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The SD Submarine Cable System

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Submarine cable systems of a new design have recently been installed between Florida and Panama, between New Jersey and Cornwall, England, and between Hawaii and Japan. Using a single lightweight armorless cable for most of the route, with electron tube amplifiers encased in rigid containers at 20-mile intervals, this type of system will carry 128 channels in each direction.

More detailed discussion of cable, repeaters, and power equipment will be found in companion articles. This article outlines the system development objectives, gives an over-all system description, and describes the equalization plan and terminal equipment.

I. INTRODUCTION

In 1954, before the installation of the first transatlantic telephone cable, growth studies had shown that submarine cable systems carrying many more channels than the systems then under development would be required to carry future traffic. The development of these wider-band systems was therefore initiated before the development of the SB submarine cable system[1] was complete. Exploratory studies indicated that a new approach to cable and repeater design would be required. The SB system used armored coaxial cables, one for each direction of transmission. The repeaters were long and flexible so they could be handled on shipboard without major modifications to the cable machinery, which had been developed to lay submarine telegraph systems. While these long, flexible repeaters have proven to be sound in concept and reliable in performance, the form factor is such as to introduce large parasitic inductance and capacitance in the interconnections between the stages of the repeater and in the feedback path from input to output. In consequence, it is not possible to design a wideband repeater using this mechanical approach. For the new broader-band systems, therefore, the repeater circuit was placed in a rigid cylindrical container.

The cable concept was changed, and the strength was placed in the center of the cable rather than in the armor wires on the outside. Such construction makes possible a cable with a very stable transmission characteristic and eliminates the tendency of the cable to untwist under tension. This latter feature makes it easier to lay the large, heavy repeaters in deep water.

The decision to use a new cable and rigid repeaters made it necessary to consider the impact of these new components on the cable laying process. This resulted in the development of new cable laying machinery and techniques, which were combined to produce a new cable laying ship — the C.S. *Long Lines*.

The SD submarine cable system is the result of this development approach. It will transmit 128 channels of 3-kc bandwidth in each direction over a single cable, and experience with initial installations in the Caribbean from Florida to Panama via Jamaica, in the North Atlantic from New Jersey to Cornwall, England, and in the Pacific from California to Japan indicates that system objectives will be met.

II. SYSTEM OBJECTIVES

The basic objective in the development of the SD system was to make available a highly reliable transoceanic facility which would be comparable in quality to the land plant of the continents to be connected, at a cost per channel-mile substantially lower than the earlier relatively narrow-band systems. Consistent with the trend to establish more stringent noise requirements on long continental circuits, noise of 41 dbrn at the zero level transmission point over the life of a 4000-statute mile system was taken as a design objective. This is about 3 db quieter than the transmission noise objective used for many years for continental circuits within the United States.

The system was also designed to carry a greater magnitude of signal per kc of transmitted bandwidth than usual in AM telephone systems. This was necessary for several reasons. In the first place, transatlantic callers have tended to speak at higher volumes than customers do on local calls within the United States or Europe. Secondly, because trans-oceanic spectrum is more expensive than land plant, it is worthwhile to make more efficient use of it by stacking channels more closely together. This loads the system more heavily. In addition, the probable application of TASI[2] makes it necessary to engineer for a talker activity about three times as great as that normally assumed in engineering land systems. The SD system has therefore been engineered to meet the 41-dbrn noise objective while carrying a signal load about six db higher than the CCITT recommendation for an equivalent eight-group land system, as indicated by Table I.

Many other objectives governed the design and layout of the system. Paramount, of course, was the reliability and stability of all the undersea equipment employed. Convenience of maintenance of the shore terminal stations and a high degree of reliability for the equipment employed at these terminals were also considered important objectives.

III. SYSTEM LAYOUT

As shown by the block diagram of the system in Fig. 1, the length of cable between repeaters is approximately 20 nautical miles (nm). An ocean-block equalizer to correct misalignment is located in the section following every tenth repeater in the direction of the cable lay. The length of cable between ocean-block equalizers and adjacent repeaters is 6 nm. The adjustable equalizer loss is thus approximately equivalent to the loss of 8 miles of cable. The repeaters, equalizers and cable are described in companion articles.[3,4] Transmission in one direction is carried in the frequency band of 108 to 504 kc and in the other direction by the band 660 to 1052 kc. These frequency allocations for 128 channels are shown in Fig. 2. After a system is installed it is possible that an additional 10 channels will meet requirements. When these channels are used the frequency bands are expanded to 90 to 516 kc and 630 to 1052 kc. The two directions of transmission are amplified in a common am-

Table I — Load Assumptions

	SD System	CCITT
Average talker volume (VU)	−10.8	−12.0
Standard deviation (db)	5.8	5.0
Activity	0.75	0.25
RMS power/channel (dbm)	−9.6	−15*
RMS power/group (dbm)	+2.4	−4.2
RMS power/band (dbm)	+11.5	+4.8

* Includes an allowance for power of signaling tones.

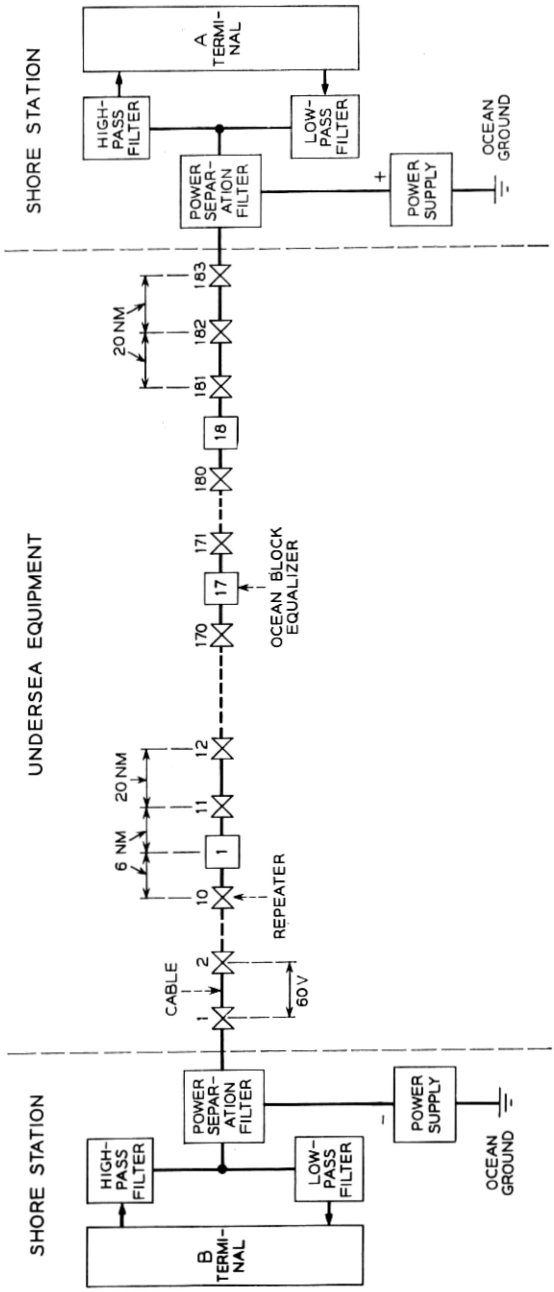

Fig. 1 — Block diagram of system.

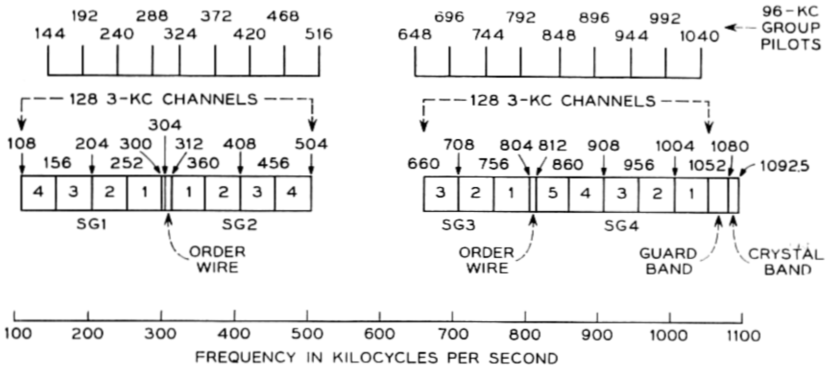

Fig. 2 — Frequency allocations for 128 3-kc message channels.

plifier by the use of directional filters. Parallel amplifiers, each containing three electron tubes, are used to provide protection against tube failure; these amplifiers share a common feedback or beta circuit, as indicated in the block diagram of Fig. 3.

The cable used for the major part of a system has an over-all diameter of $1\frac{1}{4}$ inches and a breaking strength of 18,000 pounds. Armored cable designs are available for use in shallow water to give protection against

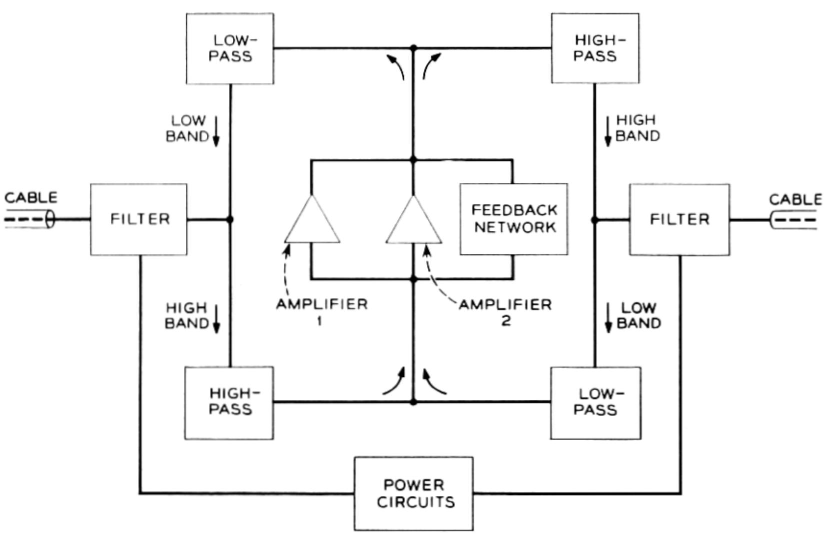

Fig. 3 — Repeater block schematic.

anchor or fishing damage. A shield may also be added to the cable structure at locations where radio or similar electromagnetic interference might be expected. The length of the shore-end section is restricted to the range 5 to 15 nm to minimize noise disturbances.

Power for operating the repeaters is supplied from the shore over the central conductor of the cable. The power system is described in more detail in a companion article.[5] A positive dc voltage is supplied to the cable at the A terminal between the central conductor and ground and a negative potential is supplied at the B terminal. The current path is thus over the central conductor, returning via the ocean. The power supplies provide precise regulation of cable current to a value of 389 ma. The voltage drop in the undersea system is approximately 60 volts per repeater section in armorless cable and 50 volts per repeater section in armored cable. A 3500-nm system will require a nominal supply voltage of 5500 volts at each terminal.

At the shore terminal the signals to be transmitted are frequency multiplexed and pre-emphasized in preparation for transmission through the undersea system. Signals received over the cable are equalized, amplified, demodulated and separated for transmission beyond the shore terminal. Monitoring of performance and trouble location are the other important functions at the shore station.

A description of the shore terminal is given in Section IV, followed by a description of the equalization plan for the complete system in Section V. Facilities for administration and maintenance are covered in Sections VI and VII. The performance characteristics of the first long system between New Jersey and England are given in Section VIII.

IV. SHORE TERMINAL EQUIPMENT

4.1 *Multiplex Equipment*

Multiplex signals to be transmitted over the submarine cable system may be obtained from the land plant on a group connector basis or from channel equipment at the submarine cable terminal. In the latter case, high-efficiency channel banks are normally used. These allocate a 3-kc section of the carrier frequency spectrum to each telephone conversation, instead of the 4 kc common in the land plant. By using two steps of modulation and by imposing more severe requirements on the channel filters, it is possible to obtain a speech bandwidth of approximately 2800 cycles. It is thus possible to transmit 16 channels in the 48-kc carrier frequency spectrum normally allocated to a 12-channel group. The small degradation resulting from this narrowing of the spectrum of each channel is considered tolerable for submarine cable systems in view of the considerable economy obtained. Channel banks of this type, which are described elsewhere in the literature, are manufactured by several foreign manufacturers.[6]

The group and supergroup equipment used is essentially standard L-type carrier multiplex or equivalent equipment supplied by the foreign partner, with minor modifications for pilot insertion and monitoring purposes.

4.2 *Pilots*

As in the land plant, a pilot frequency is transmitted in each group to permit monitoring and adjustment of group transmission at the various terminal stations and switching points. A 96-kc pilot is used to be compatible with the frequency allocation of the 3-kc channel banks. The pilot is inserted in each group modulator as shown in Fig. 4. They appear on the high-frequency line at the frequencies indicated in Fig. 2. The nominal power in each pilot is −20 dbm at zero level. The pilot in any group may be removed if a special service signal requiring a cleared 48-kc spectrum is to be transmitted.

In order to make possible maintenance without service interruption, much of the terminal equipment must be provided in duplicate. It is therefore convenient and desirable to arrange the terminal equipment as two independent transmission paths, one regular and one alternate, each fed by common channel bank equipment, as shown in Fig. 5. With this arrangement it is possible to use the pilots to initiate automatic protection switching from the working to the standby equipment to prevent loss of service in the event of a failure of the terminal equipment. Switching is inhibited if the standby equipment is nonfunctional.

Pilots are monitored at a number of points in the transmitting and receiving terminal. Fig. 6 is a block schematic of one of the monitoring circuits. At each point a narrow-band crystal filter and a narrow-band amplifier, either at 96-kc for monitoring at group input and group output or at line frequencies for monitoring at the supergroups or in the high-frequency line, are used. Meters of high accuracy for maintenance and adjustment purposes, and lower-accuracy relay-type meters to control alarms — and, in some cases, protection switching — are provided. A departure from normal amplitudes of approximately 1.5 db of any pilot will cause a protection switch from regular to alternate terminal equipment.

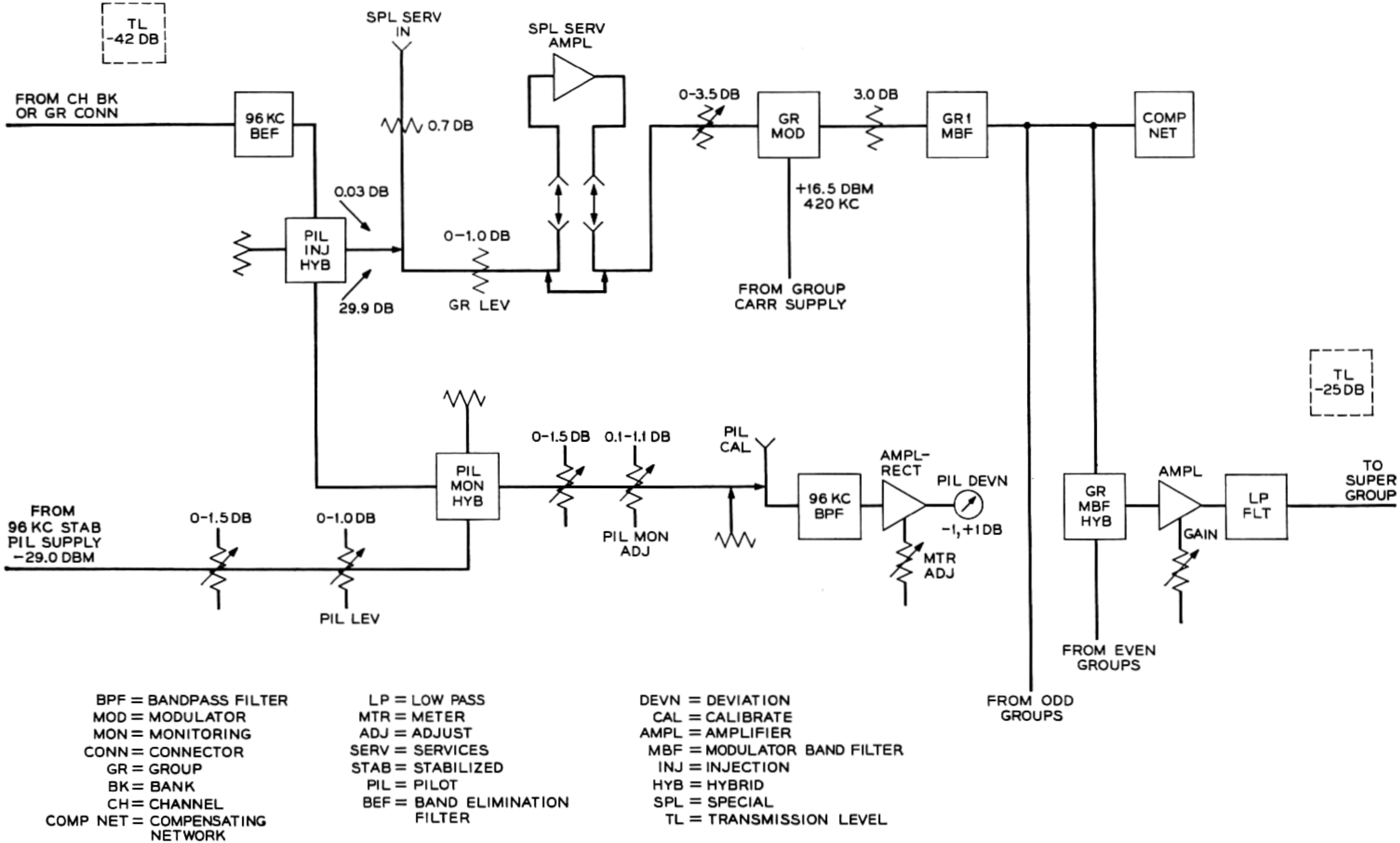

Fig. 4 — Group pilot insertion.

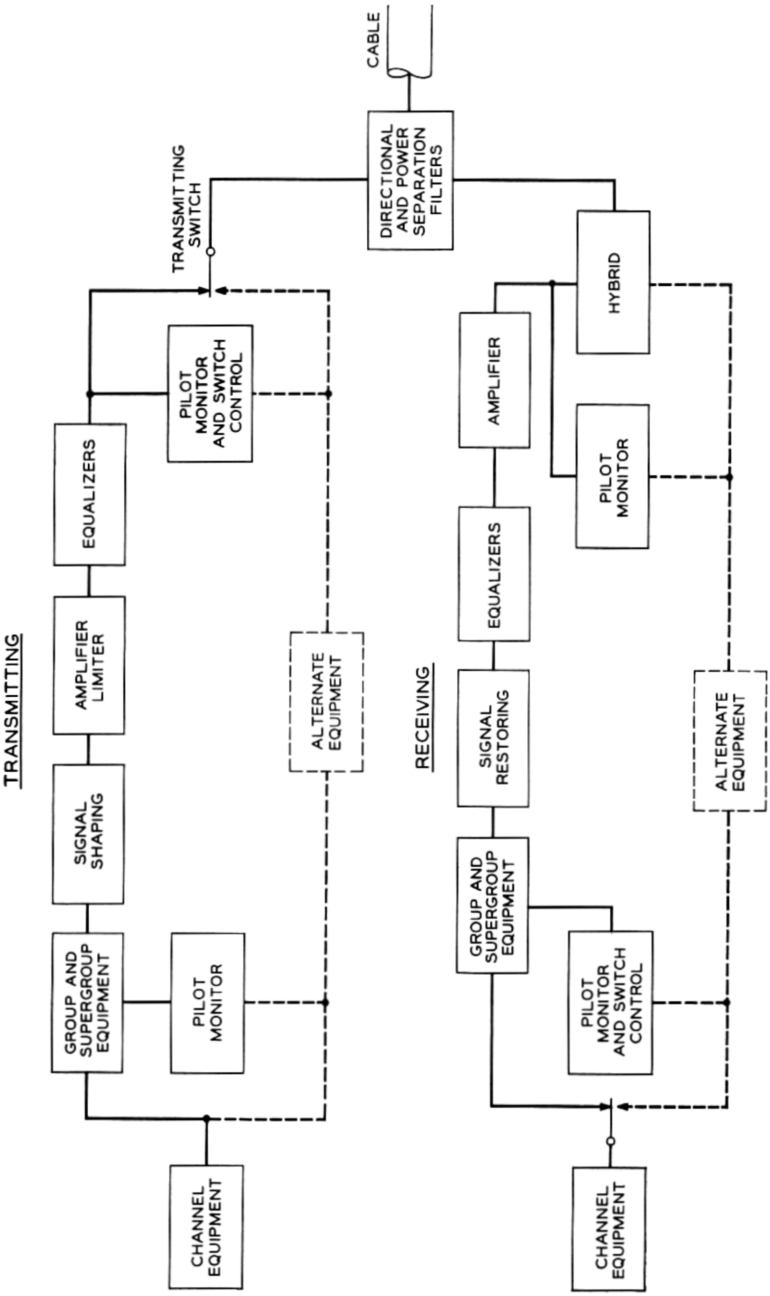

Fig. 5 — Shore terminal block schematic.

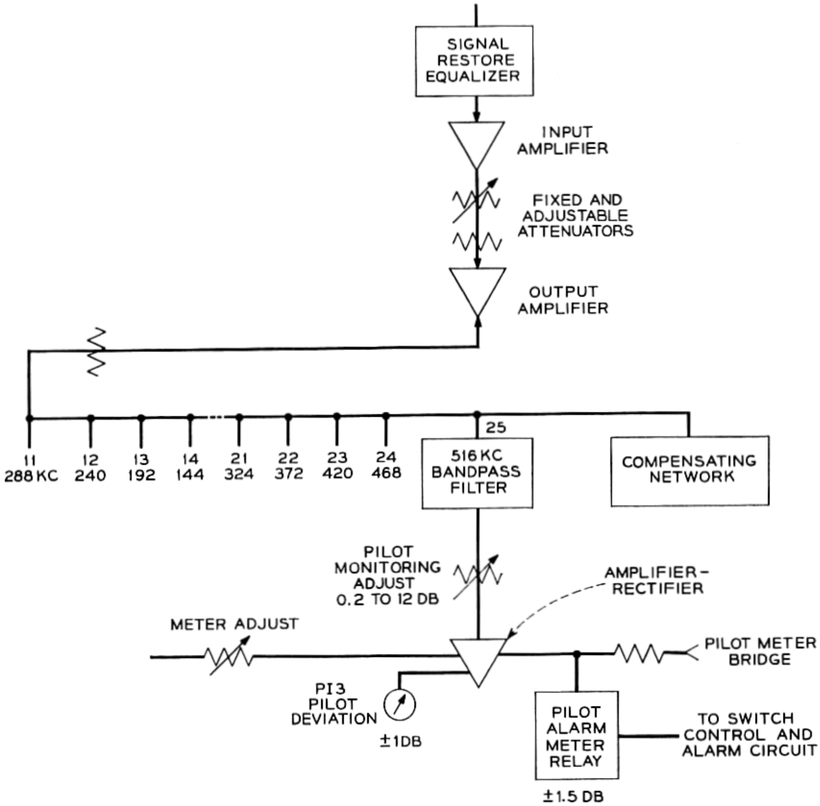

Fig. 6 — Pilot monitoring equipment.

4.3 *High-Frequency Line Equipment*

The final preparation of the signal for transmission over the ocean cable is accomplished in the so-called high-frequency line equipment, which accepts the multichannel load from the supergroup equipment and performs the necessary signal shaping, amplitude limiting and equalization functions.

Fig. 7 shows a block schematic of the transmitting high-frequency line equipment. The output from the supergroups is fed into a hybrid coil which provides for connection of the order wire signal and for pilot monitoring. This is followed by an amplifier and another hybrid that permits maintenance testing on an in-service basis and permits application of test signals for out-of-service adjustment. This is followed by a

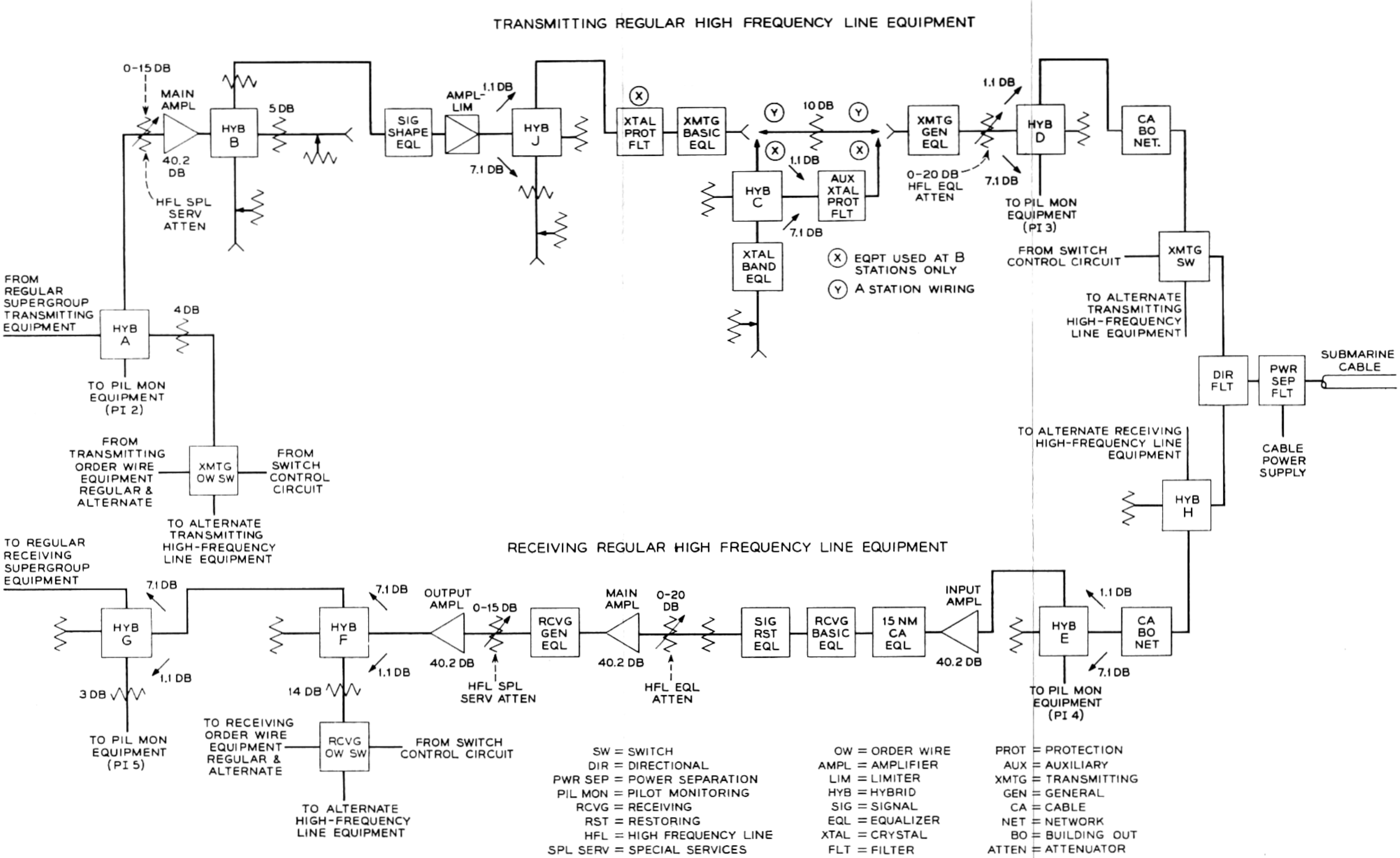

Fig. 7 — High-frequency line equipment.

signal shaping equalizer which predistorts the signal from the multiplex equipment in order to obtain approximately equal noise performance in all channels after transmission over the undersea system. As is commonly the case in cable systems, channels transmitted at high frequencies tend to emerge with a poorer signal-to-noise ratio than those transmitted at lower carrier frequencies unless special provisions — such as predistortion — are made. Such a difference in signal-to-noise performance between various channels is undesirable in any event, since the system performance is limited by the noisier channels. It is particularly undesirable in a system on which TASI may be used, since the customer would notice a sharp difference between noisy and quiet channels as the TASI terminal switched him from one to another. These undesirable effects are eliminated by the signal shaping. The smoothed curves of Fig. 8 indicate the effects of signal shaping on random noise in an SD system. The A curves show the rise in noise with carrier frequency when all channels are transmitted at the same power in the undersea equipment. By lowering the magnitude of all the low-band signals and raising the magnitude of all high-band signals, the noise in the two directions can be made equal (B curves) without increasing the total signal imposed on the system. Finally, the noise for each channel can be made equal by signal shaping (C curves). The characteristics of the signal shaping networks themselves are shown on Fig. 9.

An amplifier limiter which provides 30 db of gain and sharp limiting of the amplitude of the transmitted signal provides protection against overload of the undersea repeaters which might shorten their life. This is followed at B stations by a crystal protection filter to eliminate signals which might fall near the crystal peaks of the undersea repeaters. In this region system gain is so high that additional loss is required to furnish

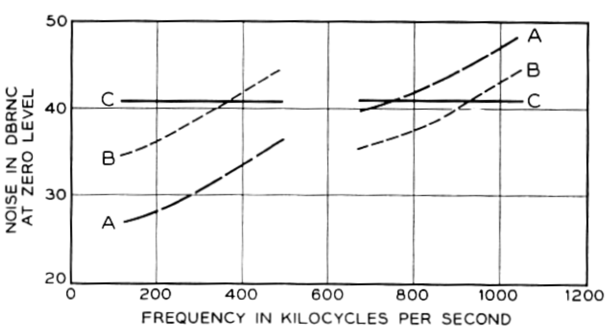

Fig. 8 — Effect of signal shaping on random noise.

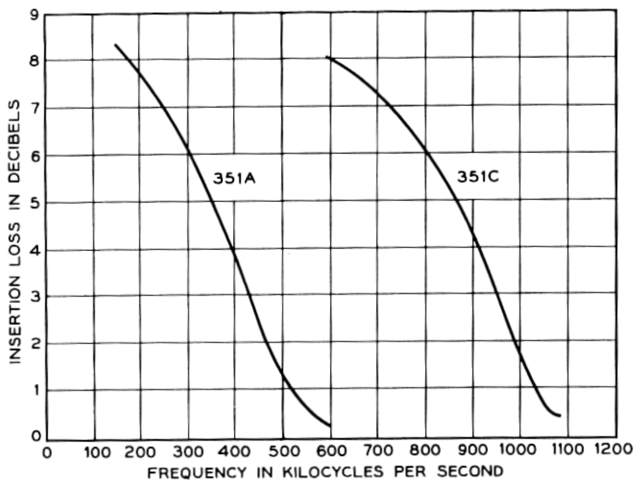

Fig. 9 — Signal shaping networks.

adequate protection. The cable build-out network adjusts for variation in the shore end sections of cable, building out the actual length to an electrical length of fifteen miles plus or minus 0.25 mile. The functions of the directional filter and the power separation filter are similar to those of the corresponding networks in each undersea repeater. Before discussing the various equalizers in the shore terminal equipment, it is appropriate to describe the over-all system equalization plan.

V. EQUALIZATION PLAN

The total cable transmission loss in a 3500-nm system will approach 9000 db at the highest transmitted frequency. This must be matched by the gain of 180 or more repeaters. Obviously, very small deviations in this match must be corrected at intervals along the system to prevent them from accumulating as large misalignments.

Basic equalization of the cable loss is accomplished by shaping the repeater gain to match the loss of the cable at a temperature of 3°C and a pressure equivalent to a depth of 2000 fathoms. The shaping takes place in the input network, the output network, and the feedback circuit of the amplifier.

The lengths of manufactured sections of cable are trimmed at the factory to obtain the desired loss at the highest transmitted frequency. In this way, it is possible to adjust to a first approximation for known departures from the design temperature and pressure conditions.

The accumulated factory cable deviations, plus those arising from uncertainties in ocean-bottom temperature and depth, temperature and pressure coefficients, and transmission effects introduced by the laying process, are equalized at 200-nm intervals during the cable lay with the adjustable ocean-block equalizers. The available shapes, selected by a stepping switch that can be operated on shipboard, are shown in Fig. 10. The choice of shapes is based on the following rationale. The loss of coaxial cable at high frequencies may be approximated as the sum of two terms, one proportional to the square root of frequency (resistance loss) and the other directly proportional to frequency (conductance loss). Experience so far has shown that providing these two shapes in the ocean-block equalizer permits compensation for any cable changes, regardless of source, and is an effective tool for reducing other misalignments as well.

The ocean-block equalizer also forms a convenient point for introducing a fixed equalizer to compensate for accumulated repeater deviations. Without intermediate equalization of this type along the route, the requirements on the repeater characteristic would be so stringent that undue complexity in the amplifier circuitry would be required. This would increase the probability of a failure of a repeater and would increase repeater cost.

During laying, measurements are made between the shore station and the end of the 200-nm ocean block being laid. As the cable reaches the bottom, its loss, which was high while on shipboard because of its relatively high temperature, begins to approach its ultimate value. Shortly before the equalizer goes overboard, it is adjusted for the desired block transmission as nearly as possible. After adjustment, the measuring equipment is connected to the output of the subsequent block and the process repeated until all the cable has been laid.

The choice of the optimum equalizer network is facilitated by using digital computer programs to carry out a "paper lay" in advance of the actual system installation. These programs utilize factory data on cable, repeaters and equalizers (including transmission characteristic and noise figure), depth and temperature information from route surveys, and apply temperature, pressure and laying effect coefficients obtained from a combination of theory and experience. This makes it possible to evaluate the signal-to-noise ratio obtained for the entire system as a result of various choices made in setting the eighteen or more ocean-block equalizers required in a long system. The foresight thus obtained has proven a valuable guide during the actual lay.

Fig. 11 illustrates the degree to which an ocean-block equalizer decreases misalignment. Two curves are shown — one the misalignment

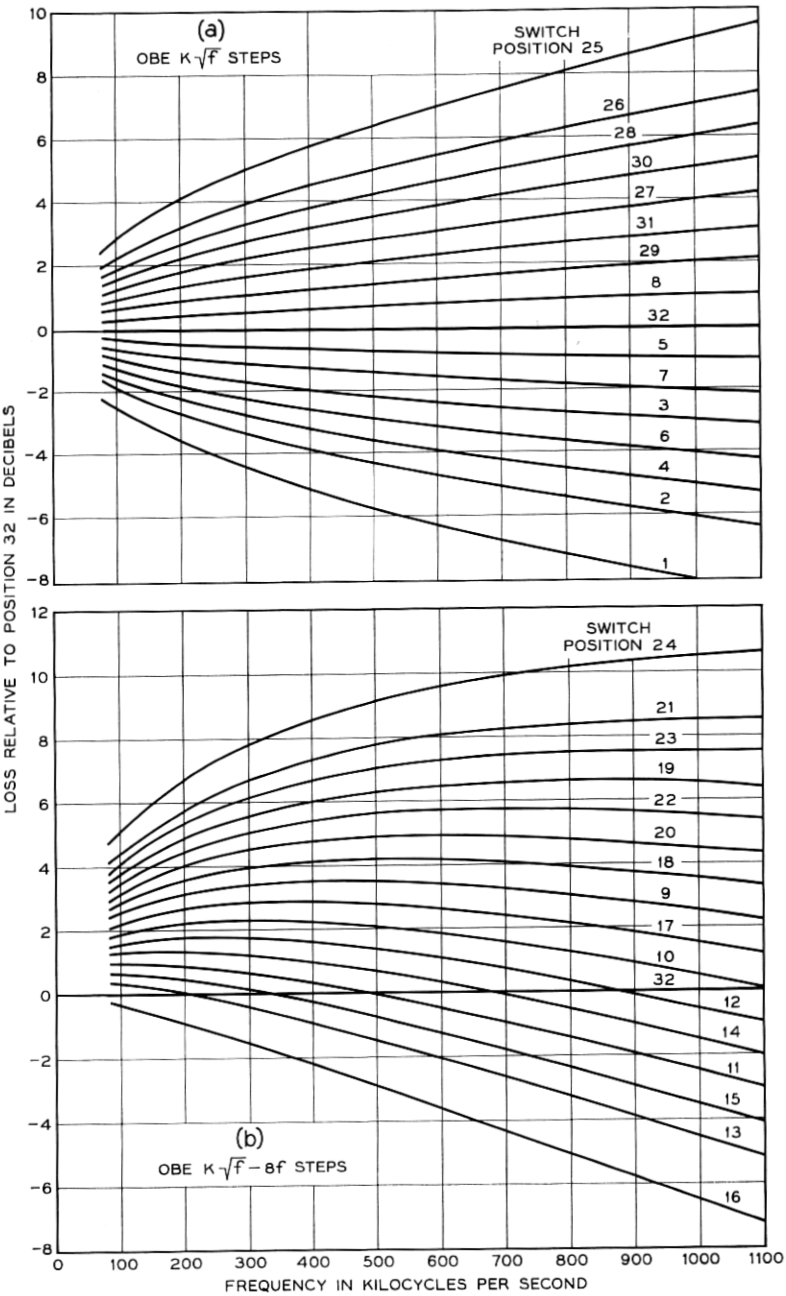

Fig. 10 — Ocean-block equalizer shapes.

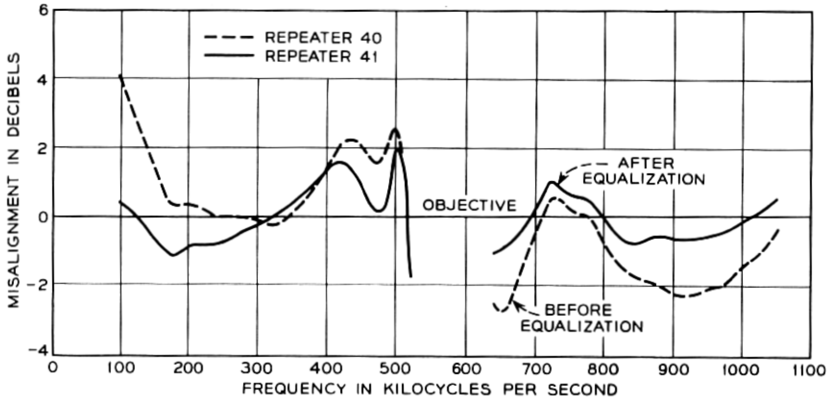

Fig. 11 — Reduction of misalignment by an ocean-block equalizer.

accumulated by the time 40 repeaters had been laid, the other the misalignment at the next (41st) repeater following an ocean-block equalizer. The misalignment has been reduced from a maximum of about 4 db to a maximum of about 2 db. The benefits of repeating such a reduction about eighteen times in a 3500-mile system are obvious.

5.1 *Terminal Equalization*

Once the system has been laid, the misalignments in the undersea system are set. From this point on, careful adjustment of signal levels to obtain maximum signal-to-noise ratios without overloading the repeaters is the only method available to optimize system performance. It is the function of the transmitting terminal equalizers to provide this optimization.

A convenient point of reference in describing the terminal equalization problem is the amplifier-limiter in the transmitting terminal. This is assumed to be an ideal limiter, flat with frequency, which will hold the instantaneous waveform to a fixed predetermined maximum value on both positive and negative peaks. Under gross overload, the output of the limiter will therefore have somewhat the appearance of a square wave. The most important function of the limiter is to prevent overloading the undersea repeaters in case of excessive inputs caused by trouble conditions. To obtain the greatest assurance of protection from overload, only passive circuit elements are installed following the limiter.

The question of what constitutes adequate protection needs to be answered. It is convenient to consider the problem initially in a perfectly aligned system. The overload point of the repeater is determined by the start of grid current. This occurs at a value of third-grid voltage (output stage grid voltage) which is essentially constant with frequency. Since the limiter operation is independent of frequency, this implies that the transmission between the limiter output and the third grid should be flat with frequency. The waveform out of the limiter will then be reproduced essentially undistorted at the third grid and will appear as a square wave for severe overloads at the input to the system, neglecting waveform distortion caused by nonlinear phase.

In an equivalent four-wire system, the signal voltage at the third grid will be the sum of the voltages supplied from the two ends of the system. It has been assumed that repeaters must not be overloaded even in the unlikely event that these signals add in phase. The repeaters can be protected against this possibility by inserting an additional 6-db loss at each end or by adding unequal values, e.g., 2.4 db for the high band and 12.4 db for the low band, at the two ends, so that the voltage sum adds up to unity. By using the second procedure a 3.6-db signal-to-noise advantage for the high band is obtained.

Operation with only one of the parallel amplifiers working has been assumed in determining the repeater overload, since this is the most limiting condition. An additional 3-db loss has been included in the terminals to cover uncertainties in the repeater levels and variations in the overload point of individual limiters and repeaters.

When misalignments are considered, the point of concern is the highest-level repeater in the system. This is not necessarily the same repeater at all frequencies. In particular, an equivalent four-wire system may have the highest-level repeater at opposite ends of the system for the two frequency bands transmitted in opposite directions. If misalignment is not uniform, the highest-level repeater at a particular frequency may be at some midway point in the system. Theoretically, some advantage might be taken of the fact that simultaneous overloads from the two ends of the system will not have maximum impact on the same repeater. In practice, however, this would lead to unworkable complexity in the rules for adjusting the terminal equalizers, and the signal-to-noise advantages so obtained would be small. Thus, to recapitulate, the loss in the general equalizer and associated attenuator following the limiter at a B terminal is adjusted so that the maximum signal which can be applied to the undersea system is from 2.4 to 5.4 db below the value which would overload the most vulnerable repeater operating with only a single amplifier. The maximum signal which an A terminal can apply is ten db lower than for the B station.

The transmitting *basic* equalizer shown in Fig. 12 has a fixed loss characteristic. It is intended to provide the optimum overload protection as a function of frequency for a nonmisaligned system. The criterion for its design might be stated as follows: when all transmission components between amplifier-limiter and the third grid of the nearest repeater have their nominal values, the basic equalizer characteristic shall shape the signals so that the relationship between power at limiter output and voltage at repeater grid is independent of frequency.

The transmitting *general* equalizer shown in Fig. 13 is intended to provide the additional loss required when the system misalignments are positive. The equalizer will be adjusted at the time the system is initially lined up and will be readjusted subsequently whenever changes are called for because of system gain changes caused by aging, temperature or repairs. Before adjustment during initial line-up of the system — i.e., with all dials at nominal settings — the loss of the equalizer is flat with frequency. The objective of the line-up procedure is to make the amount of loss change from the flat condition numerically equal to

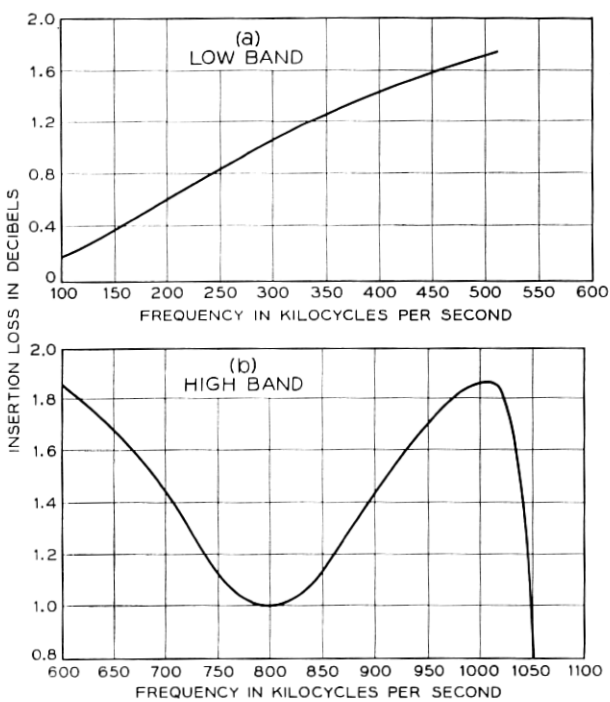

Fig. 12 — Transmitting basic equalizer shape.

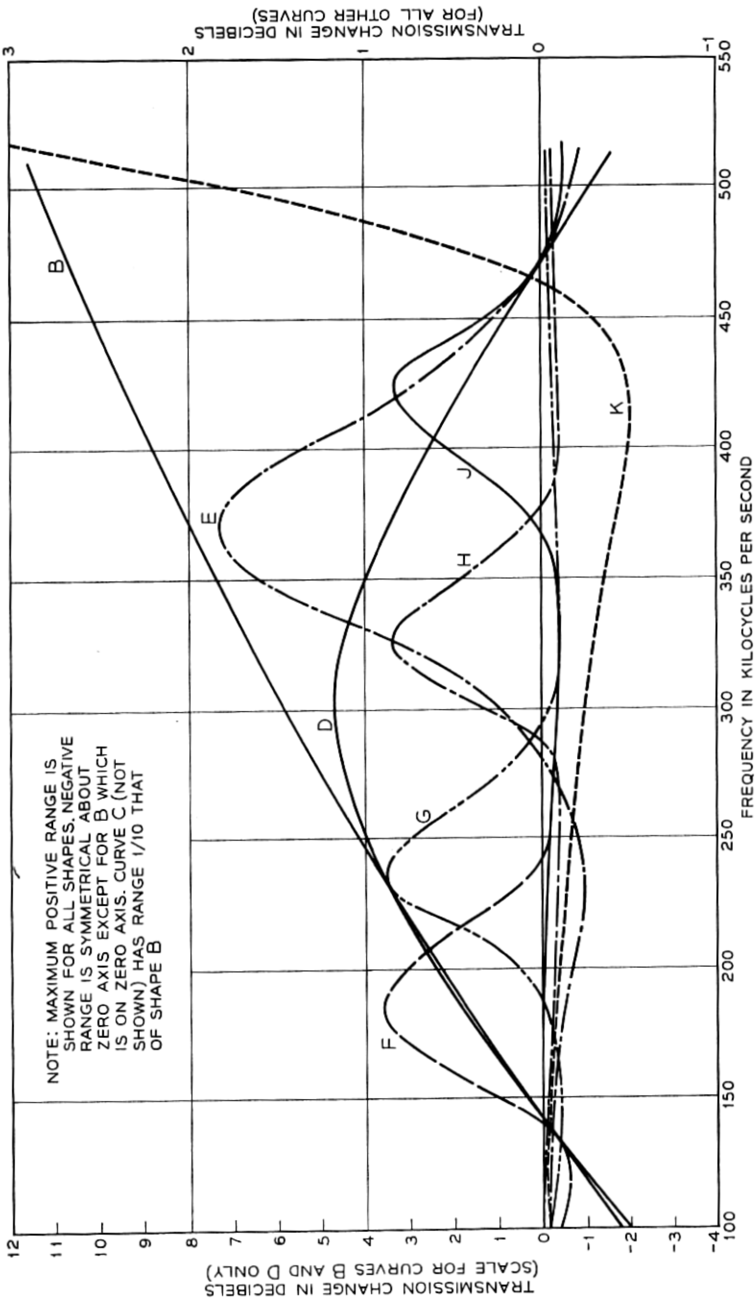

Fig. 13 — Transmitting general equalizer shape.

the maximum positive misalignment at the most vulnerable point in the system.

The function of the receiving terminal equalizers is to provide flat frequency response for the system, end to end. The cable build-out network is intended to bring the electrical length of the shore-end repeater section up to a nominal value of 15 nm. The 15-nm cable equalizer provides a flat transmission characteristic between the output of the last repeater and the input to the receiving basic equalizer. The receiving basic equalizer has a frequency characteristic complementary to the characteristic of the basic equalizer of the transmitting terminal at the other end of the system. The characteristics of the signal-restoring network are complementary to the characteristics of the signal-shaping network in the transmitting terminal.

As mentioned previously, positive misalignments are equalized at the transmitting terminal for overload reasons. Under these conditions, the receiving general equalizer is adjusted to its flat position. For negative misalignments, the total correction is made in the receiving terminal with the transmitting general equalizer set to its flat position. In either case the misalignments in the system will be completely equalized by this process of adjustment.

An exception to these statements occurs when the misalignments are not uniformly positive or negative along the length of the system. In this case the highest-level repeater will, in general, occur at some intermediate point in the system. Where this situation exists, the adjustable transmitting equalizer is used to provide overload protection for this repeater, and the adjustable receiving equalizer is used to compensate for the subsequent misalignment and thus obtain flat transmission for the entire system.

VI. ORDER WIRE

In order to permit communication over the submarine cable system between the terminal shore stations and between these and the gateway stations of the land plants involved, without preempting commercial circuits for the purpose, so-called "order wire circuits" are provided. To economize on the use of the spectrum of the undersea system, special provisions are made to put these maintenance circuits into the gap which normally exists between supergroups by using modified type ON terminal equipment. Fig. 14 shows in block schematic form the arrangements for this purpose. The ON-type channelizing and group frequency equipment is used to take the voice-frequency signals and form a spectrum lying between 100 and 108 kc for one direction of transmission and from

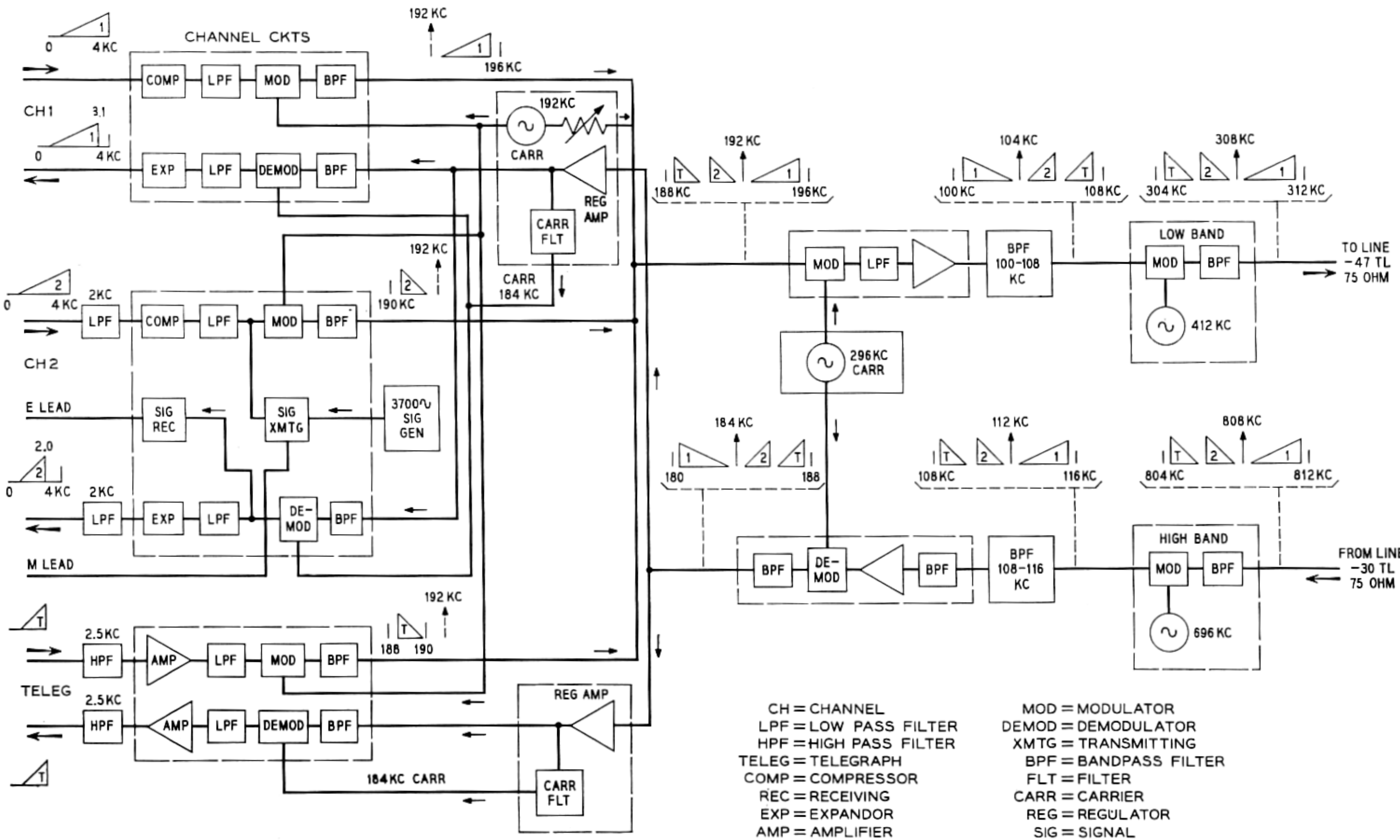

Fig. 14 — Order wire block schematic.

108 to 116 kc for the opposite direction. These signals are further modulated and placed in the 304 to 312 kc deadspace between supergroups 1 and 2, and in the 804 and 812 kc space between supergroups 3 and 4.

The channels thus appear on the line as upper and lower sidebands of 308 and 808 kc. The upper sideband channel is operated at full bandwidth for so-called express order wire service between gateway and land plant cities. The lower sideband channel is operated on a split basis, half of its spectrum being used for voice communication between the submarine cable shore terminal stations and the other half for teletypewriter signals. The use of teletypewriter communications giving a written record is particularly appropriate where language differences exist between the two ends of a system or among the various inland offices administering the circuits.

These signals are introduced into the high-frequency line equipment at a point following the supergroup equipment so that functioning group and supergroup equipment is not required for initial lineup or maintenance of the high-frequency line portion of the system. Switching circuits, interlocked with the automatic switching circuit which protects the multichannel signals, are provided so that the order wire is always connected to the working high-frequency line equipment at the transmitting and receiving ends of the system. Standby order wire equipment is available on a patching basis in the event that the working order wire equipment fails or requires routine maintenance.

Two additional channels are made available as upper and lower sidebands of 300 and 800 kc for use during system installation.

VII. MAINTENANCE TEST EQUIPMENT

In order to continue to obtain satisfactory performance over the life of the system and properly maintain it, various more or less conventional items of test equipment are required. These in conjunction with the pilot monitoring arrangements discussed above permit periodic adjustment of the transmitting and receiving equalizers to compensate for temperature changes, if necessary, and for long-term aging of the system. The items of test equipment required are sufficiently conventional to call for no further discussion here. Of somewhat more interest, in that they are peculiar to submarine cable systems, are the items of test equipment provided for fault locating. Three different types of test sets are employed for three different types of faults presently envisioned. These are:

(*i*) cable fault locating test sets which, in the event that the cable is broken or shorted, permit balancing the physical cable against an artificial cable to determine with fairly high accuracy the distance from the shore station to the fault;

(*ii*) the crystal band set, which permits measurements of system transmission at the frequencies of the crystals in the undersea repeaters, or measurements of noise peaks originating in these repeaters in the event that transmission from terminal to terminal cannot be obtained;

(*iii*) a repeater low-band fault locating test set which permits identification of a repeater whose transmission of low-band frequencies is faulty although transmission at the crystal frequency is not seriously affected.

7.1 *Cable Fault Locating Test Set*

Cable fault locating test sets of the type employed on the SD system have been described in the literature.[7] The basic philosophy is to provide a network which simulates, section by section, the iterative structure of the undersea system. Low-amplitude direct current, pulsed at a low-frequency rate (1, 2, or 4-second pulses of 50 per cent duty cycle), is sent into a bridge circuit of which one arm is the physical cable and one arm the simulating artificial cable. It is necessary to simulate only those system elements — cable, power separation filters, and repeater dc resistance — which are important at very low frequencies. A short or open (or intermediate resistance fault) can then, in essence, be moved along the artificial cable until the low-frequency impedance of the real and the artificial cable are seen to be equal. From a knowledge of where the fault in the artificial cable must be situated to obtain the best balance, the position of the fault in the real cable can be determined.

7.2 *Crystal Band Test Set*

The crystal band set is also similar to the measuring equipment described for use on earlier submarine cable systems.[8] Each undersea amplifier in the system is equipped with a crystal of unique frequency across the feedback network. At the resonant frequency the feedback path is shunted and the amplifier gain rises to a value determined by its forward gain. The test set essentially consists of a carefully controlled oscillator capable of supplying a signal at the crystal frequency of the repeater or slightly away from the crystal peak in order to determine the gain peak introduced by each repeater crystal circuit.

Alternatively, the receiving components of the crystal band set can be used to measure the noise peaks originating at the crystal frequencies of each repeater even if no signal is applied in the crystal band. In the event of a failure of transmission not caused by a cable fault and therefore not detectable by the cable fault test set described above, the noise peaks originating in the submarine cable system can be scanned and the results of this roll-call will indicate the location of the faulty repeater in the system.

7.3 *Repeater Fault Locating Test Set*

The basic concepts of the repeater fault locating test sets are indicated in Fig. 15. From the A terminal (low-frequency transmit, high-frequency receive) short pulses of 350 kc are transmitted. For any particular system, the repetition rate is set so that there is time for a signal to traverse the entire length of the system and return before the next pulse is launched. An answering pulse of 700 kc, produced by second-order modulation, is evoked in each repeater and propagates back toward the A terminal. At the A terminal, these returned 700-kc pulses, which are separated in time by the round-trip delay of 20 miles of cable, are observed. A marker pulse locked to the basic pulse timing circuits permits ready identification of the signal from a particular repeater. The presence or absence — and magnitude — of the pulses from the various ocean-bottom repeaters constitutes a roll-call of the system, and information about low-frequency transmission, high-frequency transmission, and second-order modulation of the repeaters

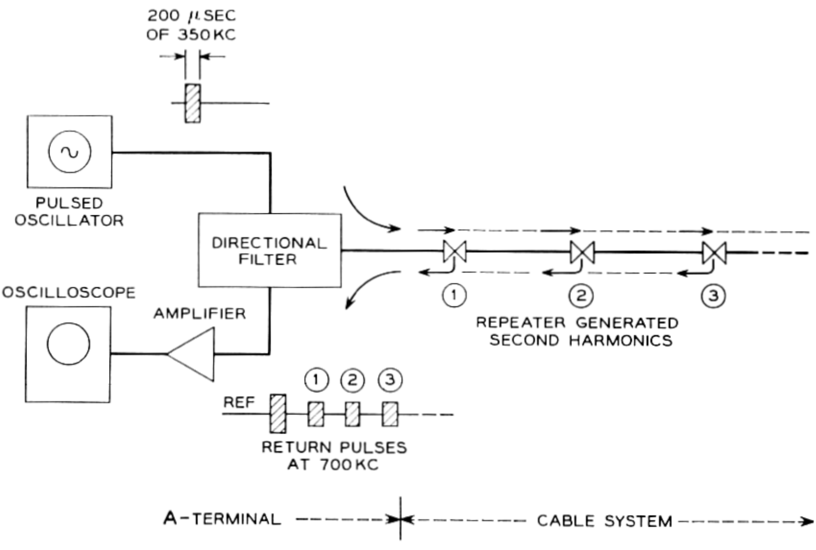

Fig. 15 — Repeater fault locating test set.

which answered the roll-call can be deduced. In a system with relatively little misalignment, the returned pulse trains can be displayed and examined on an oscilloscope. A photograph of a sample display is shown in Fig. 16. Should a system suffer considerable misalignment (6 db or more) the signal-to-noise ratio with respect to the 700-kc pulse would be so poor as to make oscilloscope presentation inadequate. Field experiments have shown that in such a case the presence or absence of a given repeater can be determined, even if the noise (in a 3-kc band) is 30 db greater than the returned pulse, by gating the detector and integrating the return signal over a long period of time — many minutes may be required under the least favorable circumstances.

VIII. SYSTEM INSTALLATION

At present an SD submarine cable system is in operation between Florida and the Canal Zone with an intermediate terminal at Jamaica, W.I. Another is in operation between Tuckerton, New Jersey and Widemouth, England. Installation of a system between Hawaii and Japan has just been completed. Since the system between the United

(a)

(b)

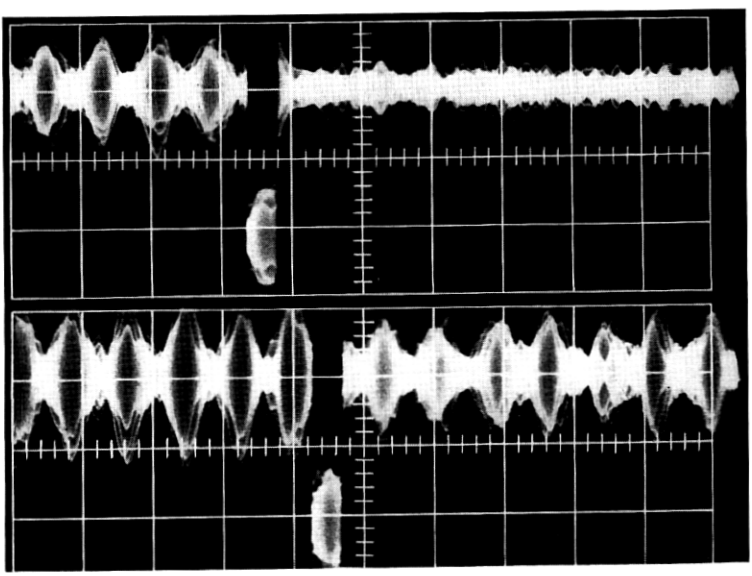

Fig. 16 — Repeater fault locating test set displays: (a) pulse returns from repeaters 178–182 — the pulse from the last repeater in the system (182) has been displaced for identification; (b) returns from repeaters 165–178 — repeater 171 has been displaced for identification.

States and England (commonly called TAT-3) has proved to be typical of long transoceanic systems, its performance will be discussed in some detail.

The length of the TAT-3 cable system is 3511 nm; the system follows a route shown approximately in Fig. 17. Maximum depth is 2800 fathoms. The system uses 182 repeaters and 17 equalizers. Approximately 12 per cent of the total cable is armored.

Laying operations were carried out during the summer of 1963. The British cable ship *Alert* laid the first 612 miles, starting at Tuckerton, New Jersey. Cable Ship *Long Lines* picked up at this point and completed the installation in two operations.

8.1 *Measurements During Laying*

Measurements made during the installation are summarized in Fig. 18 for four frequencies. The measurements show good agreement with the levels predicted from cable and repeater data, using ocean-block equalizer settings chosen during the laying operation.

8.2 *System Transmission*

The net gain of the undersea system (cable, repeaters and equalizers) is shown in Fig. 19. This was measured in October 1963, shortly after completion of laying, and shows similarly good agreement with computations. The transmission characteristic after equalization at the shore stations is shown in Fig. 20. This figure shows the deviation from flat transmission measured at the points where the multiplex signal is connected.

8.3 *Channel Noise*

Random noise measured at channel output with no talker load applied is plotted in Fig. 21. Since cable loss is a function of temperature, the random noise will exhibit a seasonal variation. The measured noise has been corrected to a mean annual temperature for comparison with computed noise under the same temperature conditions. It should be noted that most of the channels meet the 41-dbrn noise objective. Actually, 138 channels are acceptable for service.

8.4 *Modulation Performance*

The computed modulation noise produced by the talker load for which the SD system was engineered is shown in Fig. 22. The method of computation, which — like the equalization and random noise programs

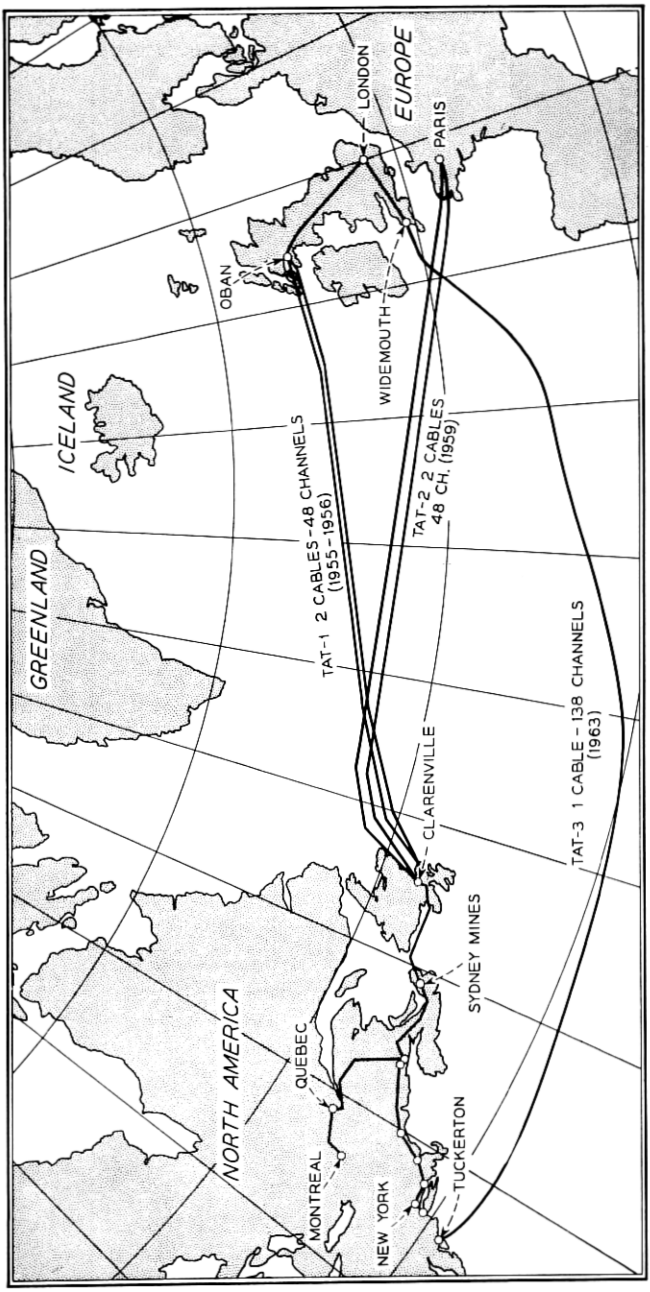

Fig. 17 — Route of TAT-3 system.

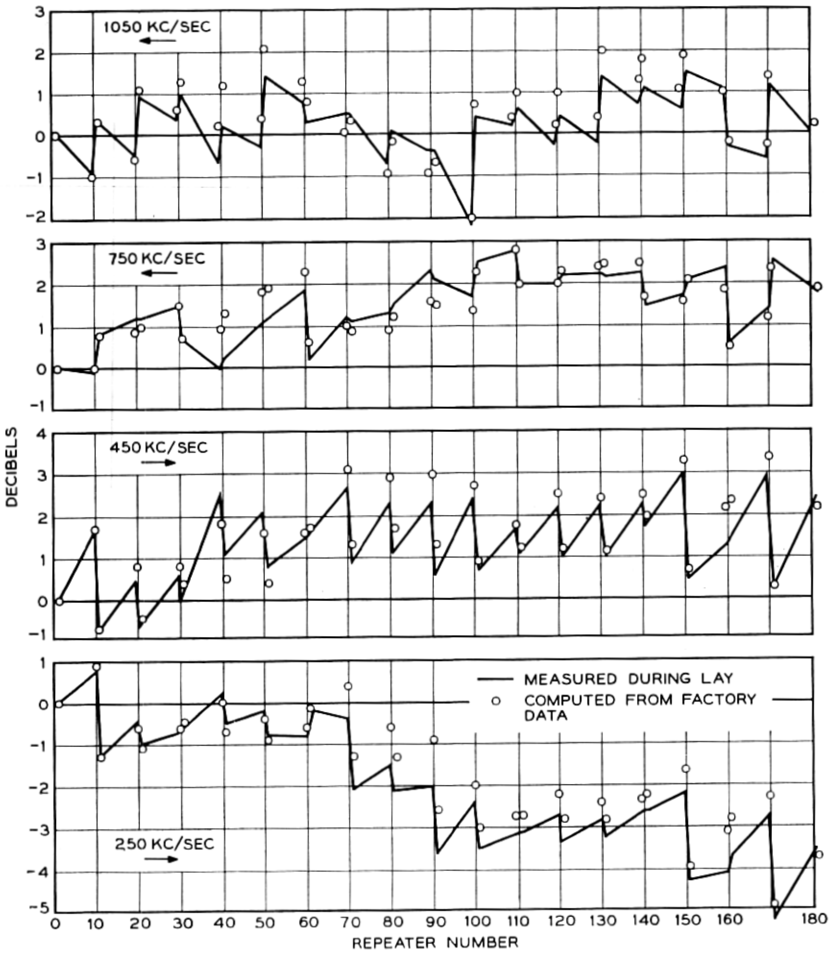

Fig. 18 — TAT-3 level diagrams, showing deviation of repeater output level from nominal.

discussed above — makes use of digital computer techniques, takes into account the effects of directional filter delay distortions on the addition of modulation product contributions from the various ocean-bottom repeaters. Two- and three-frequency intermodulation product measurements made on the undersea portions of the system give results which are consistent with the modulation noise values plotted versus frequency in Fig. 22.

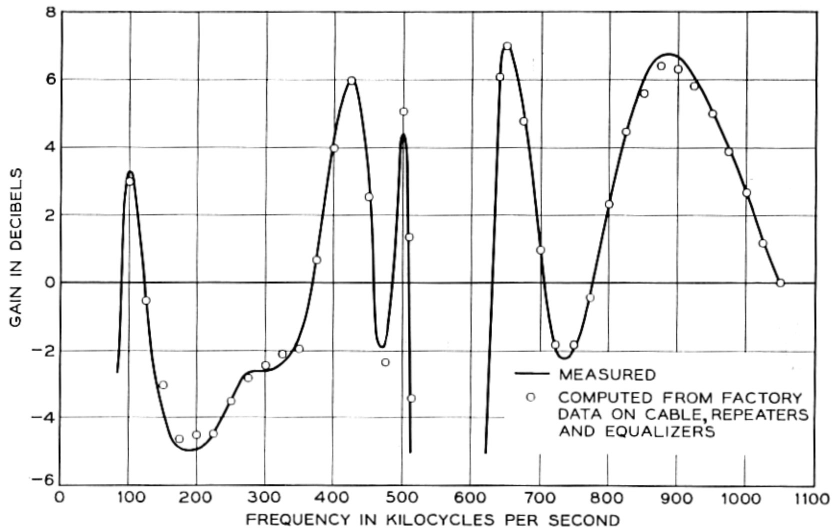

Fig. 19 — Net gain of undersea TAT-3 system.

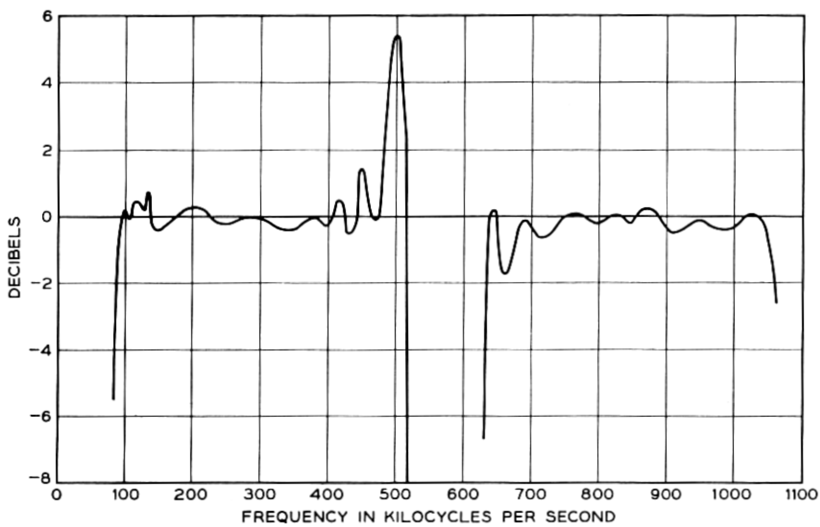

Fig. 20 — Net gain of TAT-3 system after shore terminal equalization.

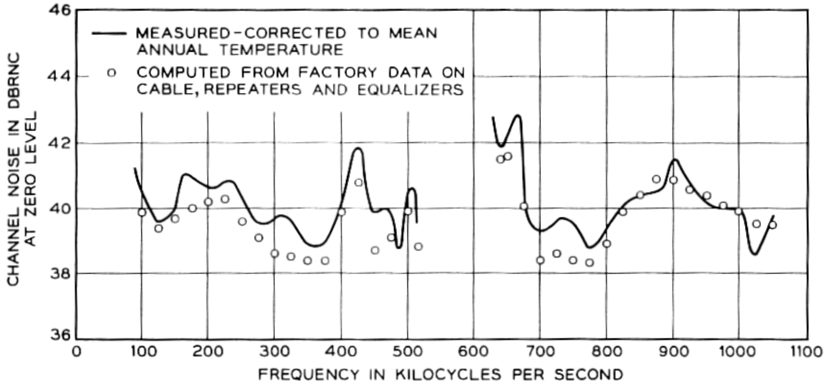

Fig. 21 — Random noise of TAT-3 system at channel bank outputs.

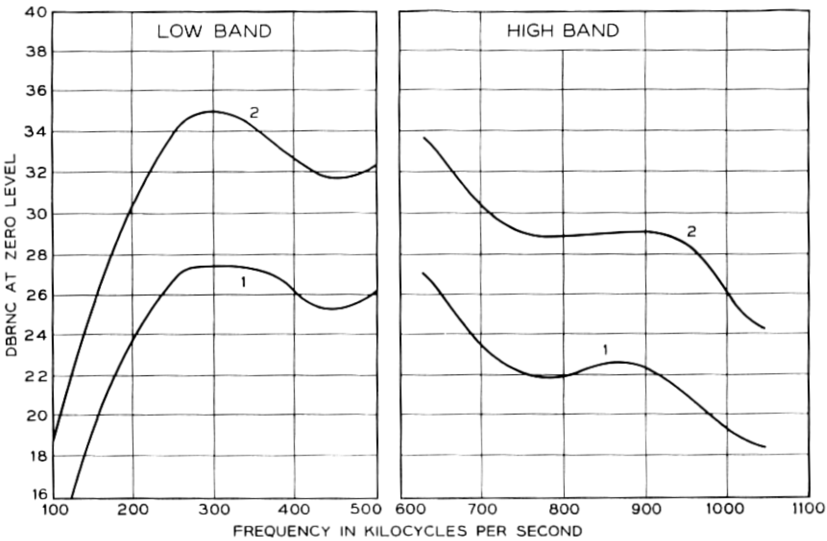

Fig. 22 — Computed modulation noise — TAT-3 system. Load assumptions: talker volume, −10.8 VU; standard deviation, 5.8 db; activity, 0.75. Curve 1 shows average modulation noise; curve 2 shows noise level that will be exceeded only 1 per cent of the time.

8.5 *Change in Transmission with Time (Aging)*

As of March 1964 the Florida-Canal Zone system had been in operation for 13 months and TAT-3 for 6 months. There has been no significant change in transmission that could not be accounted for by temperature changes. It appears that the aging of cable and repeaters will be very small.

REFERENCES

1. Special Transatlantic Cable Issue, B.S.T.J., **36,** January, 1957.
2. Bullington, K., and Fraser, J. M., Engineering Aspects of TASI, B.S.T.J., **38,** Mar., 1959, p. 353.
3. Brewer, S. T., Dickinson, F. R., and von Roesgen, C. A., Repeaters and Equalizers for the SD Submarine Cable System, B.S.T.J., this issue, p. 1243.
4. Bowker, M. W., Nutt, W. G., and Riley, R. M., Design of Armorless Ocean Cable, B.S.T.J., this issue, p. 1185.
5. Bishop, J. D., and Mottel, S., Cable Power Facility, B.S.T.J., this issue, p. 1339.
6. Law, H. B., Reynolds, J., and Simpson, W. G., Channel Equipment Design for Economy of Bandwidth, Jour. P.O.E.E., **53,** 1960, p. 112. See also Tucker, R. S., 16-Channel Banks for Submarine Cable, Bell Laboratories Record, **38,** July, 1960, p. 248.
7. Weber, E. F., Fault Localization Test Set for Submarine Cable, to be published in Bell Laboratories Record.
8. Lewis, H. A., Tucker, R. S., Lovell, G. H., and Fraser, J. M., System Design for the North Atlantic Link, B.S.T.J., **36,** January, 1957, p. 57.