Shore Terminal Facilities and Fault Location

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(Manuscript received August 13, 1969)

A special shore terminal transmission facility has been developed for the SF Cable System. The multiplex portion differs from similar domestic plant in that the frequency allocation follows international standard, and can operate with 3-kHz as well as conventional 4-kHz spaced message channels. High reliability is achieved through duplication of equipment combined with added failure detection circuitry and protection switching. Additional features include broadband flexible equalization capability to optimize transmission performance, a separate 4-channel order wire, and automatic pilot measuring equipment. From the point of view of physical design, two departures from conventional practice are the use of shorter than normal bay frameworks and enclosures to cover them, both of which are compatible with foreign design practice.

Newly designed test equipment enables monitoring undersea performance and fault locating from the shore terminal. Inclusion of a supervisory oscillator in each repeater is a major change from previous submarine cable systems.

I. INTRODUCTION

1.1 *General*

Shore terminals at each end of an SF Submarine Cable System provide an interface between the undersea portion of the system and inland transmission facilities. Conventional frequency-division multiplexing techniques are used to translate message signals received from the domestic network to the appropriate frequencies for transmission over the ocean cable; the inverse process is performed on signals received from the cable.

The high-frequency portion of the shore terminal provides broadband signal shaping (pre-emphasis) and equalization to optimize the signal-to-noise performance of an SF System. Final adjustment of equalization for a particular system takes place after the cable has been laid and its actual transmission characteristic has been determined.

Once a submarine cable system is installed, information concerning its performance can be obtained only from measurements made at the shore. Thus, another function of the terminal is to provide means for gathering information necessary for system maintenance and for locating faults that might occur either in cable or repeaters.

These functions of the SF Terminal are described in more detail in the sections that follow. Emphasis is placed primarily on those features unique to the SF System and, secondarily, on those features unique to a submarine cable terminal. Generic categories of terminal equipment are as follows:

(*i*) Multiplex and carrier supply,
(*ii*) High-frequency line,
(*iii*) Pilot monitoring and measuring circuits,
(*iv*) Order-wire, and
(*v*) Maintenance and fault locating test sets.

DC power for operating the undersea repeaters is supplied from the shore terminal over the cable. The power plant is described in a companion article.[1]

1.2 *Frequency Allocation*

The line frequency allocation of the SF System is shown in Fig. 1. Since the undersea portion of the system is equivalent 4-wire, the overall

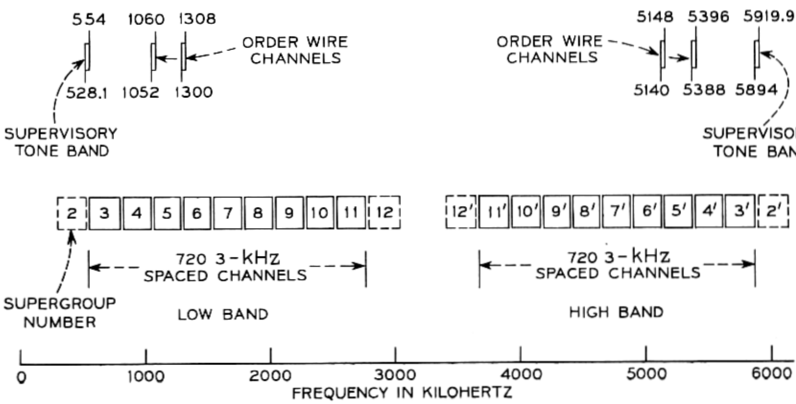

Fig. 1—Frequency allocation—SF System.

transmission spectrum is divided into low and high bands. The terminal that transmits in the low band and receives in the high band is designated an A Station; the B Station, at the other end of the system, is complementary. The actual usable system bandwidth will vary from installation to installation, depending principally on system length and equalization.[2,3] Each band consists of nine complete 240-kHz-wide supergroups (numbered 3 through 11) plus whatever additional capacity is obtainable in the spectrum of supergroups 2 and 12.

The low band is obtained as a direct output of the multiplex equipment. Its formation from voice frequency is shown schematically in Fig. 2. The supergroup frequency assignments conform to CCITT* recommendations. Efficient use is made of the available bandwidth, since guard bands only 8 kHz wide are between all supergroups except 2 and 3, which have 12-kHz separation. The high band is formed by amplitude modulating a 6448-kHz carrier with the multiplex output and selecting the lower sideband. Because of its relationship to the direction of signal transmission, this step is often referred to as directional modulation.

1.3 *Reliability*

High reliability has always been an essential design objective of the undersea portion of submarine cable systems. Shore terminal reliability is also important. Although shore-based equipment is much more accessible for repair, loss of service because of terminal failure is indistinguishable, from the point of view of the customer, from undersea failure. The reliability criterion established for the SF Terminal is that no single failure will result in the loss of more than the equivalent of one supergroup. As illustrated in Fig. 3, which is a simplified block schematic of the SF Terminal transmission arrangement, duplication of equipment is the major means used to meet this requirement. Supergroup banks and high-frequency lines are duplicated with automatic protection switching between units, under control of pilot monitoring circuitry. A spare group bank is available on a patch-in basis.

II. MULTIPLEX AND CARRIER SUPPLY

2.1 *Channel Banks*

Signals to be transmitted over the SF System can be obtained from the domestic plant via group connectors (for signals already translated to the group frequency band), or from channel bank equipment at the

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* The International Telegraph and Telephone Consultative Committee.

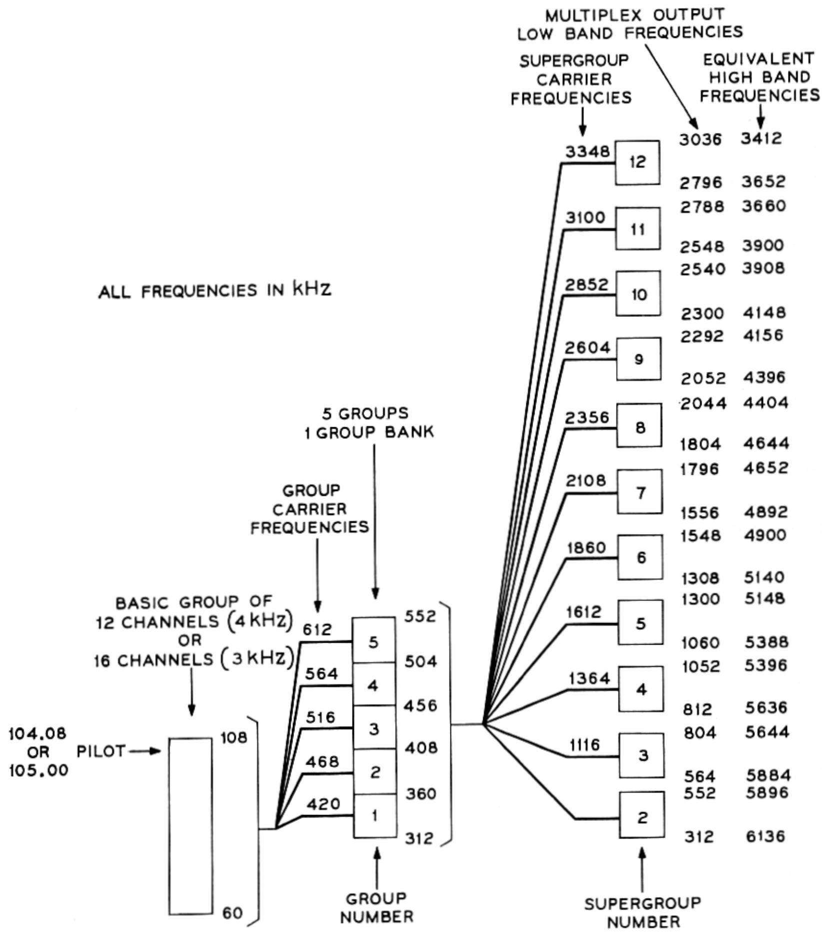


Fig. 2—Frequency allocation—SF Multiplex.

shore terminal. In the latter case, high-efficiency banks are generally used. They include sixteen 3-kHz-spaced channels in the 48-kHz group band that normally accommodates twelve 4-kHz-spaced channels. By careful design a voice bandwidth of about 2800 Hz is obtained. Although larger and more expensive than conventional channel banks, these prove to be economically more advantageous for use with submarine cable systems. Channel banks of this type, which are described in the literature,[4,5] are manufactured by several telephone equipment suppliers.

2.2 *Group and Supergroup Banks*

The group and supergroup portion of the SF Multiplex is an extensively modified version of the new L Multiplex Terminal.[6] Modifications were required to:

(*i*) operate with 3-kHz-, as well as 4-kHz-spaced channels*,
(*ii*) conform to CCITT supergroup frequency assignments,
(*iii*) achieve the increased reliability required of a submarine cable terminal, and
(*iv*) house the equipment in bays that are only 2.74 meters (9.0 feet) high.

By far the most difficult requirement was the first. Although not obvious, the reason is simple. All group and supergroup carrier frequencies (as well as a number of other tones generated by the carrier supply) are harmonics of 4-kHz. The power of these tones is generally quite high compared to that of a message circuit, and although normally subjected to high attenuation they nevertheless find their way into the transmission path (for example, via common-ground impedances, or because of inadequate modulator balance) with sufficient energy to potentially degrade performance. With 4-kHz operation, however, these carrier leaks, as they are often called, fall between channels and are of little concern.† On the other hand, many carrier leaks fall within 3-kHz-spaced channels and are of serious concern. It can be shown that for the SF Multiplex spectrum, the carriers for groups 4 and 5 of supergroup "n" fall as a 1050-Hz tone in channel 2 of groups 1 and 2 of supergroup $(n - 1)$, for $n = 4$ through 12. Similarly, the supergroup n carrier falls as a 1050-Hz tone in channel 14 of group 4, supergroup $(n + 2)$, for $n = 3$ through 9.

In group equipment, relatively minor modifications reduced the offending tones below the requirement of −65 dBm at zero transmission level (−65 dBm0) for inband frequencies, and −55 dBm0 otherwise. Modifications to the standard group bank design include the addition of shields to twisted pair wiring, some replacement of pairs by coaxial cable, changes in cable routing, and the addition of special, experimentally determined circuit ground arrangements.

The supergroup bank is another matter entirely. The need to hold

* Three- and four-kHz-spaced channel groups can not be mixed within a supergroup because the relatively slow cutoff of 4-kHz channel filters allows crosstalk between edge channels which are adjacent in the supergroup spectrum.

† Although this is true for voice service, the presence of spurious tones in broadband data services is of concern. Even here, however, requirements are not as severe as for voice channels.

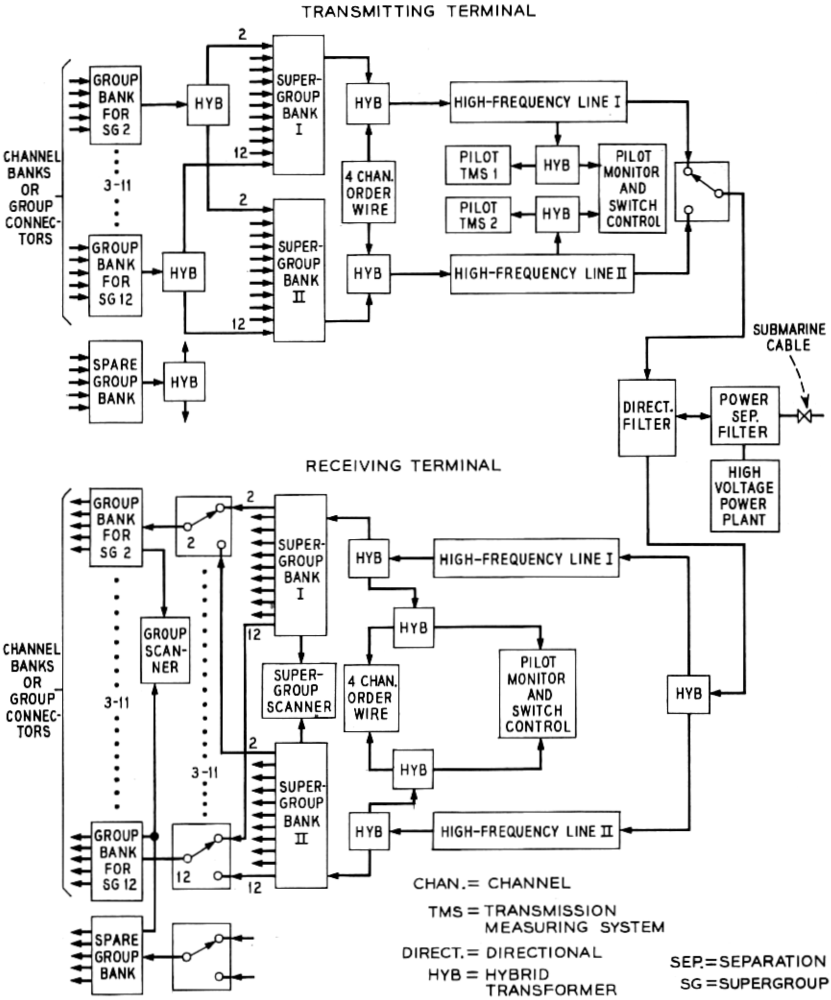


Fig. 3—Block diagram—SF Terminal transmission arrangement.

at least 135 dB isolation between the carrier leads and the lowest transmission level point in the transmitting supergroup bank dictated extensive mechanical and electrical redesign. Auxiliary filters were designed for each supergroup to provide additional loss in the transmission path at the carrier frequency, and a special carrier bandpass filter was added in each carrier lead to suppress spurious energy at transmission band frequencies. Use of CCITT frequency assignments forced the design of three new supergroup bandpass filters, but in fact all ten supergroup filters were redesigned to meet more recent Bell System objectives on amplitude distortion in the supergroup bands.

The new physical layout of the supergroup bank was carefully designed to minimize length of critical leads, to separate high- and low-level cabling, to provide shielding between circuitry associated with different supergroups, and to preserve the coaxial structure through connectors linking the fixed portion of the bank and plug-in modules. The design makes use of a relatively small, flexible, double-shielded coaxial cable that is used extensively in other shore terminal equipment.

2.3 *Pilots*

A reference pilot tone is inserted into each group in the transmitting terminal to facilitate monitoring and adjustment of transmission at various points. It is also used to control the automatic gain regulation of the receiving group circuits. Conventional 104.08-kHz pilots are used with 4-kHz-spaced channel groups. This frequency is not compatible with 3-kHz operation, however. A frequency of 105 kHz was chosen for this case, since it has the same advantage, at least potentially, as the 104.08-kHz pilot; that is, it is but one channel spacing from the top (108 kHz) of the group band and so would not interfere with broadband services. Group reference pilots are inserted at a power of -20 dBm at zero transmission level.

2.4 *Carrier and Pilot Supply*

Like group and supergroup banks, the carrier and pilot supply portion of the SF multiplex is made up largely of modified equipment from the new L multiplex terminal.[7] Primarily, modifications were necessary to provide:

(*i*) duplicate equipment to achieve increased reliability;
(*ii*) auxiliary group and supergroup carrier capacity for supplying the terminal order-wire facility, pilot monitoring and measuring equipment, and duplicate multiplex equipment;
(*iii*) the capability of generating 105-kHz pilots required by 3-kHz channel banks;
(*iv*) the capability of generating a 120-kHz channel carrier required by 3-kHz channel banks;
(*v*) the capability of generating a 6448-kHz carrier required for the step of directional modulation; and
(*vi*) the capability of generating a 620-kHz carrier used in the remote carrier-supply synchronization scheme.

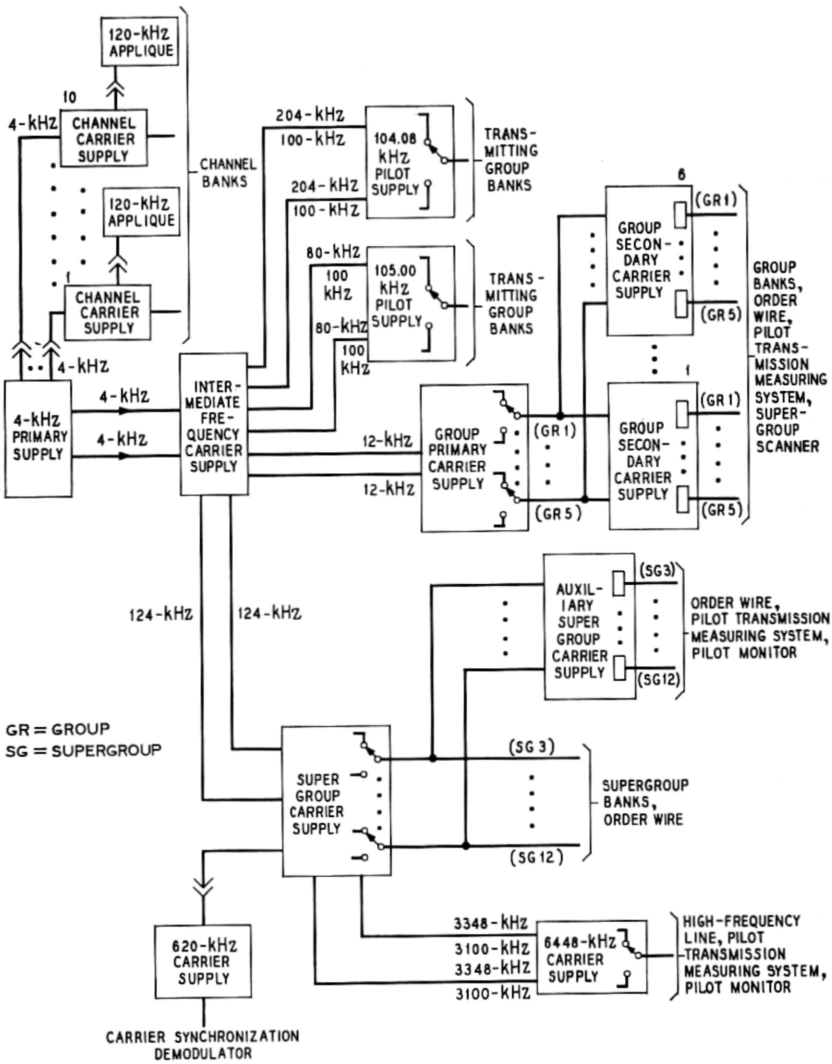


Fig. 4—Block diagram—carrier and pilot supply.

The carrier supply block diagram is shown in Fig. 4. Complete duplication of equipment is provided from the 4-kHz primary frequency supply to the distribution bus for the:

(*i*) 104.08-kHz and 105-kHz pilot supplies,
(*ii*) group primary carrier supply,

(*iii*) supergroup carrier supply, and
(*iv*) 6448-kHz carrier supply.

Trunks from a test tap on each of these distribution buses are brought to a carrier test panel where they can be connected by push-button selection to a measurement jack. Alarms are provided for each bus and there is automatic failure detection and switching between duplicate equipment. The group secondary and the auxiliary supergroup carrier-supply distribution buses include test point and alarm features.

The 105-kHz stabilized pilot is generated in a way similar to the 104.08 kHz. An 80-kHz signal is divided by 16 and the resulting 5 kHz is added to 100 kHz. The 80-kHz and 100-kHz signals are obtained from the standard intermediate-frequency supply. The output of the pilot supplies is stabilized so that it remains within 0.1 dB of the adjusted setting for variations in temperature between 0 and 50°C, changes in input power of ±5 dB, and changes in supply voltage of ±5 volts.

The 6448-kHz carrier frequency is obtained by adding the carriers associated with supergroups 11 (3100 kHz) and 12 (3348 kHz). The extra 120-kHz channel carrier required by 3-kHz channel banks is obtained directly from the output of the regular channel carrier supply by selective filtering.

2.4.1 *Carrier Synchronization*

At the heart of the carrier supply is the 4-kHz primary frequency generator.[8] When the SF Terminal was planned, the standard primary supply, designed for domestic use, could be synchronized from an external source of either 64 or 308 kHz. Since neither frequency falls within the SF Transmission Band, frequency translation is necessary for synchronization of the far end primary supply over the undersea system. At the synchronizing terminal, an 88-kHz tone is inserted between two channels in the transmitting order-wire and translated to a low band line frequency of 1056 kHz. At the remote synchronized terminal, the tone undergoes two steps of demodulation* (to 308 kHz at an A station, or to 64 kHz at a B station). A non-standard 620-kHz carrier, which is required for the second step of demodulation in a B station, is obtained directly from the supergroup carrier supply harmonic generator by selective filtering.

* A change in frequency of any carrier used to demodulate the synchronizing tone introduces that change (magnitude and direction) in the tone itself. An even number of demodulation steps is required to insure that the error signal derived within the primary frequency supply (by comparing the received and locally generated tones) has the correct sense for stable operation.

III. HIGH-FREQUENCY LINE

3.1 *Description*

The high-frequency line, which is a completely new design, provides a transmission path between the multiplex and the ocean cable itself, via the power separation filter. It includes low-to-high-band modulation or high-to-low-band demodulation, as required, broadband equalization capability, and access to the transmission path for order-wire signals and test equipment. Figure 5 shows a considerably simplified block schematic of the high-frequency line. A number of amplifiers, attenuators, hybrid transformers, and filters are not shown. The role of the high-frequency line in system equalization is discussed separately in Section IV.

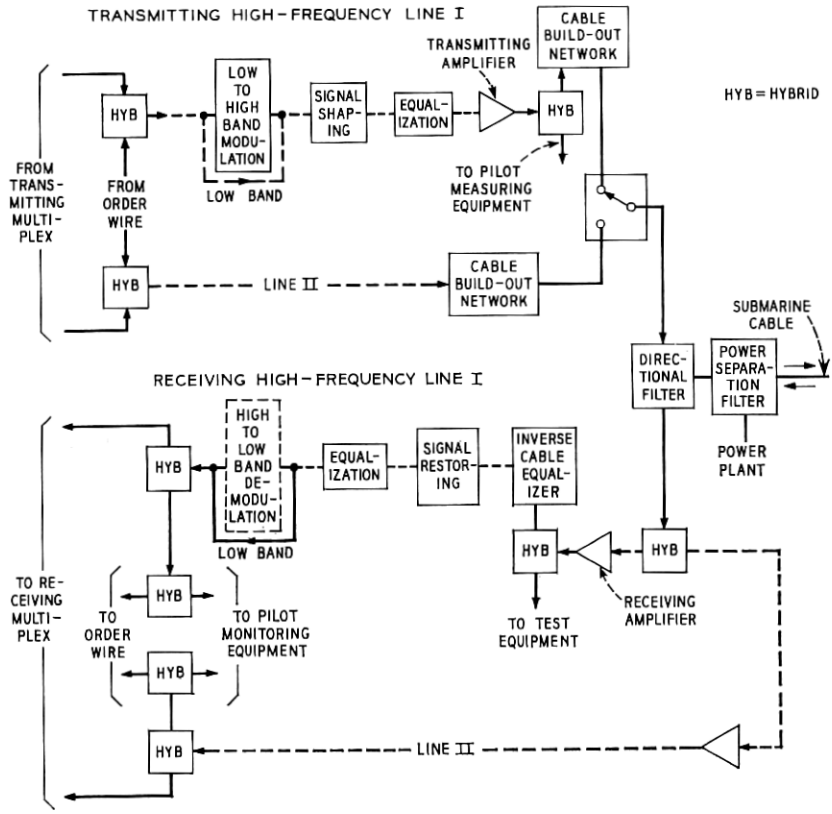


Fig. 5—Simplified schematic—high-frequency lines.

3.2 *Design Considerations*

An important design requirement is to keep the noise contribution of the high-frequency line negligible with respect to that of the undersea system. Potential sources of excessive high-frequency line noise are:

(*i*) intermodulation noise from high level amplifiers,
(*ii*) thermal noise from low level amplifiers, and
(*iii*) intermodulation and thermal noise in the directional modulation circuitry.

In general, the last amplifier in the transmitting line will be operating at the highest level and the first amplifier in the receiving line at the lowest, because these levels depend on the maximum allowable length of the shore-end section of ocean cable.* For the SF System this length is equal to one repeater spacing. In that case transmission levels at the terminal-submarine cable interface are the same as for a repeater. Therefore, the power output capability of the transmitting amplifier and the thermal noise performance of the receiving amplifier must be at least comparable to those of a repeater to keep their noise contribution negligible relative to that of the undersea portion of even a short system. These requirements were most easily met by using the basic design of the input and output amplifiers developed for the basic repeater in the L4 System.[9] The latest transistor and circuit design technology had achieved a low noise figure and a high-power linear output capability. Modification of the L4 design was necessary to remove the gain-frequency shape that is characteristic of analog transmission system line repeaters. Only minimal changes were necessary in the critical high-frequency cutoff region of the feedback loop (to beyond 100 MHz).

Typical noise performance of the two modified amplifier designs is shown in Fig. 6. The low thermal noise preamplifier has a maximum noise figure of about 6.0 dB and a flat 75-ohm insertion gain of 15.1 dB. The power amplifier has a flat 75-ohm insertion gain of 24.4 dB. The intermodulation noise portion of the curves of Fig. 6 are based on measurements using broadband random noise loading to simulate the multiplex signal. Correlation of intermodulation noise with amplifier output transmission level is based on a simulated rms signal power of +19.0 dBm0 per band, the maximum design load of the SF System.[2]

Figure 7(a) shows the low-to-high-band directional modulation arrangement. A conventional double-balanced diode ring modulator is used. Because of the relatively wide baseband and its closeness in

* The shore-end section is that cable between the terminal and the first repeater.

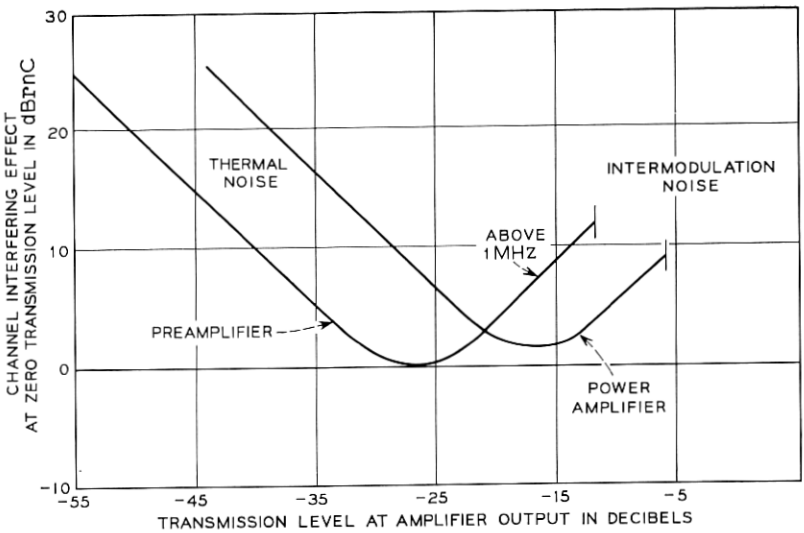


Fig. 6—Thermal and intermodulation noise performance of high-frequency line amplifiers.

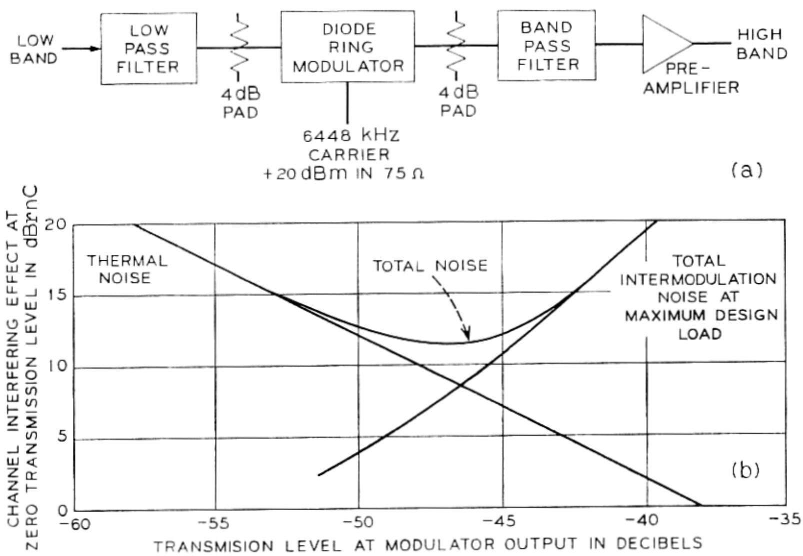


Fig. 7—Directional modulation scheme: (a) block schematic; (b) noise performance.

frequency to the wanted sideband (see Fig. 1), a great many intermodulation products fall into the transmission spectrum. Second- and third-order sideband as well as second-order baseband intermodulation are significant. The low noise amplifier described in Section 3.2 is an integral part of the frequency translation scheme because the operating transmission level is set to make the intermodulation noise of the modulator itself equal to the combined thermal noise of both modulator and amplifier. The noise performance is shown in Fig. 7(b). The intermodulation product distribution versus frequency is such that the noise is approximately equal across the band. Demodulation is less critical because of fewer in-band intermodulation products; in this step a noise contribution of less than 10 dBrnC at zero level is achieved.

3.3 *Power Separation Filter*

The primary function of the power separation filter (PSF) is to combine transmission signals and dc power for application to the ocean cable. It is designed to permit safe and convenient disconnection of the combined transmission and power path from the submarine cable when power is turned down in order that

(*i*) the cable fault localization test set (CFLTS), which will be described later, can be connected to the cable or
(*ii*) the power feed path can be reconnected to an auxiliary dc test load located within the PSF equipment bay.

With the auxiliary load connected, the high-voltage facilities can be tested up to the last possible point prior to the submarine cable itself.

All these functions are accomplished without compromising safety. A PSF key interlock system is used in combination with the key interlock scheme of the power plant[1] to ensure that the plant is shut down before connections can be changed and that all stored energy is dissipated before access is allowed to the high voltage areas. Carbon protector blocks are used to limit voltages that can be induced on the transmission or ocean ground cables and to provide a short circuit to building ground if the ocean ground is disabled while the power plant is operating.

Since signals received from the submarine cable are quite weak, another important design feature of the PSF is protection against radio frequency interference. The high-voltage enclosure within the PSF bay, where the ocean cable terminates, is a copper box that is normally at the potential of the cable's outer conductor (return tape ground). As a shield, it is effectively an extension of the coaxial structure of the cable. The two other grounds at the PSF are the familiar building ground and an ocean ground, which is used instead of building ground for the dc cable return current to avoid corrosion by electrolysis to nearby underground metallic structures. The ocean ground is brought into the terminal via armored ocean-type cable from a ground bed usually located near the terminal building. At transmission frequencies, there is no need to maintain isolation between these grounds. In fact, judicious capacitive interconnecting, which may vary from location to location, is used to minimize the pickup of spurious signals.

IV. TERMINAL ASPECTS OF SYSTEM EQUALIZATION

4.1 *Initial Lineup*

Once an SF System has been installed and its actual transmission characteristics estsblished, its signal-to-noise performance is a function of the operating signal levels on the system, as determined by the transmitting terminal. When the system is initially aligned, equalizer-networks in the transmitting high-frequency line are adjusted in an attempt to obtain maximum and equal channel signal-to-noise ratios. Equalizer-networks in the receiving high-frequency line are then adjusted to provide the correct level at the input to the receiving multiplex.

The specific design approach that realizes these objectives is illustrated in Fig. 8(a). (The means of coping with equalization changes with time are shown in Fig. 8(b). The means will be discussed later.) Signal shaping utilizes both fixed and adjustable equalization. The fixed *signal shaping network* would be adequate for an ideal system, that is, basically one with no misalignment. The adjustable *special shapes equalizer* is used to obtain more nearly optimum signal shaping for each specific installation. Figure 9 depicts the kinds of shapes obtainable with the special shapes equalizer. After all other transmitting terminal equalizer-networks have been adjusted, the setting of the special shapes equalizer is determined experimentally, using noise loading techniques.*

The *system equalizers* are a series of networks designed for a particular installation after the actual system misalignment is established. Because the SF System is modulation limited,[2,10] a simple yet effective rule for approximately minimizing the noise penalty associated with a given misalignment characteristic is to equalize half in the transmitting

* The special shapes equalizer is adjusted to obtain approximately equal total noise (thermal plus intermodulation) near the top, middle, and bottom of both transmission bands when the system is carrying its maximum design rms load of +19.0 dBmO per band, as simulated by gaussian noise.

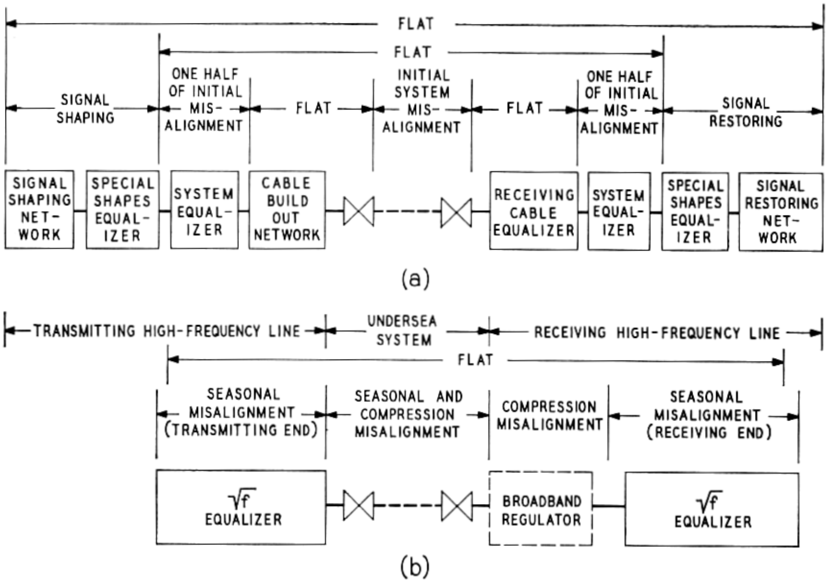


Fig. 8—SF Shore Terminal equalization plan: (a) initial lineup; (b) subsequent alignment.

terminal, and the other half in the receiving terminal. In practice, the system equalizers also compensate for transmission deviations in high-frequency line equipment.

The *cable buildout network* is adjusted with strapping options so that its loss plus the loss of the shore-end section of cable is equivalent to the loss of one full cable section (10 nm). This buildout is required because shore-end lengths vary from system to system. The *receiving cable equalizer* is made up of inverse cable-shape networks similarly adjusted for each system so that the sum of equalizer and shore-end section cable loss is approximately flat across the transmission band.

Signal restoring in the receiving high-frequency line, that is, *special shapes equalizer* plus *signal restoring network*, provides a shape complementary to that of signal shaping. Thus, the combined loss of signal shaping and restoring for a particular system is a constant.

4.2 *Maintaining Alignment*

Subsequent changes in undersea transmission with time must also be equalized by readjustments in the terminal. Relatively slow changes can occur due to seasonal variations in sea bottom temperature in the shallow water near shore. Permanent changes can occur, for example,

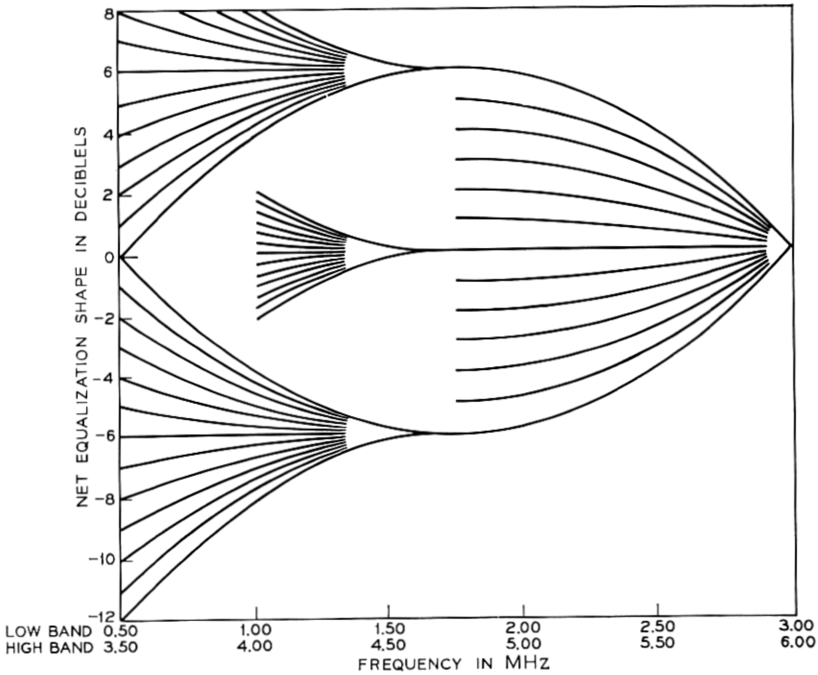


Fig. 9—Special shapes equalizer—some composite shapes.

due to aging of repeaters or cable, or as a result of undersea repairs. Gain compression in the undersea repeaters[2,11] as a function of signal load results in rather rapid fluctuations in system gain.

The specific design approach for equalization of these changes with time is illustrated in Fig. 8(b). Since variations in undersea transmission because of seasonal temperature swings are, to a great extent, proportional to the square root of frequency, an adjustable $(f)^{1/2}$ *equalizer** compensates for this effect. For example, when cable loss near shore increases, loss is removed from the transmitting $(f)^{1/2}$ equalizer to restore signal levels on the bulk of the system to their former value. At the same terminal, loss would be removed from the receiving $(f)^{1/2}$ equalizer to maintain the correct level at the input to the multiplex.

It is difficult to be specific about equalization of a permanent change in undersea transmission. In general, should such a change occur, it would be equalized in a manner similar to that used during the initial lineup.

* Equalizer loss $= K \pm n\ (f/6)^{1/2}$ dB, where K is a constant, f is frequency in MHz, and $n = 0, .5, 1, 1.5, 2.0 \cdots 8$.

At present, it is expected that gain compression will be compensated for by a relatively high speed broadband *regulator* functioning as an expandor, which will be located in the receiving high-frequency line. It will be controlled by a tone inserted in the distant terminal transmitting high frequency line. As a result of the dynamic behavior of the system gain the tone will be amplitude modulated. At the receiving terminal the variations in amplitude will be extracted by the regulator to provide an expansion characteristic complementary to that of system compression. This approach is feasible only when compression is approximately flat with frequency across the transmission band.

At this point, however, the design of the regulation scheme must still be considered experimental. An important parameter yet to be established is the speed at which the regulator must operate in order to eliminate transmission impairments resulting from compression. The answer certainly depends on the dynamic behavior of both the system compression characteristic and the signal load itself.

V. OPERATION AND MAINTENANCE

5.1 *General*

It was convenient, from the point of view of maintenance, to take full advantage of the duplicate supergroup and high-frequency line equipment by arranging two independent transmission paths, designated I and II (See Fig. 3). Hybrid transformers provide the required double feed. Duplicate paths meet again at hitless type switches, so that, in addition to fulfilling a reliability requirement, this arrangement permits a considerable amount of routine maintenance to be performed without even momentary service interruptions.

5.2 *Pilot Measuring and Monitoring Arrangements*

There are no special line pilots in the SF System. Terminal maintenance is based on use of group reference pilots. Built-in automatic and semi-automatic pilot measuring circuitry is part of the terminal. This includes:

(*i*) pilot monitor and switch control equipment,
(*ii*) the pilot transmission measuring system (transmitting scanner),
(*iii*) receiving supergroup scanner, and
(*iv*) receiving group scanner.

To avoid the difficulty of realizing very narrow bandpass (pilot pickoff) filters, which would otherwise be required to separate the pilots from the multiplex signal at SF line frequencies, all pilot measurements are made at group baseband frequency (104.08 or 105 kHz). Thus, frequency translation is an integral part of the first three arangements.

5.2.1 *Pilot Monitoring, Switch Control and Alarm Equipment*

In case of a failure in either duplicate transmitting or receiving high-frequency line, alarms are initiated and, if the failed path were the one in service, protection switching automatically substitutes the duplicate path. This is done by transmitting and receiving pilot monitor, switch control and alarm equipment. In the transmitting direction, two specific pilots are monitored continuously near the output of lines I and II* (See Fig. 3). In case of a failure, logical comparison of the results of the four pilot measurements automatically determines which of the two transmitting paths is more suitable for service. For maintenance purposes, a manual control allows either path to be locked in as the working path. A similar arrangement near the output of the two receiving high-frequency lines initiates alarms and controls the receiving switches.

5.2.2 *Pilot Transmission Measuring System (PIL TMS)*

The normal function of the pilot transmission measuring system is that of an automatic transmitting pilot scanner. In this operating mode, a PIL TMS is connected near the output of each transmitting high-frequency line. Each of the approximately 50 pilots is automatically measured in sequence and compared with a normal value (generally different for each pilot). The difference is displayed on a meter. A pilot deviation of more than 1.5 dB will initiate an alarm. The time required for a complete scan is about four and a half minutes.

In addition to the automatic pilot scanning capability, this measuring system can be used manually for a number of other pilot frequency measurements, as summarized below.

(*i*) Direct measurement of deviation from normal pilot power at the following flat transmission level points:

- (a) Transmitting channel bank or group connector output (2 frequencies),
- (b) Transmitting group bank output (10 frequencies),
- (c) Transmitting supergroup bank output (100 frequencies),
- (d) Receiving high-frequency line output (100 frequencies), and
- (e) Receiving supergroup output (10 frequencies).

* The group 1 pilot in supergroups 4 and 11.

(*ii*) Measurement of absolute power at any low and high band pilot frequency within the range from -30 to -69 dBm.
(*iii*) Measurement, on an out-of-service basis, of the conversion loss of group and supergroup banks at pilot frequencies.

Finally, a stable source of any of the pilot frequencies at 0 dBm can be obtained for general purpose terminal measurements.

5.2.3 *Receiving Supergroup Scanner*

In the scan mode, the group 1 pilot in each receiving supergroup is automatically measured in sequence by the supergroup scanner. Each pilot measurement is compared to the normal value and the difference is displayed. Detection of a pilot failure initiates an alarm. A complete scan of both receiving supergroup banks requires about one and a half minutes. The scan mode can be interrupted and manual measurements made by pushbutton and selector switch operation.

5.2.4 *Receiving Group Scanner*

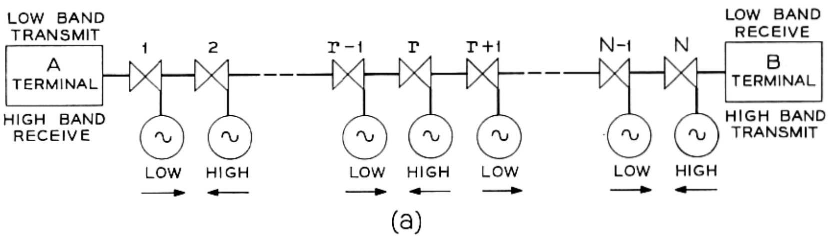
Both pilot output power and receiving group amplifier gain are measured in sequence by the receiving group scanner. The duration of one complete scan cycle for the working and spare group banks is about four and a half minutes. In the scan mode this cycle is repeated continually. Since the receiving group amplifiers are regulated, the deviation from normal gain is a measure of the amount of regulation an amplifier is providing. Gain deviations up to ± 4.0 dB are allowed before an end-of-range alarm is initiated. The receiving group scanner can also be operated manually.

5.3 *Order-Wire*

A 4-channel order-wire facility is part of the SF Terminal. It allows communications over the submarine cable between shore stations without pre-empting commercial circuits for this purpose. Any of these circuits can be interconnected at voice frequency with similar inland facilities to allow, for example, communications between so-called gateway cities. To economize on the use of undersea transmission spectrum, these maintenance channels are transmitted between particular supergroups (See Fig. 1). Steps of "channel," "group," and "supergroup" modulation are used to place two 4-kHz channels in the 8-kHz spacing between supergroups 4 and 5, and two more between supergroups 5 and 6. It was necessary to add a special filter in transmitting channels 2 and 4 to increase band edge discrimination to avoid interference with adjacent message channels. A modified A5 channel bank provides channel modulation. Group and supergroup functions are accomplished by a unique arrangement of standard and modified multiplex equipment, and some new apparatus designs. Carriers are obtained from the terminal carrier supply.

5.4 *Undersea System Monitoring*

To maintain near optimum system performance after initial lineup, it is necessary to monitor the behavior of the undersea transmission. One method is through use of supervisory tones. A supervisory oscillator, located in each undersea repeater,[11] continuously transmits a tone to a shore terminal. In a given SF System, the frequency associated with each repeater is unique. The tones, spaced nominally 100 Hz apart, lie in two 26-kHz wide bands: 528 to 554 kHz in the low band, and 5894 to 5920 kHz in the high band (Refer to Fig. 1). Adjacent repeaters have tones in opposite bands, so that the frequency sequence along the system is alternately high and low band. An A station receives only high band tones (from every other repeater) and a B station only low band tones. This arrangement is illustrated in Fig. 10(a). The means of launching these tones at the repeater are shown in Fig. 10(b). At the terminals these tones are measured with the supervisory tone test set,



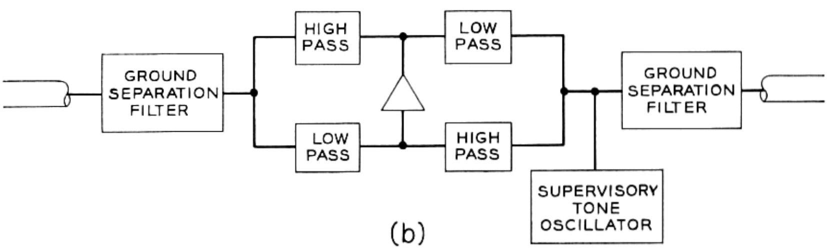


Fig. 10(a)—System layout with respect to supervisory tones.

Fig. 10(b)—Block diagram of repeater showing location of supervisory oscillator.

which will be discussed in some detail in the next section on fault location. Information about the distribution of transmission changes with distance along the cable can be inferred from these measurements.

A second monitoring method, which has been used in the past, is to measure the absolute power of the group reference pilots (at their line frequencies) simultaneously at each terminal physically as close to the ocean cable as practical. The difference at each frequency is approximately the loss of the undersea system at the time of measurement. Pilot measurements are most easily made with the pilot transmission measuring system.

One of the problems that system gain compression introduces is to make difficult the accurate measurement of undersea transmission changes due to causes other than compression. Data obtained from either of the above monitoring techniques will necessarily contain a certain, generally unknown, amount of compression effect. To precisely determine permanent changes from pilot measurements, it would be necessary to remove the system signal load. On the other hand, the amount a particular supervisory tone is affected by compression will, to a first approximation, be linearly proportional to the distance between the terminal and the repeater sending the tone. Thus tones from repeaters relatively close to the shore will be affected least. Fortunately, supervisory tone data from these repeaters are precisely what is needed to determine seasonal transmission changes because they are concentrated in cable relatively close to shore.

5.5 *Data Handling*

To facilitate recording and disseminating measurement data collected as part of the maintenance operation, a simple data handling scheme was assembled for the SF Terminal. It is composed of data translator, a teletypewriter equipped with tape punch and reader, and a data set. The output data of the pilot transmission measuring system and the supervisory tone test set are made available in binary coded decimal form. The data translator converts this into the ASCII* code acceptable to the teletypewriter, which produces printed page and punched paper tape output. Punched tape can be used to transmit data over the cable to the remote terminal. The *Teletype*® tape reader connects via a data set to an order-wire channel. Data can also be transmitted inland over a voice channel if a receiving terminal is suitably equipped.

For cable laying operations this setup is used with the Cable Laying Test Set.[3]

* American Standard Code for Information Interchange.

VI. FAULT LOCATING

6.1 *General*

If a fault occurs in the undersea system, it is essential that it be located accurately and quickly. The required accuracy is dependent on repair technology. In shallow water, the accuracy objective is about plus or minus one mile. The critical factor here is to determine whether repair is feasible without disturbing a repeater. In deep water, it is desirable to determine the location to within a repeater spacing at least. The time required to locate the fault should be short enough to avoid delaying the dispatch of a repair ship.

Three distinct methods are available for locating faults in the undersea portion of an SF System. The special test equipments designed to exploit each method are:

(*i*) supervisory tone test set,
(*ii*) repeater locating test set, and
(*iii*) cable fault localization test set.

One distinction among these sets is that the first two can be used only when the system is powered, the last only when the system is not powered. At best, the first two can locate a fault to within a repeater section, because their measurements are specifically associated with individual repeaters. Other observations, however, such as a change in received noise power at one terminal, can provide further information that may allow a more specific fault location estimate to be made.

6.2 *Supervisory Tone Test Set*

The supervisory tone test set is a special purpose selective detector that can accurately measure the absolute power and frequency of individual tones in the supervisory bands. Frequency selectivity is about 25 Hz, and dynamic range is between -30 and -80 dBm. With external calibration the accuracy is ± 0.1 dB and at least ± 1 Hz. One of the difficulties normally encountered in tuning such a narrow-band detector is that of finding and holding the measured tone at the precise "bottom" of the selective filter. To solve this problem a phase-locked feedback loop was incorporated around the filter. In operation it is necessary only to tune to the neighborhood of a particular tone (about ± 5 Hz). The phase-lock will then automatically seek and maintain fine tuning.

Recall that in addition to providing fault locating information, supervisory tone measurements are used as a system maintenance tool and, during cable laying operations, as an aid in determining transmission misalignment as a function of distance.[2,3] Actually, supervisory tone measurements can only locate a fault unambiguously to within two adjacent repeaters and the intervening cable [See Figs. 10(a) and (b) and note that, relative to the bands in which they operate, high band oscillators are connected at the repeater inputs, whereas low band oscillators are connected at the outputs.] As an example, postulate a transmission fault that does not affect the ability to power the system. The A station would receive tones only from repeaters 2, 4, $\cdots$, r, while the B station would receive only from repeaters $(r + 1)$, $(r + 3)$, $\cdots$, $(N - 1)$. In this case the fault is probably in repeater $(r + 1)$ or the cable between r and $(r + 1)$. However, the fault could be in the ground separation filter or coupling of repeater r. This example is an oversimplification because it assumes loss of transmission in each direction beyond the fault. It is possible to obtain high resistance faults between the cable center conductor and sea water that have virtually no effect on transmission loss, but do generate considerable noise unless the dc voltage at the fault is adjusted to zero.* In this case, supervisory tone measurements are of little use. Fortunately, for faults of this type, the repeater locating test set becomes a very useful tool.

6.3 *Repeater Locating Test Set*

The repeater locating test set identifies repeaters by using their slight and normally undesirable nonlinearity. In response to a transmitted signal a return modulation product is obtained from each repeater. The mode of operation depends on whether operation is from an A or B station. At an A station, periodic bursts of a particular low band frequency are applied to the system. Bursts of second harmonic produced in each repeater fall in the high band, return to the A station, and are detected. The unique round trip delay to each repeater allows the returned signal from individual repeaters to be identified. At a B station, which transmits in the high band, a continuous tone as well as periodic bursts of another high band frequency are applied to the system. Bursts of the difference modulation product fall in the low band and return to the B station. All signals generated and detected by the test set fall in the standard group band of 60 to 108 kHz; terminal multiplex and high-frequency line equipment are used to translate these signals to and from line frequency.

The principal feature of the receiving portion of the set is a com-

* On a system with a power plant at each terminal, zero fault voltage is obtained if each plant can be adjusted to supply equal current.

mercial digital-memory oscilloscope. It can achieve a significant improvement in signal-to-noise ratio over conventional detection techniques through use of its computation and data storage capabilities. The results of a large number of repetitive measurements are automatically added and stored; the wanted signal adds systematically from sample to sample whereas the background noise adds on a random basis. When a measurement sequence is complete, the results are printed out in digital form. When the additional signal-to-noise advantage is not required, the detected signals can be directly displayed on a conventional oscilloscope. Two such displays are pictured in Fig. 11. The amplitude of a return pulse from any given repeater is a function of the nonlinearity of that repeater and both low and high band misalignments between it and shore. For example, the large decrease in pulse height between repeaters 11 and 12 in Fig. 11(a) is explained by the fact that about 900 meters of extra cable were added between these repeaters for purpose of equalization.

If a system fault occurs that does not affect the ability to maintain power, or if the system can be powered to the fault, then location to within a repeater spacing (two repeater ambiguity) is obtained by observing the presence or absence of return pulses, or, in some instances, amplitude changes from previous measurements.

One of the most difficult faults to locate is the relatively high im-

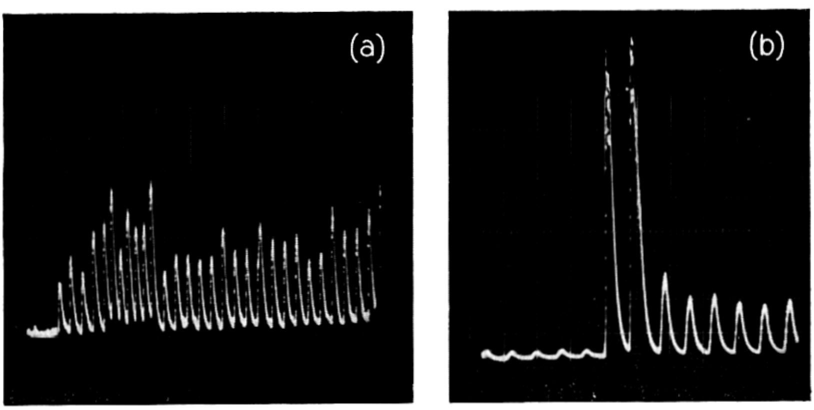


Fig. 11(a) and (b)—Repeater locating test set displays: (a) return pulses from first 30 repeaters out from the Jacksonville Beach, Florida, terminal; (b) a portion of the return pulses during a fault condition. Shore supplying normal current of 136 mA but ship receiving only 56 mA. Increase in modulation of current starved repeaters reveals location of fault to within a repeater spacing (two repeater ambiguity).

pedance shunt type, described in the previous section, which has little effect on transmission loss. A fault finding technique that proved very effective when such a trouble developed during installation of the new Florida-St. Thomas system was to adjust the power plants at each end of the system (in this case ship and shore) so that repeaters on one side of the fault were receiving substantially less current than those on the other. The increase in nonlinearity and decrease in gain of the current-starved repeaters was detected as shown in Fig. 11(b).

6.4 *Cable Fault Localization Test Set*

Historically, the most frequent cause of lost service time on submarine cable systems has been cable breaks resulting from fishing activity. It will usually be possible to power an SF System to the fault for most cable breaks and, using the repeater locating test set, locate the fault to within one repeater section. If it is not possible to power the system to the fault, the cable fault localization test set can be used.

Basically, this test set utilizes a complex artificial line that simulates the repeatered cable at very low frequencies ($\leqq 1$ Hz). Under fault conditions, the artificial cable is compared to the actual faulted cable in a bridge configuration. Provision is made for the insertion of a complex fault impedance (resistance and capacitance in parallel) at points along the artificial line until optimum balance conditions are obtained. The major difficulty in this method of fault location is that it is quite difficult to distinguish between the magnitude of the fault impedance and equivalent cable length; that is, similar bridge balances can be obtained at different points along the cable by varying the simulated fault impedance. This uncertainty can be reduced by testing at different low frequency currents and analyzing the resulting data with empirically-determined relationships that tend to separate fault impedance and cable parameters.

VII. PHYSICAL DESIGN OF TERMINAL EQUIPMENT

7.1 *General*

From the point of view of physical design, terminal equipment is separable into two categories:

(*i*) duct type bay construction and
(*ii*) cabinet construction.

The power separation filter and fault locating test sets are housed in 1.95-meter-high cabinets. This type of construction is illustrated in Fig.

12 which shows the cable fault localization test set. All operating controls and indicators are accessible from the front. Components are mounted in drawers that slide out individually to allow access for maintenance purposes.

The remaining terminal transmission equipment is mounted in 2.74-meter-high (9 feet), duct-type bays. Although not standard to

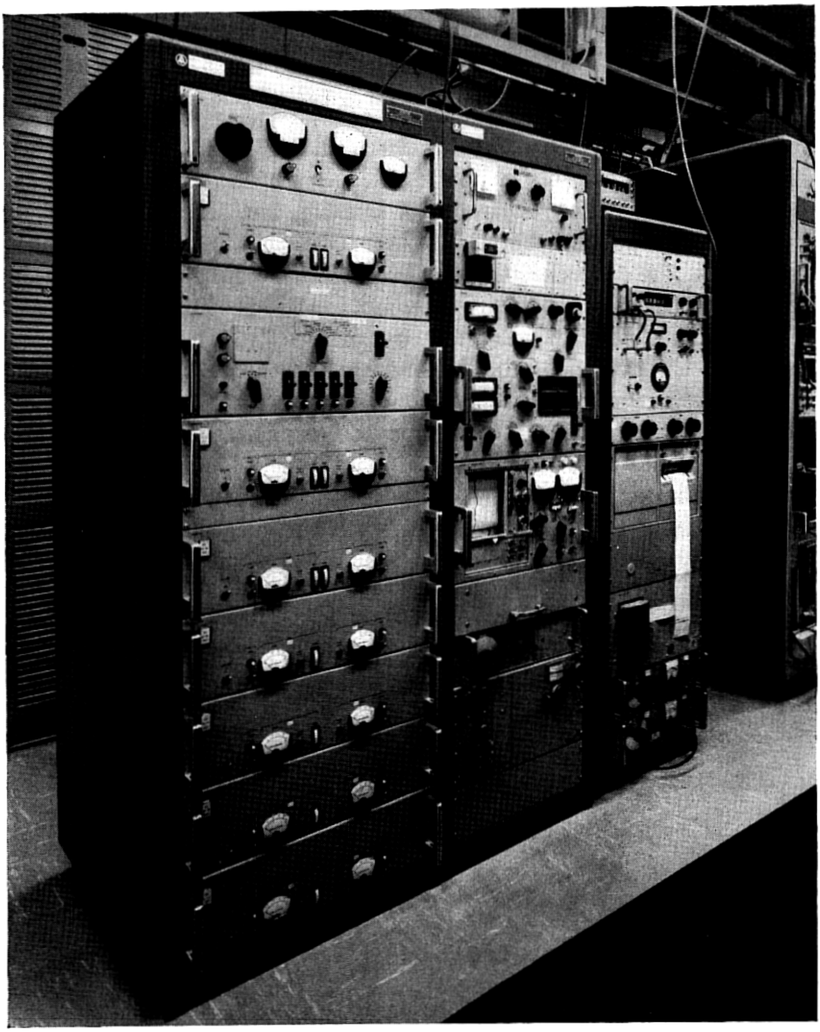


Fig. 12—Cable fault localization test set.

the Bell System, this height was chosen because it is more compatible with foreign equipment design practice and terminal buildings. The mechanical arrangement within the bays consists mainly of shelf-type units rigidly attached to the ducts, which contain the intershelf and interbay cabling. Apparatus of a passive nature are typically mounted on slide out units that rest on the shelves. Circuitry containing active devices is usually packaged in plug-in modules. In this way, ease of access is generally matched to the likelihood that maintenance will be required.

7.2 *Bay Enclosures*

The appearance of SF Terminal equipment has been a matter of more than usual concern, primarily because of the international character of submarine cable installations. It was recognized early in the design stage that harmonious appearance would be difficult to achieve because existing equipment of differing physical designs as well as equipment of new and modified designs would be included in the terminal. As a solution, a unique enclosure scheme was developed for use with duct-type bays to unify their appearance. A four bay lineup is pictured in Fig. 13. The front of the enclosure consists of two pairs of side-hinged doors for each bay in the lineup. When the doors are opened they can be slid into the area between ducts at the side of each bay. The upper and lower doors are separated by a rigid supplementary bay framework on which closed-door access panels are mounted. When the doors are in their normally closed position, they are flush with the panels, presenting a smooth uncluttered line. As the name implies, these closed-door access panels provide easy visual and physical access to fuses, alarm lamps, meters, keys, and test jacks required for routine operation of the system. The doors and access panels have a light gray textured vinyl finish. Surrounding this area is an interbay cabling trough at the top, a guard rail at the bottom, and end panels at the sides. The dark blue-gray textured finish of these items results in a picture frame effect.

VIII. ACKNOWLEDGMENTS

The design of the SF Terminal and fault locating equipment is the result of the efforts of many individuals within the Bell Telephone Laboratories. In addition to these individuals directly responsible for the overall designs, whose contributions are gratefully acknowledged here, mention should be made of the considerable design support provided by personnel of the network and multiplex areas.

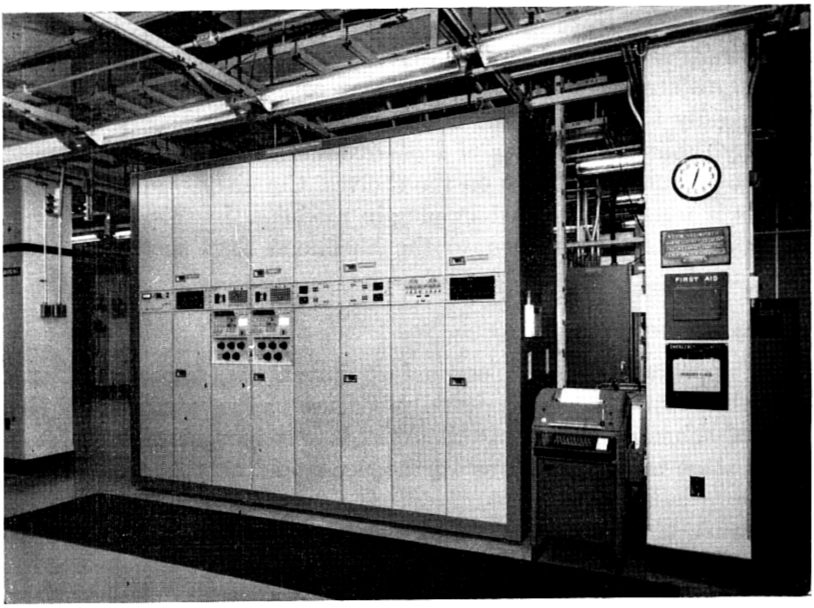


Fig. 13—Four bay lineup of transmission equipment showing the enclosure scheme.

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