equalization was to be achieved, the received band had to remain within the channel filter frequency allocation within the 20-Hz tolerance. This made clear the need to eliminate the frequency shift introduced by the N-repeatered line, which can be as large as 100 Hz. In order to achieve the desired transmission improvements, it was necessary to incorporate frequency correction units in the terminal design which essentially eliminate this source of frequency error.

Further studies, assuming no repeatered line frequency shift, indicated that the long term frequency stability attainable with economically practical independent oscillators for the terminal modulators (similar to those used in existing Bell System short-haul carrier systems) was marginal for single-sideband operation, particularly with respect to temperature variations. Economic considerations led to the provision of a common carrier supply rather than stabilized individual oscillators. The primary frequency source stability specified was ± 7 parts per million over a six month period. While this value is substantially better than the precision required for message trunk considerations, it was deemed necessary for possible future program channels and other special service applications.

III. SYSTEM ORGANIZATION

3.1 *Modulation Plan*

The modulation plan adopted for the N3 system derives the 24-channel line signal within the terminal from two 12-channel groups in two steps of modulation. Fig. 1 illustrates the frequency allocation. Twelve channel filter designs, each with a 4-kHz upper sideband allocation, are provided in the frequency range 148–196 kHz. Each set of twelve channels forms a channel group. Each channel group is then group-modulated (280 or 232 kHz) to form the N-carrier low group

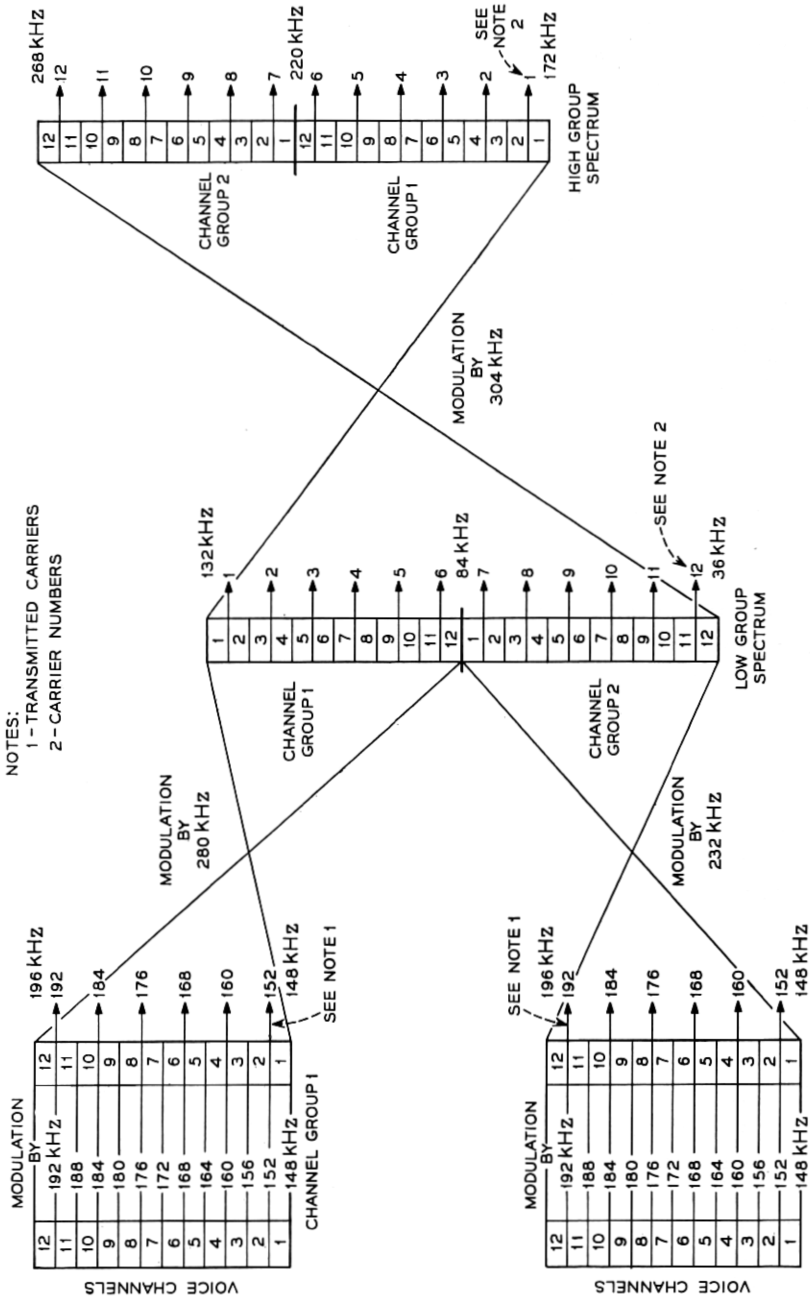

Fig. 1 — N3 carrier system frequency allocation.

band (36–132 kHz). Depending on the office location, either the 24-channel low group signal is fed directly to the line or the signal is given an additional step of modulation (304 kHz) to form the N-carrier high group band (172–268 kHz). The carriers associated with even channels are transmitted on the line to accommodate total power regulation of the type N repeaters; they are inserted separately for each channel group in the 148–196 kHz band.

The two 12-channel group organization of the N3 terminal was guided by three major factors: (*i*) the six, 4-channel group organization of the ON2 system, dictated by the use of O-carrier channelizing equipment, was uneconomical in terms of the excessive number of group modulators and amplifiers required; (*ii*) present rates of circuit growth normally can justify additions in units of twelve rather than four channels; (*iii*) field requests had indicated the desirability of interconnecting short and long-haul carrier facilities at group rather than voice frequencies. Sideband orientation was chosen on the basis of (*iii*) above. In the 148–196 kHz band, channel filters select the upper sideband. A single step of group modulation with a carrier at 256 kHz could translate the N3 channel group band to the 60–108 kHz lower sideband oriented group signal long established in the long-haul plant. Such group interconnecting equipment for short and long-haul systems is now being developed.

3.2 *Terminal Description*

The N3 carrier system, as illustrated in Fig. 2, is comprised of a transmitting and receiving terminal, carrier supplies, and an N-repeatered line. While the over-all N3 development included the packaged double bay arrangement, the VF jack field, signaling, and trunk processing components are not normally considered part of the carrier system.

For message service the signal in each of the 24 channels in the two 12-channel groups is compressed at a syllabic rate and modulated into the 148–196 kHz band. Each of the twelve channel filters passes the upper sideband, provides some suppression to the carrier, and rejects the lower sideband and other products of the modulator output. A balanced resistive multiple combines the twelve single-sideband filter outputs. The transmitted carriers (for the even channels) are also inserted at this multiple. Each 12-channel group is then modulated into its portion of the low group N carrier band.

A hybrid circuit combines the two channel group signals providing a continuous 24-channel spectrum with inserted transmitted carriers in the low group N-frequency range of 36–132 kHz. The group transmitting unit slope equalizes and amplifies the signal for line transmission. Both low and high group transmitting units are available; the high group unit contains an additional modulator to provide the frequency translation.

A line terminating unit is placed between the group equipment and the line pairs. The line terminating unit includes provisions for: (*i*) powering the repeaters in the line power section (up to three repeaters) adjacent to the terminal, (*ii*) the insertion of optional input and output span pads to adjust receive and transmit levels, and (*iii*) terminal secondary lightning protection for both line pairs.

In the receiving terminal the modulation steps are reversed. The group receiving unit slope equalizes, amplifies, and regulates the signal received from the line. Both high and low group receiving units are available; the high group receiver contains an additional modulator for frequency translation. At the output of either group receiving unit, the composite 24-channel signal is in the low group N-frequency band. The output signal is fed to two channel group demodulators via a balanced resistive splitting network.

Each channel group demodulator translates the appropriate portion of the low group N-carrier band to the 148–196 kHz band. The output of each channel group demodulator is fed to six double-channel regulators; in addition, the terminal frequency correction and alarm units are bridged at this point.

Frequency correction units are provided separately for each channel group. The function of the frequency correction unit is to derive the channel group demodulator carrier frequency. In order to eliminate the frequency shift introduced by the N-repeatered line, this derived channel group demodulator frequency is offset from its nominal value by an amount equal to the line frequency shift.

Separate alarm units are provided for each 12-channel group; these function not only to determine a carrier failure but also to determine when carrier transmission is satisfactory for service restoral.

The double-channel regulators automatically adjust the level of the two channels immediately adjacent to a transmitted carrier. A double-channel regulator is associated with each transmitted carrier since amplitude distortion in the repeatered line can create a substantial difference in the level of the received carriers. A channel demodulating carrier signal for the associated even channel is also obtained from this regulator. Odd channel demodulating carriers are obtained from

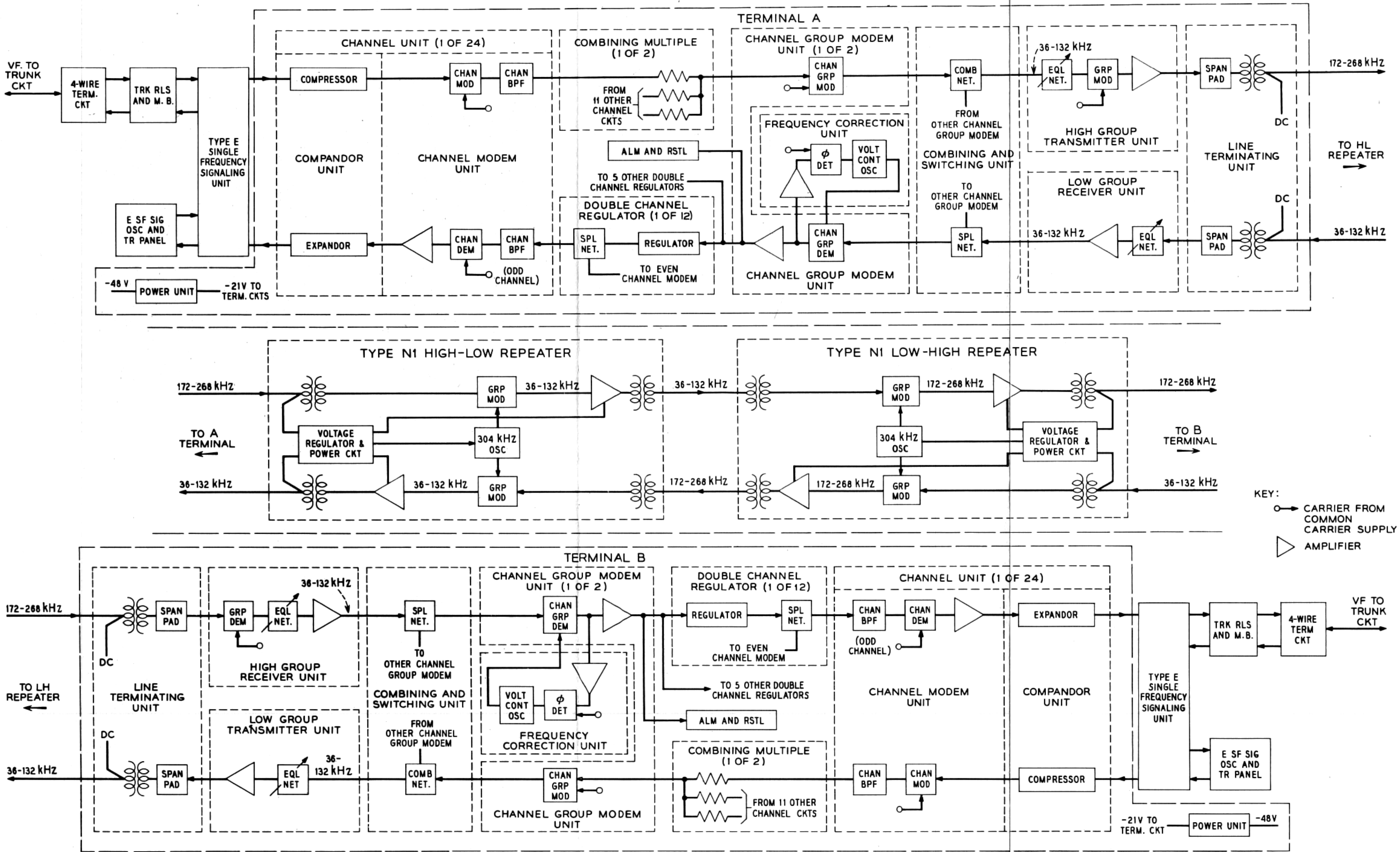

Fig. 2 — N3 Carrier system block diagram.

the common carrier supply. Each double-channel regulator signal output is fed to two channel demodulators.

The channel demodulator circuits include the receiving channel filter, demodulator, amplifier, and low-pass filter. The amplifier includes a feedback equalizer to compensate for band-edge amplitude distortion of both transmitting and receiving channel filters; the low-pass filter provides a peak of suppression at 4 kHz to suppress any tone resulting from the transmitted carriers. To complete the N3 channel, an expandor restores the original level range.

3.3 *N-Repeatered Line*

Essential features* of the N-repeatered line are also illustrated in Fig. 2. Originally developed for the N1 carrier system, the N-repeatered line is now also used for Western Electric ON1, ON2, N2, and N3 carrier systems. A separate cable pair is employed for each direction of transmission, usually within the same cable sheath. Further electrical separation of these signals is obtained by using different frequency bands for each direction of transmission; 36–140 kHz (low group) for one direction and 164–268 kHz (high group) for the other direction. These high and low group bands allow frequency space for 26 single-sideband (13 double-sideband) channels. In the N3 carrier system application, however, only 24 channels are transmitted within the fixed frequency bands 36–132 kHz and 172–268 kHz.

Frequency frogging, a feature of the N-repeatered line, involves the interchange of high and low group frequency bands at each repeater. Two types of repeater equipment units are employed; the first is called high-low (HL) and the second low-high (LH). Both types of repeaters interchange the group bands, each including a modulator for each direction of transmission and a common local oscillator operating at 304 kHz. Frequency frogging blocks a major circulating crosstalk path around each repeater and provides first-order equalization of line slope (increasing attenuation at higher frequencies). Other methods of slope control are also available including fixed slope networks for significant slope equalization and a slope switch on each repeater for small slope adjustments. In combination, these slope controls allow the transmission engineer to minimize line noise by design.

Primary power for N-type repeaters is either provided locally or transmitted over the cable pairs. For the transistorized designs, as many

* More detailed descriptions and objectives of N-repeatered lines can be found in Refs. 1 and 3.

as three repeaters in tandem can be powered via simplex circuits on the cable transmission pairs.

3.4 *System Levels*

Certain restraints on the transmission levels of the N3 carrier system were imposed by the nature of the development. As previously discussed, use of N-repeatered lines of existing design and the need for coordination with other N and ON systems operating within the same cable sheath clearly defines the required levels on the line side of the terminal. The compandor design chosen is the same as that used in the N2 carrier system; this defines the levels throughout the compandor circuit.

Fig. 3 indicates the transmission levels at major functional points throughout the N3 system. The voice-frequency and sideband values shown are those which would be *measured* if a 0 dBm, 1-kHz sine wave tone were applied at the zero transmission level point (0 TLP). This means that the levels shown between the output of the compressor variolosser and the input of the expandor variolosser are the actual, compressed levels.*

For that portion of the carrier system where the transmitted carriers are present, (including all of the repeatered line) system levels are quoted on the basis of the transmitted carrier amplitude.

The channel sideband power transmitted on the line (compressed) for a 0 dBm test tone at the 0 TLP is nominally 3.5 dB below the transmitted carrier power. This is the same carrier-to-sideband ratio employed in the ON2 system. (Historically, this carrier-to-sideband ratio was first employed in type O systems to minimize static noise.) The single sideband has 9 dB more power than is contained in each sideband of the double-sideband N carrier systems. The two sidebands of the double-sideband systems add in phase while the noise powers, being noncoherent, add on a power basis; this results in a 3-dB signal-to-noise advantage for a double-sideband system over a single-sideband system with equal sideband amplitudes. Since the N3 single-sideband power is 9 dB greater, a theoretical 6-dB signal-to-noise advantage is obtained. This has proved advantageous since the single-sideband systems are usually applied on the longer circuits.

Single-sideband systems such as N3 do not have the overmodula-

* In Ref. 1, fictitious "message level" values were given as an indication of what the level would be if the 0 dBm test signal at the 0 TLP was not compressed. Such values can facilitate computations but have been omitted from Fig. 3 for simplicity.

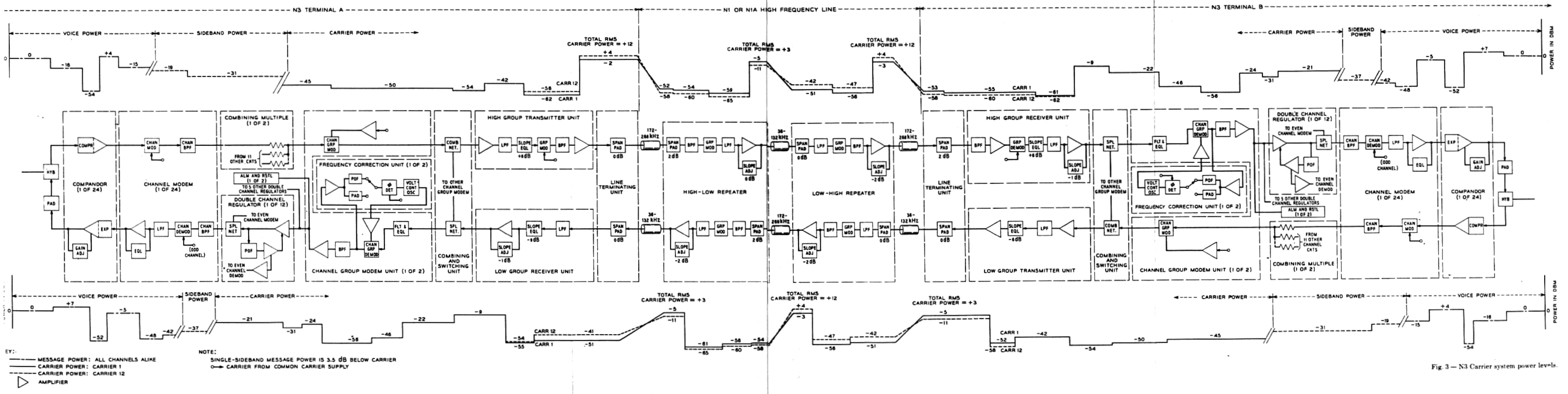

Fig. 3 — N3 Carrier system power levels.

tion restrictions inherent with double-sideband modulation. Thus, the carrier-to-sideband ratio employed does not of itself limit the load capacity of the channel. In the case of O, ON, and N3 systems, the carrier-to-sideband ratio has been chosen to maintain the line signal power reasonably constant with expected variation in system activity. Because of the total power regulation used in N-type repeaters, variations in activity result in second-order changes in the signal-to-noise performance.

Where design choice existed, signal levels within the N3 terminal were chosen as a compromise between a high level to keep the signal above noise and a low level to avoid nonlinear distortion. With normal system and channel loading the controlling noise source of the system is crosstalk and impulse noise on the N-repeatered line. For back-to-back terminals, the controlling noise source is the first circuit noise of the expandor amplifier on compandored channels and modulator noise in the high group transmit or high group receive units for noncompandored channels; some external noise from the power supply is also measurable on noncompandored channels.

One of the sources of noise is the modulation performance of the group equipment. All of the modulating and transmitted carriers of the N3 system are developed from a common carrier supply.[4] Therefore, all transmitted carriers have a fixed relationship with each other and the peak amplitude of the carrier tones can be periodically large. In addition, the peak amplitude of the sideband powers can also be large if several channels are transmitting the same signal. The sum of these peak amplitudes imposes a severe load handling requirement on each of the group units of the N3 terminal. To reduce this power handling requirement, the phase of certain transmitted and channel modulating carriers have been reversed with respect to others. Better modulation performance of the group equipment results.

Nonlinear distortion on compandored message channels is controlled primarily by the variable loss "variolosser" elements in the compandor. For noncompandored channels, the channel demodulator amplifier contributes the most nonlinear distortion.

IV. SYSTEM FEATURES

4.1 *Compandor*

Short-haul carrier systems have enjoyed rapid growth in the Bell System since the introduction of type N1 carrier in 1950. At the end of 1965, over 700,000 two-way, short-haul channels derived by frequency division multiplex had been placed in commercial service. This is now nearly two-thirds of all frequency division carrier channels in the Bell System. A major factor in this widespread acceptance has been the relative ease in adapting a great mass of cable pairs, most of them originally installed for VF transmission, for short-haul carrier use. A key factor in this ease of application is the built-in compandor, a feature of all previous short-haul carrier systems retained in type N3. By compressing the volume range transmitted and by making a corresponding expansion of the received volume range, a compandor affords a substantial increase in the amount of crosstalk and noise which can be tolerated in the carrier frequency part of the system. This includes the entire line transmission facility as well as most of the carrier terminal. A compandor avoids the need for expensive line treatment such as crosstalk balancing or short repeater spacing and effectively enhances band filter discrimination.

The compandor design chosen for N3 is the same as that employed in the N2 carrier system.[7] This choice was made with the benefit of some operating experience of the N2 compandor in the field; excellent stability, harmonic distortion, and tracking performance observed on early N2 systems gave promise (which has since been verified) that needed improvements in these areas over early short-haul carrier systems could be achieved with the chosen design.

4.2 *Channel Filters*

The over-all performance of a single-sideband, amplitude modulated, frequency division multiplex carrier terminal is influenced in large measure by the channel filter discrimination and in-band amplitude distortion characteristics. The two-section, quartz crystal channel filters of new design are a major factor in the improved performance of the N3 carrier terminal. The insertion loss characteristic of a typical channel filter is illustrated in Fig. 4.

As opposed to the twin channel (one upper, one lower sideband about a common carrier) arrangement used in previous O and ON carrier system designs, the N3 carrier terminal employs the same sideband orientation for all channels. This was chosen partly to achieve a substantial improvement in adjacent channel crosstalk, particularly at low voice frequencies. In the twin channel arrangement, the high-energy, low frequency portions of the speech spectrum of both channels are clustered closely around the common carrier. Any vestige of the

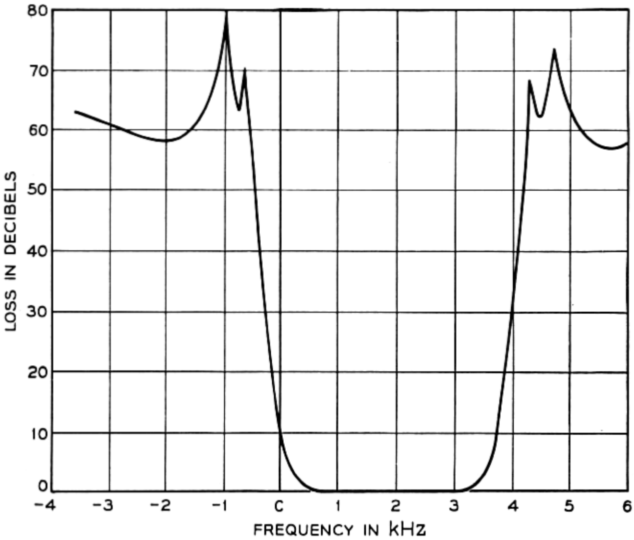

Fig. 4 — N3 channel filter discrimination.

unwanted sideband falls upright in the adjacent channel, placing most stringent requirements on the channel filter discrimination shape in the narrow frequency range between pass and stop bands. Common orientation of sidebands separates the high energy portions of adjacent channels to the full extent of the channel spacing; this provides about 10 dB less crosstalk interference than the twin channel arrangement, assuming speech type signals and the same discrimination shapes for both. In addition, the interference for the common sideband orientation arrangement is inverted in the disturbed channel, even further reducing the effect of this form of crosstalk.

The decision to depart from the earlier twin-channel arrangement ruled out the possibility of terminal-to-terminal compatibility with ON2. Yet the excellent crosstalk performance reported in Section 6.5 for back-to-back terminals makes clear the sacrifice of terminal compatibility was not without reward.

4.3 *Net Loss Stability*

Particular care was taken throughout the N3 terminal design to assure a high order of net loss stability. Liberal use of negative feedback, close control of compandor tracking, the use of a regulated power converter, group and double channel regulation, precise regulation of the transmitted carrier insertion level and temperature compensation of networks all contribute to the excellent stability attained.

No transmit level adjustment is provided and some variation in the carrier-to-sideband ratio is tolerated from channel-to-channel as a result of manufacturing tolerances. The absolute power of each transmitted carrier is factory adjusted and maintained at the regulator output to within ±0.05 dB of a nominal value. Variation in the carrier-to-sideband ratio is acceptable within limits as long as it is not time variant. Temperature equalization is provided to compensate for the transmitting crystal channel filter loss variations which are in the order of 0.015 dB per degree Fahrenheit.

Having established the carrier-to-sideband ratio at an early point in the transmitting terminal, one can expect the same ratio to be maintained throughout the broadband terminal circuitry and repeatered line. From a general stability point of view, the major consideration involves maintaining the frequency spectrum essentially flat for each transmitted carrier and its two associated sidebands (a bandwidth of 8 kHz). This was accomplished by incorporating amplitude equalizers in several of the group and channel group filters, reducing the ripple distortion in these units to less than 0.1 dB over any 4-kHz increment of the band.

The N-repeatered line is a factor in both the stability and channel frequency response performance of the system. Any amplitude distortion which exists over the bandwidth of a channel is reflected in the channel frequency response; any time variant change in the amplitude distortion which exists over the two sidebands associated with each transmitted carrier results in correlated level changes within the channels. A well-engineered and maintained N-repeatered line is essential to obtain the superior transmission performance built into the N3 terminals.

The double-channel regulator automatically maintains the received carrier level essentially constant at its output. Since the carrier-to-sideband ratio is fixed, the associated channel sidebands are also regulated. This accommodates flat loss changes in the received signal. Wide range and extreme regulation stiffness are provided. Part of the need for good regulation stems from the use of common sideband orientation; in the odd channels, a 1-kHz test tone is separated from the transmitted carrier controlling its regulation by 3 kHz. This emphasizes the need to reduce the amplitude distortion of the repeatered line and terminal group equipments outlined in the above paragraph. Each double-channel regulator also supplies the channel demodulator carrier signal for its associated even channel. Two elements within the double-channel regulator are subject to significant temperature variation: (*i*) a voltage reference diode and (*ii*) the narrowband crystal pick-off filter. These elements have opposite effects and a net temperature compensation is accomplished with a single temperature compensating resistor.

In the receiving channel demodulator circuit temperature compensation is also provided to compensate for the receiving crystal channel filter variation.

The expandor in the receiving terminal contains the only operating level adjustment provided for each channel. Its purpose is to accommodate the small level variations which accrue from manufacturing tolerances and length differences in central office cabling as well as the inherent long term aging. Once set there is little likelihood that it will need readjustment for at least six months.

4.4 *Frequency Correction*

As a result of the frequency-frogging process in each N repeater, small errors in the 304-kHz repeater oscillators tend to shift the transmitted line signal from nominal by the amount of frequency error. These small errors at each repeater can accumulate, and line frequency shifts approaching 100 Hz have been observed on long repeatered lines. Frequency correction units are employed in the N3 terminal to essentially eliminate this repeatered line frequency shift.

The line frequency shift is eliminated* with the aid of a phase-locked-loop which compares a received carrier signal at the output of the channel group demodulator with the correct frequency generated in the office primary frequency supply. Departure from phase coherence of these two signals is used to control a variable frequency oscillator within the frequency correction unit. This oscillator provides the correct channel group demodulator carrier frequency which will synchronize the selected received carrier to the carrier frequency supply at the receiving terminal.

* Early N3 frequency correction units eliminated the line frequency shift by selecting a particular carrier by means of a pick-off filter and modulating this signal with a precise local carrier. The upper sideband of this modulation process contained the nominal channel group demodulator frequency plus the line frequency shift. Using this carrier signal for channel group demodulation resulted in a desired lower sideband output without frequency shift. The transmitted carrier pick-off filter requirements are rather severe, the range of frequency shift accommodated being compromised with desirable crosstalk objectives. The new frequency correction unit, based on the phase-lock principle, has eliminated the need for this compromise.

4.4.1 *Channel Frequency Stability*

The elimination of the line frequency shift makes it possible to obtain odd channel demodulating carriers from the carrier frequency supply at the receiving terminal. The only frequency error present in the odd channels after correction is due to the independence of the carrier frequency supplies at the transmitting and receiving terminals; this is controlled by specifying a long term (six month) stability and maintenance limit of ± 7 parts per million for each primary supply. Since the odd channels of the N3 terminal are demodulated with locally generated carriers, frequency differences between the primary frequency supplies at transmitting and receiving terminals result in a frequency error in the detected signal. With the two primary frequency supplies at opposite tolerance extremes, the maximum frequency error in an odd channel, demodulated voice-frequency signal is 0.6 Hz. Even channels are coherently detected with their associated transmitted carrier and no frequency error is present.

4.5 *Voice-Frequency Equalization*

The precise control of frequency within the N3 terminal allows voice-frequency equalization of the carrier frequency amplitude distortion caused by the channel filter roll-off at the band edges. Equalization is provided at both band edges for amplitude distortion introduced by the transmit and receive channel filters with a network in the receiving channel demodulator amplifier.

4.6 *Alarm Provisions*

The failure of an N-repeatered line or an N3 terminal group unit causes the loss of 24 carrier derived trunks; failure in a 12-channel group equipment or a frequency correction unit causes the loss of 12 trunks. Rather extensive carrier alarm features have been incorporated in the N3 system design to minimize the effects of such failures on customer service and office switching equipment. Separate carrier alarm units are provided for each twelve channel group; these function independently, not only to determine a carrier failure, but also to determine when transmission is satisfactory for service restoral. The terminal alarm units control auxiliary trunk release and make-busy panels which "condition" the trunks during the failed interval by dc control of the trunk supervision leads. Trunk conditioning during a carrier failure interval first involves making the trunk idle to stop subscriber charges and, for most trunks, automatically disconnecting the subscriber. Subsequently, the trunks are made busy to avoid selection of an unusable trunk by the switching machine. The trunk is held in the busy state until transmission is satisfactory for service restoral; at such time the trunk conditioning is removed thus making it available for service.

The carrier alarm units are bridged on the output of the channel group demodulator circuit and register an alarm if the received power drops below threshold for more than about two seconds. Following registration of the alarm, a forced transmission failure in the same channel group is induced toward the far* terminal and a control signal to condition the associated trunks to the idle state is maintained for about 10 seconds. Note that the forced transmission failure results in the registration of an alarm in the same channel group at the far terminal. At the end of this 10 second interval a control signal to condition trunks to the busy state is generated and maintained for the duration of the carrier failure; also the automatic restoral sequence is initiated.

The automatic restoral sequence is controlled by the alarm unit as it applies and monitors transmission test tones on two of the channels (which are out-of-service during the failure interval). Recalling that alarms are registered at both near and far terminals, a test tone is applied on the first test channel of the near terminal which is monitored at the far terminal; also, a test tone applied on the first test channel of the far terminal is monitored at the near terminal. Within both alarm units the signal-to-noise ratios are evaluated. When the signal-to-noise performance in one direction is satisfactory for service restoral, and such performance is maintained for a period of about 10 seconds, tone is applied on a second test channel. In the case of a unidirectional transmission failure, the signal-to-noise performance is satisfactory in one direction and unsatisfactory in the other. Service restoral is withheld in this instance since the terminal receiving satisfactory transmission does not have an indication on the second test channel that transmission is satisfactory in the other direction. When the fault is cleared, both terminals have an indication that transmission has been satisfactory in both directions. At essentially that instant, both terminals are restored to service by removing the transmission test tones and trunk conditioning.

In connection with the automatic trunk conditioning provisions, an

* Alarm arrangements at the two terminals of an N3 carrier system are identical. Because of this symmetry, the terms *near* and *far* are used for terminal distinction

option is available to allow manual overriding of the trunk conditioning. Such overriding of conditioning permits trunks with this applied option to be restored to service during the carrier failure interval by patching to alternate transmission facilities.

4.7 *Special Service Provisions*

In addition to the conventional use of compandored N3 channels for direct, toll-connecting, and intertoll message trunks, most of the channels are satisfactory for Schedule C & D Program service. Exceptions* are the end channels 1 and 2 of channel group one and end channels 11 and 12 of channel group two. End channel restrictions are imposed as a result of channel frequency response variations due primarily to repeatered line characteristics.

For noncompandored channel applications a VF amplifier is available to replace the compandor. One VF amplifier application includes its use at the junction of two N3 channels wired in tandem to derive one over-all compandored circuit; use of the VF amplifiers avoids the use of two compandors in tandem.

Another common use is in the provision of private line, voice band data transmission circuits; for such signals, the signal-to-noise improvement obtained with a compandor is limited and a more economical circuit is obtained with the VF amplifier.

4.8 *Maintenance and Testing*

Rapid growth in the number of carrier channels and today's stringent transmission performance requirements are but two of many factors emphasizing the importance and need for simplified maintenance of a modern carrier system. In the N3 carrier development it was possible to incorporate many of the operating convenience and maintenance innovations originally introduced and field proven with the N2 carrier system. Included are the automatic carrier alarm and trunk processing features, the use of a regulated power supply, separate line terminating units incorporating repeater power feed circuits and plug-in, flat loss span pads, provision of easily replaceable slope equalizing

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* On systems utilizing the original frequency correction unit design, channel 6 of channel group 1 and channel 2 of channel group two were also excepted for Schedule C & D Program service. These are the channels associated with the frequency correction carriers; the restrictions are necessary to avoid crosstalk resulting from the high-energy, low frequency components of program material from entering other message channels.

networks in the group transmitting and receiving equipment, and the use of a single gain control for the adjustment of channel net loss.

The N3 terminal requires 15 distinct carrier frequencies obtained from a common carrier supply which can accommodate as many as 26 N3 terminals totalling 624 channels. The carrier supply arrangement allows the optional provision of alternate spares with automatic alarm and switching features to assure continuity of service. Active N3 terminal units handling 24 channels are provided with in-service switching capability; a terminal switching set allows essentially hit-free* in-service switching of the group transmitting unit, group receiving unit and power supply. This switching set also contains an accurate voltmeter which allows precise adjustment of the regulated power supply voltage.

In-service signal level or voltage measurements may be made on compandors, modems, group transmitting and receiving units, and the power converter by means of pin jacks on the front of the units or by connection to switching jacks. Similar pin jacks on the group transmitting and receiving units, channel group modem unit, and frequency correction unit permit in-service transistor emitter voltage measurements. On an out-of-service basis, a portable test stand allows terminated measurements on the compandor, voice-frequency amplifier, channel modem or alarm unit, as well as providing bridging access to all input and output connections of these units.

V. OBJECTIVES

5.1 *Broad Objectives*

As previously stated, the broad objective of the N3 carrier system development was to provide a modern replacement for the ON2 carrier system with improved performance. More specifically, a single-sideband, amplitude modulated frequency division multiplex terminal for N-repeatered lines was desired. Transmission performance capable of meeting today's stringent requirements for direct, toll connecting and intertoll trunks was a must. These are essentially the same broad objectives set forth for the N2 carrier system with the exception of single-sideband modulation and the replacement of the ON2 carrier system. Hence, the transmission performance objectives for the N3

* During the switching transient for group transmitting and receiving units, a 1 dB level reduction occurs for a duration of about 7 milliseconds; the phase transient during this interval is negligible.

TABLE I — N3 CARRIER SYSTEM — TRANSMISSION PERFORMANCE OBJECTIVES

Channel gain-frequency response (−3 dB points)	200–3450 Hz
Amplitude Distortion: 600–3000 Hz	±1.0 dB
Net loss stability (six months)	
Distribution grade (standard deviation)	0.5 dB
Bias (average)	0.25 dB
Short term loss variations — "beats" (intrasystem)	0.1 dB peak-to-peak
Compandor tracking (+8 to −40 dBmO)	±1.0 dB
Compandor tracking (+10 to −52 dBmO)	±2.0 dB
Compandor advantage (average/minimum)	30/28 dB
Channel noise* (at 0 TLP)	
Idle terminal (compandored)	16 dBrnC
Idle system (compandored over 100 miles)	26 dBrnC
Loaded terminal, (OVu, 40% activity, noncompandored)	48 dBrnC
Loaded terminal, (OVu, 40% activity, compandored)	20 dBrnC
Channel distortion	
2A − B; 0 dBmO fundamentals — dB below fundamentals	30 dB
Crosstalk — all terminal sources	70 dB
Equal level coupling loss	
Repeatered line amplitude distortion	
Slope across channel bandwidth 40 repeaters, 200 miles (compressed)	±0.5 dB

* Measured values are given; effective values are usually considered to be about 5 dB greater due to syllabic operation.

carrier system, as summarized in Table I, are quite similar to those for N2.

5.2 *Detailed Functional Objectives*

The over-all performance of the N3 carrier system is controlled by both the N3 carrier terminal and the N-repeatered line. Performance objectives for the various functional blocks of the N3 terminal were determined on the basis of analytical studies. For the N-repeatered line, the N2 repeater requirements[3] were assumed. Use of present N-repeatered line facilities is permissible and it is anticipated that with few exceptions, all transmission performance objectives can be met. One significant exception is the repeatered line amplitude distortion objective which is difficult to maintain on long systems using repeaters of existing design.

Substantial analysis effort was directed toward determining specific performance objectives for the various functional blocks of the N3 carrier terminal. Some of the areas covered by this work include:

(*i*) Study of the various interference mechanisms.
(*ii*) Consideration of today's state of the art, in particular with respect to filter network, modulator and amplifier preformance.
(*iii*) Selection of a judicious allocation of the over-all performance objective among the contributing functional blocks.

Table II presents some of the specific performance objectives derived with this procedure.

VI. TRANSMISSION PERFORMANCE

The various components of a carrier system may have satisfied their individual design objectives, but the transmission performance of all of the assembled individual components is the final criteria as to how well the over-all system objectives have been met. The measured transmission performance of manufactured N3 carrier systems shows that all objectives for the system have been satisfied with ample margins.

The transmission results given here represent the performance of the

Table II — Functional Unit Performance Objective

Unit	Parameter	Objective
Channel modem		
Modulator	Carrier leak(*i*)	−32 dBmO
Modulator, demodulator	Linearity(*ii*)	−54 dBmO
Receive amplifier	Linearity (*ii*)	−46 dBmO
Channel group modem	Linearity(*iii*)	−110 dB
Group transmitter	Linearity(*iii*)	−95 dB
Group receiver	Linearity(*iii*)	−100 dB
Frequency correction unit	Distortion(*iv*)	−55 dB
	Freq. shift range	±100 Hz
Alarm unit	Alarm threshold(*v*)	−18 ± 2 dB
Double channel regulator		
Through transmission amp.	Linearity(*iii*)	−105 dB
Regulation	Range/stiffness(*vi*)	±12 dB/±0.25 dB

Notes:
(*i*) excludes channel filter suppression
(*ii*) (2A − B) distortion product resulting from 0 dBmO fundamentals
(*iii*) (2A − B) distortion product relative to transmitted carrier levels.
(*iv*) second harmonic content relative to fundamental carrier output level.
(*v*) received power relative to nominal
(*vi*) output variation relative to nominal at extremes of regulation range.

N3 carrier system as measured between the VF IN and VF OUT jacks of the N3 packaged bays or their equivalent in a centralized patch bay. In addition, these results include certain interface data within the terminal. Such data will be helpful to manufacturers for non-Bell companies in developing carrier terminals compatible on an end-to-end basis with N3 terminals. Items included for this reason are compressor input-output characteristics, compressor intramodulation figures and carrier-to-sideband ratios for channel voice-frequency inputs from 200–3500 Hz.

6.1 *Frequency Characteristic*

The gain-frequency characteristics of N3 channels, illustrated in Fig. 5, are representative of present N3 carrier product on a system of about average length having a good high frequency line characteristic. In general, these N3 channel characteristics compare favorably with those of the A5 channel bank and the N2 carrier channels.[3] The principal concern has been the positive peaks in the response near the band edges of the characteristic. The return losses of associated VF circuit equipment outside of the N3 carrier system at the band edge frequencies can lead to near-singing distortion if the peaks are not controlled. Some average bandwidth at the lower frequencies of the N3 channel has been sacrificed in order to minimize these gain peaks.

The design objective for the carrier-to-sideband ratio of a 0 dBmO,

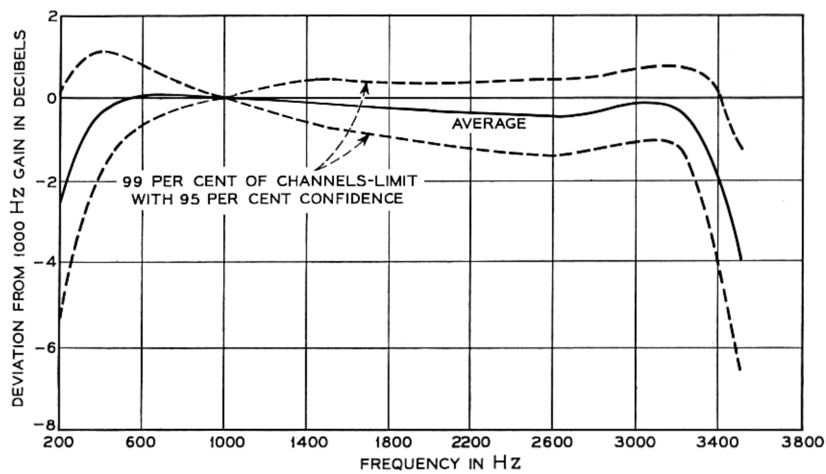

Fig. 5 — N3 channel VF gain-frequency characteristic.

1000-Hz compressed tone at the output of the N3 group transmitting unit is 3.5 dB. The carrier-to-sideband ratio for other voice frequencies that can be transmitted by the channel may vary slightly from this value, reflecting primarily the response characteristics of the channel filter of the N3 channel modulators. The mean carrier-to-sideband ratio for a 1000-Hz, 0 dBmO tone was 3.27 dB. Statistical results indicate that carrier-to-sideband ratios between 2.52 and 4.07 dB would encompass 99 per cent of the channels with 95 per cent confidence.

Fig. 6 eliminates the flat loss deviations from the carrier-to-sideband ratios and shows the transmitted sideband levels for all voice frequencies transmitted in the channel with respect to the sideband level for 1000 Hz. The characteristics shown in Fig. 6 essentially represent the passband frequency characteristic of the transmitting channel filters. The receiving channel filters are identical. The variation of the average curve of Fig. 6 for frequencies at the edge of the voice band multiplied by four (two filters and an expansion ratio of 2:1) will be worse than the deviations of the average curve for these same frequencies shown in Fig. 5. The equalizer at the receiving end of the N3 channel provides the difference between the two results at the low and high frequency ends of the voice channel.

6.2 *Compandor Tracking*

Compandor tracking performance of the N3 channels is indicated by the curves of Fig. 7.

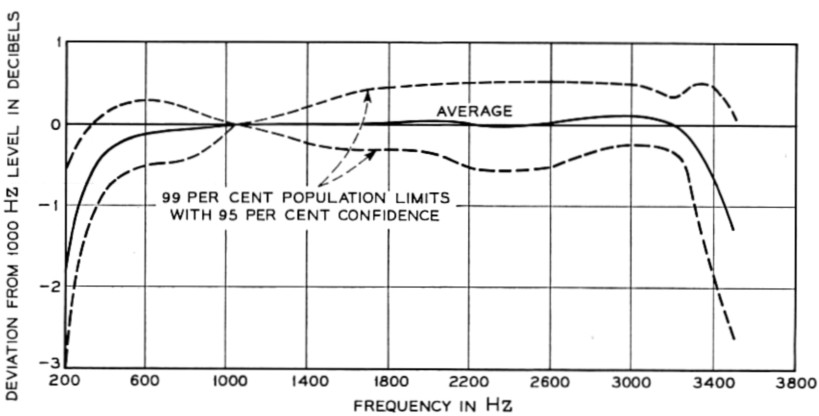

Fig. 6 — N3 channel sideband gain-frequency characteristic.

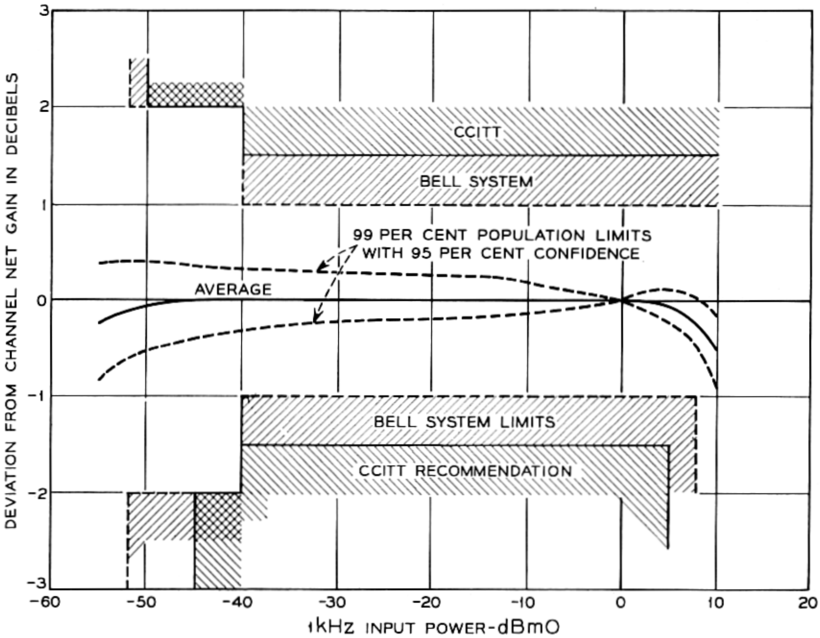

Fig. 7 — N3 channel compandor tracking characteristic.

The compandor tracking characteristics indicate the high degree of compatibility of the compressor and expandor circuits and the excellent reproducibility that is obtained with the manufactured product.

The N3 compandor circuit has a nominal 2:1 compression characteristic[3] and a 1:2 expansion characteristic. As a practical matter, the compressor and expandor circuits have been allowed to depart from the ideal 2:1 and 1:2 compression and expansion ratios. Fig. 8 presents the deviation from ideal 2:1 compression ratio as measured at the output of the compressor.

6.3 *Channel Distortion*

Table III summarizes the measured performance of the new N3 compandor units. The frequencies used in making these tests were 740 Hz and 1250 Hz. These frequencies were selected so that the important second- and third-order products would fall within the bandwidth of the voice-frequency channels, and none of the higher-order products would fall at any of the frequencies of the second- or third-order prod-

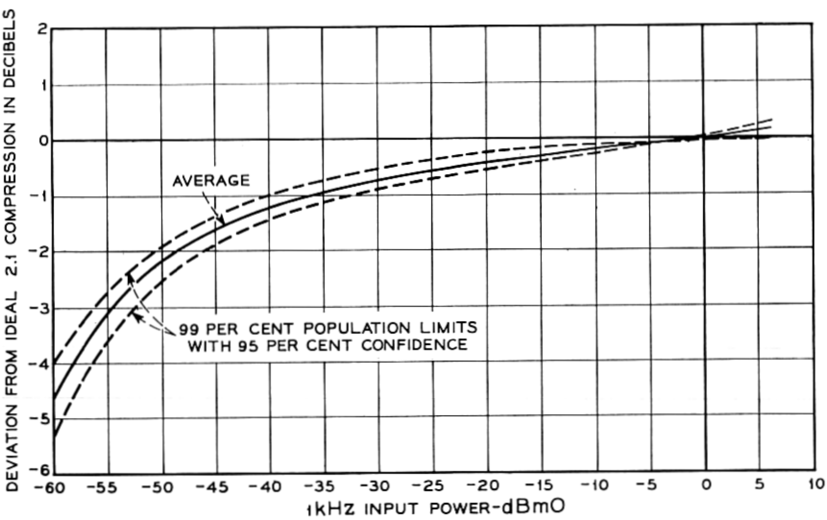

Fig. 8 — N3 channel compressor tracking characteristic.

ucts. The frequency differences between any two products, up to and including tenth order, or between fundamentals and modulation products is large enough that the desired modulation product can be measured with available test equipment.

Intramodulation products generated in the compressor and expandor circuits are about equal in magnitude. Their total magnitude will depend upon the phase relationships of the two products. If we assume that the value of the product is the same for both compressor and expandor, the maximum value will be for in phase products and have a magnitude 6 dB greater than the product from either circuit. If the separate products are 180 degrees out of phase, there will be complete cancellation and no product at the output of the compandor. The spread of maximum and minimum values of Table III reflect that distribution.

The above table gives the values of intramodulation distortion for all second- and third-order products. This has been done since there is considerable spread in the measured values for products of the same order but different frequencies. It is interesting to note that reduction of input signal level does not result in any substantial improvement in modulation distortion. The distortion certainly does not follow the power series law where a reduction of input power by 10 dB would result in a reduction of 10 dB in the relative level of second-order prod-

TABLE III — INTRACHANNEL DISTORTION FOR COMPANDORED N3 CHANNELS

Type	Frequency Hz	Value	Fundamental to Distortion Product Ratio—dB		
			Avg. Value of Fund. Power	Change in Ratio for Lower Fund. Power	
			0 dBmO	−10 dBmO	−20 dBmO
2a	1480	Avg. Max.* Min.*	47.7 40.5 56.1	2.3	0.9
2b	2500	Avg. Max. Min.	48.4 41.0 58.0	2.9	3.9
a + b	1990	Avg. Max. Min.	43.1 35.8 58.3	2.0	2.7
b − a	510	Avg. Max. Min.	42.7 35.4 57.0	−2.2	−5.0
3a	2220	Avg. Max. Min.	51.9 46.9 59.2	2.0	1.7
2a − b	230	Avg. Max. Min.	40.1 33.9 46.5	4.6	4.9
2b − a	1760	Avg. Max. Min.	37.1 34.8 39.5	2.4	2.9
2a + b	2730	Avg. Max. Min.	46.6 38.9 56.4	0.7	−0.6
2b + a	3240	Avg. Max. Min.	46.0 37.0 66.0	−0.5	−1.0

* The maximum and minimum values given in Table III are those obtained with the relatively small sample of 24 compandor units. The maximum values are indicative of the values expected. Tolerance limits are not given for this small sample since the summation of the distortion products developed in the over-all channel should not result in a normal distribution of values.

uct and 20 dB in the relative level of third-order product. The distortion products are generated in the variolossers where by design, the signal current-to-bias current ratio for the various input levels remains essentially constant; therefore, the level of the distortion products should remain essentially constant.

Table IV summarizes the performance of the compressor circuit alone as measured at the modulator input of an N3 channel.

6.4 *Channel Noise*

The back-to-back unloaded terminal noise performance of N3 channels is summarized in Table V. The performance of both compandored and non-compandored channels is well within the objectives.

TABLE IV — MODULATION DISTORTION OF THE N3 COMPRESSOR CIRCUIT

Type	Frequency Hz	Value	Fundamental to Distortion Product Ratio — dB		
			Avg. Value of Fund. Power	Change in Ratio for Lower Fund. Power	
			0 dBmO	−10 dBmO	−20 dBmO
2a	1480	Avg. Max. Min.	48.9 43.4 54.2	0.8	0.3
2b	2500	Avg. Max. Min.	50.2 43.2 56.8	1.6	0.9
a + b	1990	Avg. Max. Min.	46.2 40.2 54.7	0.0	−0.7
b − a	510	Avg. Max. Min.	43.5 36.9 47.8	−1.0	−3.5
3a	2220	Avg. Max. Min.	58.3 49.1 63.8	0.9	−0.3
2a − b	230	Avg. Max. Min.	41.9 36.8 47.5	0.4	−0.2
2b − a	1760	Avg. Max. Min.	44.9 40.6 49.1	−1.2	−1.5
2a + b	2730	Avg. Max. Min.	47.1 39.9 53.7	1.8	0.4
2b + a	3240	Avg. Max. Min.	44.8 38.8 50.0	2.6	1.6

TABLE V — UNLOADED TERMINAL CHANNEL NOISE

Type of Channel	Channel Noise at 0 TLP					
	dBrnC			dBrn 3 kHz Flat		
	Average	Max.	Min.	Average	Max.	Min.
Compandored	8.1	11.4	5.7	11.1	14.4	7.8
Non-Compandored	27.0	33.2	20.9	30.0	34.2	24.5

Measurements of the channel noise introduced by loading various combinations of channels with simulated speech indicated that certain types of system loading were detrimental to system performance. For example, several channels of one system may be loaded with identical signals by a few of the services offered by the operating companies. This has been termed "coherent" loading. Table VI gives the magnitude of noise generated by the loading of N3 channels with simulated speech, both coherent and non-coherent.

Loading the channels of an N3 carrier system with non-coherent noise does not impose a message noise problem as shown by the results when 22 channels are loaded. However, a noise advantage is obtained by loading certain channels when coherent loads are transmitted. The maximum reading for line (1) was reduced to 12.5 dB by also loading channels 2 and 6 of channel group 1 with the same signal for a total of ten loaded channels, emphasizing the benefit of the reversed phase of the modulating carriers of channels 2 and 6.

The noise performance of a carrier channel is judged on two bases: the C message weighted noise interference to a transmitted signal, and also the magnitude of impulse noise peaks. Large simultaneous amplitude peaks of speech in several channels of the N3 carrier system can

TABLE VI — CHANNEL NOISE DUE TO CHANNEL LOADING

No. of Chans Loaded	Type of Load	Channel Numbers	Grp No	Input Pwr at 0 TLP	Trsg Slope dB	Noise Value in dBrnCO	Message Rating
5	Coherent	Any combination	Any	0 Vu	0	<10	Satis
5	Non-coherent	Any combination	"	"	6	<10	"
(1) 8	Coherent	1, 3, 4, 5, 7, 8, 9, 11	1	"	0	21–26	Unsat
8	"	3, 4, 5, 7, 8, 9, 11, 12	2	"	0	26–33	"
8	"	3, 4, 5, 7, 8, 9, 11, 12	2	"	+6	35–40	"
8	"	1, 3, 4, 5, 7, 8, 9, 11	1	"	+6	≦10	Satis
10	Non-coherent	1 to 10 inclusive	1	"	0	≦10	"
22	"	All but chan 11, 12	1	−5 Vu	+6	≦10	"
22	"	All but chan 11, 12	1	−8 Vu	+6	≦10	"

generate impulse noise peaks in many channels by intermodulation processes within the group equipment. The input power of each of 22 channels loaded with simulated speech as disturbing signals had to be reduced from 0 Vu to −8 Vu at 0 TL to satisfy impulse noise objectives when the transmitting slope was +6 dB. This impulse noise performance is considered satisfactory.

The average measured noise advantage of the N3 expandor is 31.8 dB with a range between 30.8 and 32.9 dB. The subjective expandor advantage[8] is considered to average 5 dB less than the above figures when speech is being transmitted on the channel. Comparison of the unloaded noise performance of the two types of N3 channels shows an apparent expandor advantage of less than 20 dB. The unloaded noise of a compandored channel is usually controlled by the noise figure of the transistor at the input to the expandor amplifier (a low level point) which follows the expandor variolosser. Hence, the noise from this source is not reduced by the expandor loss.

6.5 *Intrasystem Crosstalk*

The far-end crosstalk performance of the N3 carrier terminals was one area where major improvements were incorporated, and the measured crosstalk values of the manufactured product reflect these improvements.

Near-end intrasystem crosstalk has never been a problem with the short-haul carrier systems since the carrier frequency allocations and operational methods were selected to eliminate the common sources of line near-end crosstalk at carrier frequencies. There were only a few measurable values of near-end intrasystem crosstalk observed with the N3 carrier systems, and these were well within the objective.

Only the minimum equal level coupling loss measured for each disturber is given in the results. Any other value would have little meaning since numerous combinations of disturbing and disturbed channels had no detectable crosstalk. In other combinations, crosstalk could be heard in the monitoring receiver but the noise of the disturbed channel masked the crosstalk contribution to the over-all meter reading. Crosstalk of this magnitude is not a problem. Far-end intrasystem modulation crosstalk generally had well-defined patterns for single-tone disturbers. However, it was never the controlling source, even for the lowest values of crosstalk interference measured.

Table VII gives the minimum equal level crosstalk coupling losses measured at the expandor output.

The out-of-band suppression of the channel filters can best be de-

TABLE VII — MINIMUM FAR-END EQUAL LEVEL CROSSTALK COUPLING LOSS AT EXPANDOR OUTPUT

Disturbing Frequency (0 dBmO)	Loss — dB	
	"C Mess Wtg"	"3 kHz Flat Wtg"
200 Hz	70.1	66.5
1000 Hz	77.4	77.7
3450 Hz	83.1	76.2
5000 Hz	86.4	83.6
Simulated Speech	80.9	75.7

termined by measuring the higher level crosstalk at the output of the demodulator. The crosstalk-to-noise ratio at this point for a 0 dBmO disturber is sufficiently large to assure accurate crosstalk measurement. Table VIII gives the minimum equal level coupling losses measured at the demodulator output.

6.6 *Net Loss Stability*

Stability of transmission has generally been referred to in terms of net loss of the derived trunk. The term net loss has been used in this section for clarity of association. The net loss stability of the N3 channels has been determined by measuring the gain at 1000 Hz at frequent intervals over a period of several months. Net loss stability tests are in progress on several operating N3 carrier systems of about average length. Table IX summarizes the measurements that have been made to date.

No adjustments have been made on any of these channels during the test period. The results are well within design objectives.

TABLE VIII — MINIMUM FAR-END EQUAL LEVEL CROSSTALK COUPLING LOSS AT DEMODULATOR OUTPUT

Disturbing Frequency (0 dBmO)	Loss — dB	
	"C Mess Wtg"	"3 kHz Flat Wtg"
200 Hz	41.7	38.4*
1000 Hz	43.9	46.9
3450 Hz	49.3	45.7
5000 Hz	55.9	55.3
Simulated speech	48.0	48.0

* All of these equal level coupling losses satisfy the objectives with the exception of the minimum value for 3 kHz flat weighting at 200 Hz. Only this single measurement fell short of the 40 dB objective. The average value for a sample of 48 measurements was 45.5 dB.

TABLE IX — N3 CHANNEL NET LOSS STABILITY

System	No. of Channels	Net Loss Stability			
		3 Mos.		6 Mos.	
		Bias (Avg)	Dist gr (Std Dev)	Bias (Avg)	Dist gr (Std Dev)
Hartford-Waterbury	96	−0.04	0.16	+0.20*	0.27*
Dayton-Springfield	78	−0.03	0.13	−0.094	0.20

* The elapsed time between initial and these measurements was seven months.

6.7 *Envelope Delay*

Fig. 9 shows the envelope delay distortion of N3 compandored channels as measured with terminals connected back-to-back. This distortion is due primarily to the channel filters. The type of voice-frequency unit (compandor or VF amplifier) has only a small effect on the magnitude of the distortion. The curve of Fig. 9 is applicable for both types of channels.

The absolute delay of a carrier channel is also important for some installations. Table X gives the absolute terminal delay in microseconds applicable to channels equipped with either the compandor or VF amplifier units. The absolute delay of a typical N-repeatered line is about 10 microseconds per mile.

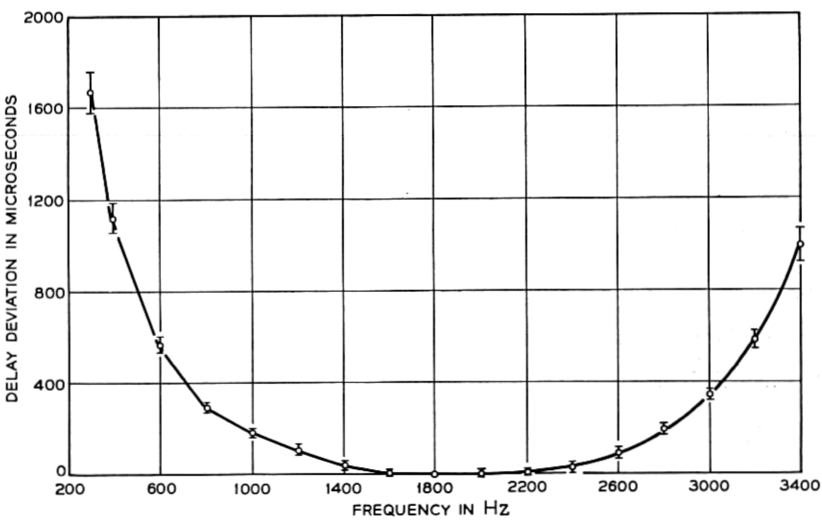

Fig. 9 — N3 channel delay distortion characteristic.

TABLE X — N3 CHANNEL DELAY AT 1800 Hz

Input Power dBmO	Absolute Terminal Delay in Microseconds	
	Avg. Delay	Limits for 99% of Chans with 95% Confidence
+1.0	983	±78.0
−9.0	1001	±76.0
−14.0	1006	±74.5

6.8 *Alarm Operation*

Tests of the carrier failure alarms, automatic trunk conditioning and automatic service restoral features of the N3 carrier system have indicated satisfactory performance within design objectives. Measured alarm thresholds (loss in carrier power sufficient for alarm registration) ranged from 17 to 20 dB below nominal received carrier power. Such threshold values had been established to assure satisfactory operation during the restoral gain transient of an N-repeatered line.

Idle channel noise at the instant of service restoral ranged from 33.5 to 37.0 dBrnCO. While this noise value is above the normal system objective, experience has shown that any restored N3 carrier system whose channel noise measurements are in the above range can meet the severe system objectives within a short time. This prevents restoral of systems with degraded transmission performance.

VII. ACKNOWLEDGMENT

The development of a carrier telephone system necessarily involves the contributions of many people. While it is not possible to mention all, the authors wish to acknowledge, with thanks, the contributions of F. H. Blecher, R. C. Boyd, F. J. Herr, Mrs. R. A. King, W. R. Lundry, D. D. Sagaser, T. W. Thatcher, and L. F. Willey.

REFERENCES

1. Caruthers, R. S., The Type N1 Carrier Telephone System: Objectives and Transmission Features, B.S.T.J., *30*, Jan., 1951, pp. 1–32.
2. Fracassi, R. D. and Kahl, H., Type ON Carrier Telephone, Trans. AIEE, *72*, Jan., 1954, pp. 713–21.
3. Boyd, R. C. and Herr, F. J., The N2 Carrier Terminal — Objectives and Analysis, B.S.T.J., *44*, May–June, 1965, pp. 731–59.
4. Haner, R. L. and Wood, I. E., N3 Carrier System — Circuit Design, B.S.T.J., This Issue, pp. 801–844.

5. Bowie, L. A., Giguere, W. J., and Watters, J. A., Equipment Design of N3 Carrier Terminals and Carrier Supply, B.S.T.J., This Issue, pp. 845–894.
6. Weaver, A. and Newell, N. A., In-Band Single Frequency Signaling, B.S.T.J., *33*, November, 1954, p. 1381.
7. Lundry, W. R. and Willey, L. F., The N2 Carrier Terminal — Circuit Design, B.S.T.J., *44*, May–June 1965, pp. 761–87.
8. Carter, C. W., Jr., Dickieson, A. C., and Mitchell, D., Application of Compandors to Telephone Circuits, AIEE, *65*, 1946, pp. 1079–1086.