SF System:

Transmission Tests, Computations and Equalization During Installation

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The SF Submarine Cable System relies on equalization of accumulated misalignment at regular intervals along the length of the system to achieve performance objectives. Transmission tests of the undersea system during installation are required to implement this equalization. This article describes the tests that are conducted and the computations used to select equalizer settings just before an equalizer is overboarded.

I. INTRODUCTION

A continuous test program forms a part of the SF Submarine Cable System[1] installation procedures from the time material arrives at the dock for loading aboard ship through the final line-up before service. The tests and computations we describe are necessary to verify satisfactory performance of cable, repeaters, and equalizers; to obtain data for determining the optimum ocean block equalizer settings; and to obtain data for system line-up and for system administration and fault location.

The major undersea portions of the SF System are laid using the ship, equipment and techniques developed for the SD Submarine Cable System.[2–5] Transmission testing coincides with these cable-laying activities, although the transmission test equipment installed on the Cable Ship Long Lines (shown in Fig. 1) is predominantly new. A parallel transmission effort is also performed during the burial of SF System cable,[6] but with the use of considerably more primitive equipment aboard ship.

II. GENERAL

The SF Submarine Cable System has a maximum design length of 4000 nm which causes the total transmission loss at the highest system

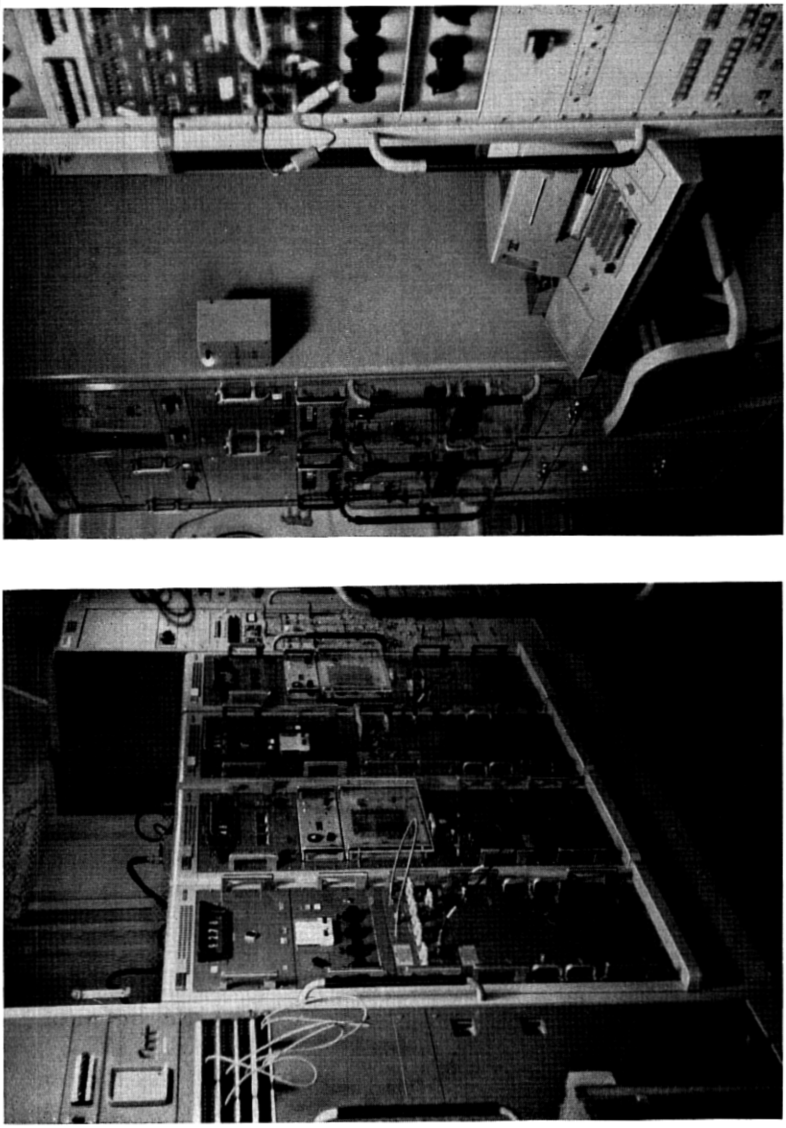

Fig. 1—Long Lines transmission test room.

frequency to reach 16,000 dB. This loss must be matched by the gain of some 400 repeaters. The repeater gain is shaped to match the cable loss at a temperature of 3°C and a pressure corresponding to a depth of 2000 fathoms. Since the installed cable experiences the actual temperature and pressure of the ocean floor, the length of each cable section is cut at the factory to obtain the desired loss at the highest system frequency. This step of equilization, based on oceanographic data on temperature and pressure for each cable section along the route, adjusts the top frequency loss for known departures from design temperature and pressure. All other equalization of the undersea system takes place in the adjustable ocean block equalizers situated after every 20 repeaters. This equalization corrects for production deviations in cable loss and repeater gain and uncertainties in predicted ocean-bottom temperature and depth as well as any cable attenuation changes due to handling. Ideally, complete information on which to base the equalization is available only after the complete system has been installed on the sea bottom. However, in order to adjust an equalizer, it must be physically accessible. The optimum adjustment for an equalizer must therefore be made before the equalizer goes overboard. Selection of the best setting for a particular equalizer must therefore be based on measurements made between the shore and that equalizer before this portion of the system has completely reached equilibrium at the sea bottom. Hence, detailed and continuous transmission measurements and computations are necessary during the actual laying of the system.

An ideal, no-misalignment system would have equal transmission levels at the output of every repeater at a given frequency. Since deviations will accumulate, however, the ocean block equalizers are used to periodically reduce the misalignment to minimize deviations from the average level. Repeaters operating at a high level contribute above-average modulation noise, while low-level repeaters cause increased thermal noise. The SF System is modulation-limited, so the undesirable modulation noise of high-level repeaters comes into effect before gross overload is reached. Figure 2 shows how misalignment accumulated and was periodically reduced at 5000 kHz on the Jacksonville-St. Thomas system, while Fig. 3 shows the improvement obtained across the transmitting and receiving bands at the end of block four.

Although the aim of transmission tests during laying is to determine the deviations of cable and repeaters when fully stabilized at sea-bottom temperature and pressure, the measurements must be made between

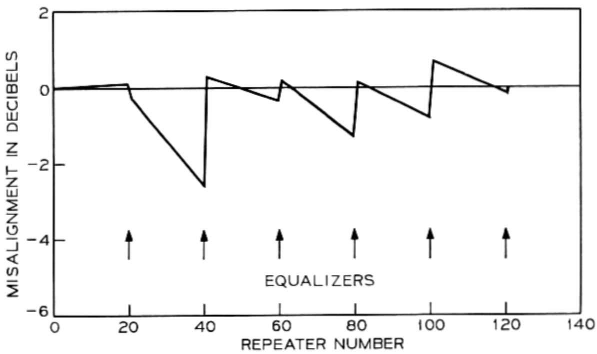

Fig. 2—Typical misalignment versus repeater number plot (data apply to Jacksonville-St. Thomas SF System at 5000 kHz).

the shore and the block-end equalizer to go overboard next. The cable in that portion trailing down from the ship to the ocean floor is warmer than it will be when it reaches the ocean floor. As the cable cools, its loss decreases. On the other hand, as the cable is subjected to increased pressure its loss increases. As a result of these two effects, the transmission changes continuously as the laying proceeds. For this reason, measurements are made at hourly intervals, and the data are plotted versus miles laid. At a prescribed time before the equalizer must go overboard, the transmission data are extrapolated to the end of the

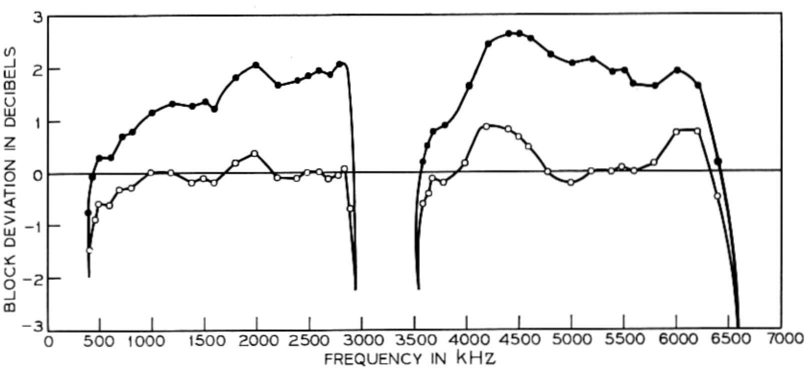

Fig. 3—Typical block deviation before and after equalizer adjustment (data apply to block four (repeater 81) of Jacksonville-St. Thomas SF System). Dots show data before equalizer adjustment and circles show data after equalizer adjustment.

block and compared with desired values. This gives the accumulated deviation corresponding to having the entire portion stabilized at sea-bottom conditions. The switchable shapes available in the equalizer are then examined to determine the optimum settings to minimize the deviation in each band. After the equalizer has been switched, measurements are made to check that the desired result has been achieved, the equalizer is prepared for overboarding, and measurements from the shore through the next block-end equalizer are begun.

III. LOADING

The submarine cable, repeaters, and ocean block equalizers which form the undersea system are tested individually at their place of manufacture and are shipped separately to be loaded aboard the cable ship. The repeaters and equalizers are brought aboard and placed in the repeater stacks in proper sequence for laying. The cable sections are coiled in the various cable tanks according to the loading plan, which is devised so that when the cable and repeaters are spliced together the system can be payed out continuously without snarls or knots. During the loading of the cable it is given the following tests: insulation resistance between center and outer conductors, dc loop resistance of center and outer conductors in series, pulse echo observation to verify length and check for impendance irregularities, and a continuous monitoring of the dc cable loop resistance while the section is being coiled in the tank. The ends of each cable section are brought to the repeater stack and placed at the appropriate end of the repeater or equalizer to which they are later spliced to form an assembled shipload.

IV. ASSEMBLED SHIPLOAD TESTS

Since this is the first time the individual parts actually form a transmission system and since the shipping, loading, and splicing could cause faults, the assembled shipload is tested to ensure that the system is free from faults prior to laying.

4.1 *Transmission Tests*

The connections necessary to power the assembled shipload and to utilize the shipboard test room equipment are shown in Fig. 4. From this figure it can be seen that for these tests the shipboard transmission equipment must transmit and receive in both bands, with

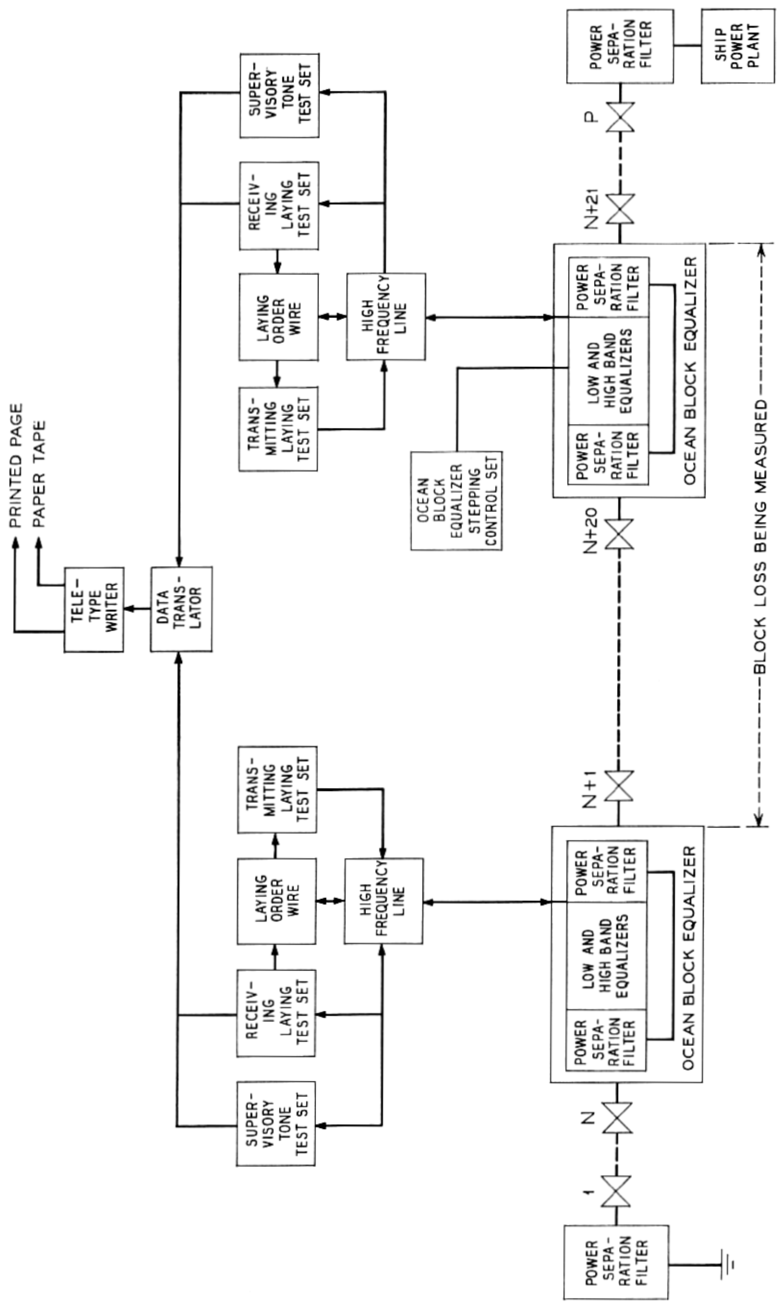

Fig. 4—Assembled shipload transmission tests.

the equipment at one end performing the function the shore equipment will perform when tests are made between ship and shore. The length of each assembled shipload is short enough to allow power to be supplied by a power supply at one end only, with the other end grounded. The connection block diagram therefore shows that each end is placed in a power separation filter, which connects the shipboard dc power plant to the center conductor at one end, grounds the center conductor at the other end, and provides 75-ohm coaxial connections for transmission tests. Before dc power is applied to the system, the insulation resistance between inner and outer conductors is measured with the far-end open circuited to ensure that there are no faults to ground which would prevent the proper application of power and cause the power plant to shut down. A measurement of the dc resistance through the center conductor path of all the cable, repeaters, and equalizers ensures that the system is properly connected.

Transmission tests through the entire assembled shipload are not feasible because, in general, the high shipboard temperature relative to that of the sea-bottom causes the cable loss to be very high. Therefore, signals are sent only through one block; that is, between two adjacent ocean block equalizers or between an equalizer and the adjoining cable end. Testing one block at a time has the added advantage that it is easier to localize any trouble that may be indicated by the test.

Refer again to Fig. 4. Transmission tests are made at a fixed set of frequencies in the low band and the high band. The paperwork, laying test sets, and computer programs are prearranged for these frequencies. For the assembled shipload tests 0-dBm test tones are generated by the test set at one end in, say, the high band and are received by the set at the other end of the block. For tests in the low band the test set at each end is reconnected to interchange transmitting and receiving functions. The laying test sets measure with an accuracy of 0.1 dB and go from one frequency to the next automatically. The frequency and received power are printed by the teletypewriter, which also prepares a punched paper tape of the data. The transmission tests at the 26 standard frequencies in the low band and 24 frequencies in the high band are completed with a permanent typed copy and a paper tape prepared in about 5 minutes per block. The power of the test tones applied to the repeaters is controlled by attenuators in the high-frequency lines. Different transmitting and receiving attenuator settings are required depending on whether the transmission connection is at an equalizer or a power separation filter, due to the different paths the test tones take between the nearest repeater and the test equipment.

4.2 *Computations*

The raw transmission test data become useful only if one can interpret them and decide whether or not the system is operating properly. The factory measurements on actual repeaters, equalizers, and cable sections in each block are compiled and used as a standard with which all test results are compared. The factory measurements on these items and the place in the system to which they are assigned are the inputs to a computer program which processes the data and prints out the compiled information, called the system data book. The system data book, prepared at Bell Telephone Laboratories before the loading or laying begins, is available in printed form and is also stored in the shipboard computer. Data at two conditions, the predicted sea-bottom temperature and pressure and at atmospheric pressure and 10°C are provided. Assembled shipload test data are compared with the system data book block loss (Fig. 4) at atmospheric pressure and 10°C, since these conditions require smaller corrections to match the shipboard temperature and pressure than sea-bottom conditions do. To determine the block loss from the measured data, the losses and gains encountered by the test tones at each frequency in the transmitting and receiving high-frequency lines, the power separation filters, all patch cords and test trunks, and the path through the equalizer taken by the tone must be known. These gains and losses are measured, at the 50 standard frequencies and for all the various attenuator settings needed, prior to the tests on the system.

The connection to each equalizer used for transmission tests is a bridge across the main transmission path between the power separation filter in the equalizer and the high- and low-band equalizing networks (Fig. 4). The test connection and the orientation of each equalizer in the system put the equalizing networks in both bands between the shore station and the ship test connection during laying. The test equipment has a 75-ohm impedance which is bridged across the 59.4-ohm system impedance. A bridging loss of 3.91 dB used in the calculations allows for the mismatch loss and an additional factor to convert the test measurements to the power which would represent the power at the bridging point if the bridge connection were not there, since this lead is removed (open-circuited) after tests are completed.

After the computation of the measured block loss from the measured data, the cable temperature coefficient must be used to correct the data to 10°C for direct comparison with the system data book. This requires temperature data from various points in the ship's cable tanks, obtained using thermocouple sensors and a multichannel readout panel. This temperature detection is the least accurate part of the test, so the difference between the temperature-corrected measured block loss and the system data book value often has a characteristic proportional to the square root of frequency, caused by the temperature measurement inaccuracy. This disparity becomes recognizable when plotted and can be subtracted out to give the real transmission deviation. This process amounts to using the transmission data as a measure of average block temperature.

All computations described here for assembled shipload tests and also all computations during laying are performed by the ship and shore personnel using specially prepared forms and procedures. The same computations are also performed using the shipboard computer. The shipboard computer installation is shown in Fig. 5. (The teletypewriter shown in Fig. 5 for use with the computer is separate from the teletypewriter shown in Figs. 4 and 6 for use with the transmission test equipment.) A shipboard computer rather than a land based computer was chosen for several reasons:

(*i*) Certain computations are done as the ship steams to the cable grounds; land based computers demand the maintenance of a data link between ship and shore.

(*ii*) A shipboard computer is available as a real time, on-line machine with a system of utility programs for general computations.

(*iii*) A shipboard computer allows laying a system from any shore station.

The repeater supervisory tones[7] are also measured during assembled shipload tests. Odd-numbered repeaters send tones in one direction and even-numbered repeaters in the other. The difference between the power of two tones gives the loss between the two repeaters at the frequency of the tone. Simple computation refers the absolute power and frequency of each tone to the repeater output for comparison with the system data book values to ensure that each tone is working

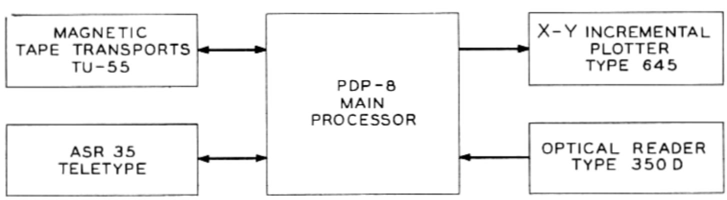

Fig. 5—Shipboard computer installation.

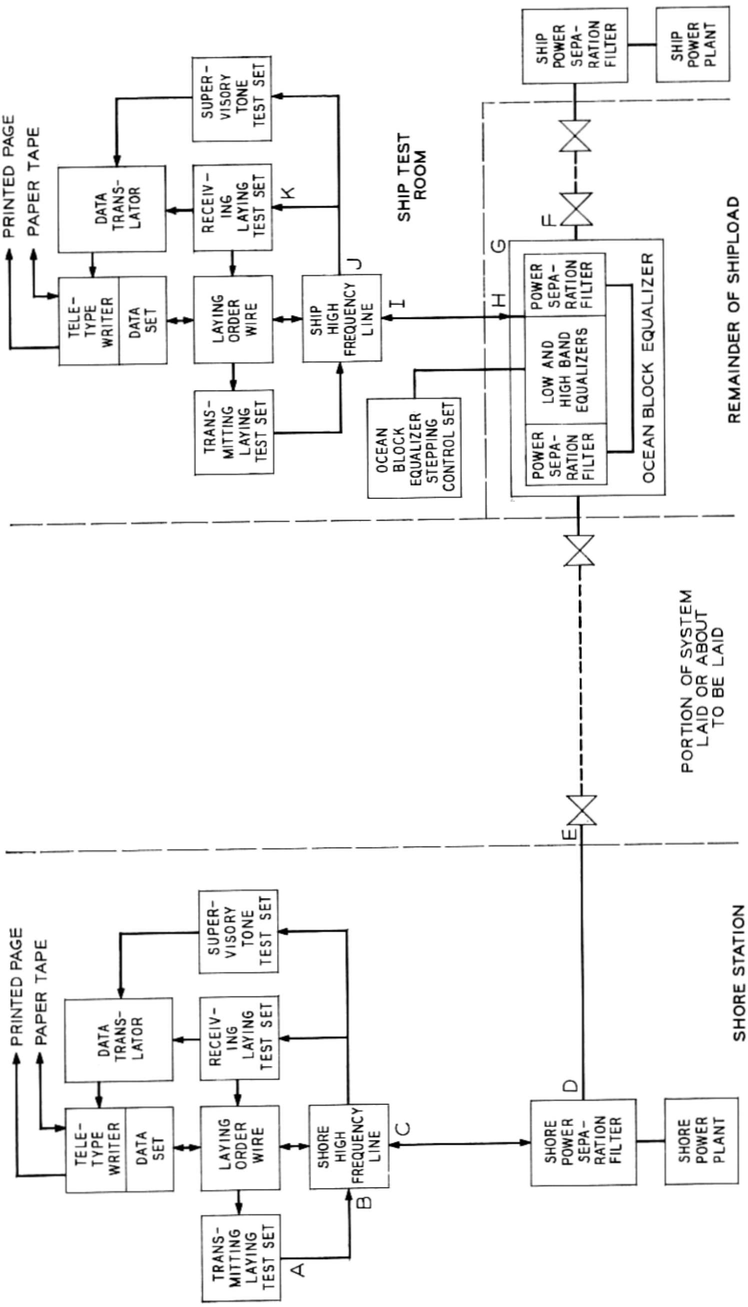

Fig. 6—Transmission tests during laying.

properly. The loss between two repeaters can also be manipulated for direct comparison with the system data book information.

4.3 *Ocean Block Equalizer Adjustment Tests*

The switchable networks in each equalizer[7] are used to modify the transmission characteristic to correct for misalignments detected during laying. It is important to verify that the networks are all on a known reference setting prior to beginning the lay and also to test the equipment used to switch the networks. This is done during assembled shipload tests by making three transmission runs on each block: the first run with the equalizer networks as shipped from the factory, the second with each of the seven networks in each band switched to the complement of the desired reference setting, and the third with the networks all set to the reference setting. This testing exercises all the switching relays and stepping equipment. Addition and subtraction of the three runs shows whether or not the equalizer was shipped with the correct reference settings and ensures that the equalizer has the reference settings for the lay. Tables of the expected transmission change between the reference setting and each of the 127 other possible combinations in each band, for each of the 50 standard frequencies, are used to check the measurements.

V. TESTS DURING LAYING

The actual laying of a shipload can begin under a variety of circumstances. For example, the first 92 nm at the Florida end of the Jacksonville-St. Thomas SF System were installed by the C. C. G. S. JOHN CABOT and part of this load was buried for protection.[6] Transmission tests were performed on this part of the system, but no equalizers were involved. The first shipload carried by the C. S. LONG LINES was installed starting at the end of the cable left by the CABOT.

5.1 *Transmission Tests*

After bringing the previously laid cable end aboard ship, tests are made from the recovered end to the shore station to verify the integrity of the previously laid system, followed by the splicing of the recovered end to the outboard end of the assembled shipload. At this point the shore, ship, and undersea parts of the system appear as in Fig. 6. Schematically, Figs. 4 and 6 are similar, but the physical separation of ship and shore by hundreds or thousands of miles represented in Fig. 6 makes the performance of transmission tests quite a different problem from the assembled shipload tests. The main communication link is the laying order wire, which provides twelve 4-kHz channels for voice, teletype data, and laying test set automatic control. After splicing, dc power is applied from the ship's power plant, and from the shore if the length requires double-ended feed.[8] The first transmission tests are made from the shore through the shipboard equalizer which will be laid first.

Transmission tests at the standard frequencies in both bands are made hourly during laying. At both ship and shore, attenuators in the high-frequency lines are adjusted before the first test through each block so that the tone power at the output of the first repeater in the transmitting direction is -10 dBm at the top frequency of both bands. The laying test set on the ship generates 0 dBm at each frequency in the ship-to-shore band, and when the shore test set has measured one tone it automatically goes to the next frequency and signals the set on the ship to do likewise via the laying order wire. For this case the shore teletypewriter prints the measured frequency and power and punches a paper tape. Since both shore and ship have two complete test sets, transmission tests in both bands can be made simultaneously. As the measurements are being made, only the receiving station for each band obtains a printed page and a paper tape of the data, so the data are exchanged between ends by running the tapes through the teletypewriter tape readers which transmit via the data sets and laying order wire.

Other tests during laying include: (*i*) continuous monitoring of one frequency in each band when no transmission tests are being made, with automatic alarms for a $\pm$ 1 dB variation, (*ii*) tests of the received power and frequency of the supervisory tones from the repeaters, (*iii*) measurements of thermal noise, (*iv*) transmission tests at more closely spaced frequency intervals, (*v*) transmission tests through the next ocean block immediately before starting to lay the block to re-verify its integrity, and (*vi*) monitoring of the power plant current and voltage.

5.2 *Setting an Equalizer*

The general discussion at the beginning of this article explains that the data from each transmission run must be plotted versus cable mileage, for each of the 50 frequencies, since the measured power continuously changes as the system is laid. The test tones are transmitted at a constant power, but as the cable leaves the ship's tanks and sinks to the ocean floor it cools and the pressure on it increases. The net effect is a decrease in loss with time which is linear (in decibels) if the ship's laying speed, ocean bottom temperature, and depth are constant. Fig. 7 gives a typical example, showing that the absolute value of the received power increases as the laying proceeds.

About three hours before the predicted time at which the equalizer should go overboard, the received power versus cable mileage data (Fig. 7) are used to predict what the measured power would be at the end of the block, that is, if it were possible to continue the transmission measurements until all the cable up to the equalizer had stabilized at ocean-bottom conditions. Extrapolating the power versus mileage data to a point near the actual equalizer mileage* provides this information. Direct comparison of the extrapolated block-end power with the transmission objective gives the block deviation. The transmission objective for each block is the expected test set received power computed assuming that the misalignment in the system is a desired amount called the misalignment objective. The misalignment objective allows the system to be laid and equalized with a desired misalignment, to take care of factors such as annual temperature variations, so that the time-averaged misalignment is minimized. The transmission objective is found by tracing the path of the 0-dBm transmitted test tone through all the known gains and losses up to the receiving test set. Referring to Fig. 6, the transmission objective for the shore-to-ship band, in minus dBm (decibel referred to 1 milliwatt), is: 0-dBm transmitted power + patch cord loss AB + shore transmitting loss BC + shore PSF loss CD + shore section loss DE − misalignment objective EF − cable loss FG − equalizer PSF loss GH + equalizer bridging loss H + test trunk loss HI − ship receiving gain IJ + patch cord loss JK.

The block deviation is the cumulative error in the system up through the equalizer about to be laid and represents the correction which should be applied by switching the equalizer's networks from the reference settings to their final settings. The block deviation definition for both directions of transmission specifies that excess gain produces a positive deviation. The 128 possible switchable combinations in each band are tabulated and plotted versus frequency as added loss relative to the reference setting, so that a direct comparison of the block deviation gain with the new equalizer setting's added loss can be made. The comparison can be made manually by superimposing a plot of deviation and plots of the available equalizer settings and choosing the setting

* The extrapolation mileage used is a function of the ship's speed, shipboard cable temperature, ocean temperature and depth, and the thermal time constant of the cable.

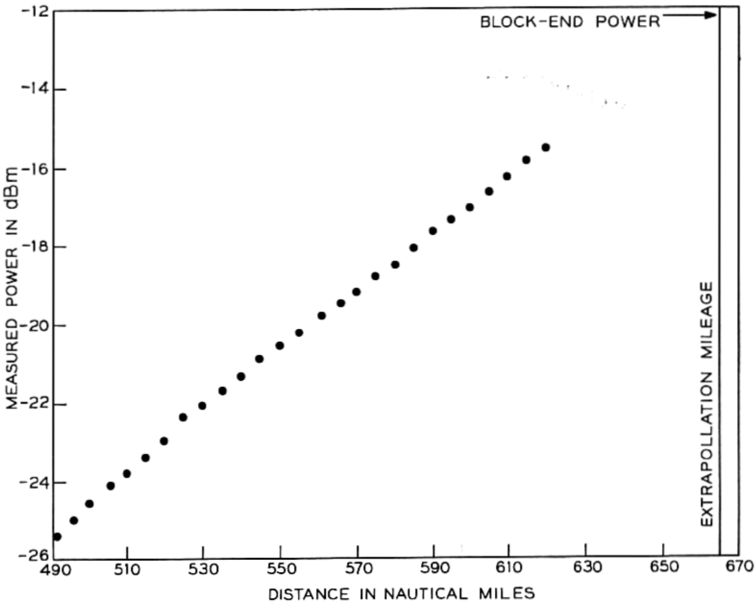

Fig. 7—Typical transmission test received power versus mileage plot (data apply to block four and 5000 kHz on Jacksonville-St. Thomas SF System).

which most closely matches the deviation over the desired frequency range. A separate decision must be made for each band. Fig. 3 shows the effect of setting the equalizer of block four of the Florida-St. Thomas SF system.

While it can be done manually, the shipboard computer operator performs the calculations which result in choosing the optimum equalizer setting by using programs stored in the computer. There are two classes of programs. Those that are designed to compute specific items such as transmission objectives, and a general set of utility routines which can be used to manipulate data under the control of the operator. Both classes of programs reside on one of the magnetic tape units and are called into the machine for use at the option of the operator. One of the other tape units is used for the logging of measured data. Operationally, a punched paper tape containing received power versus frequency and cable mileage is prepared using the test sets, data translator, and associated teletypewriter. This tape is read by the computer with the optical reader using a utility routine and logged onto magnetic tape. When approximately 20 frequency runs have been logged in this way the extrapolation routine is called into core. The data are extrapolated to find the extrapolated block-end power, defined above, and the results of this extrapolation are both printed and logged on the data tape. Next, a special program is used to compute the block deviation, using the transmission objective and extrapolated block-end power. Finally, the equalization program is used to choose the optimum equalizer setting for each band. The equalization program minimizes the frequency weighted sum of squares of the difference between the block deviation and the available equalizer switchable shapes. A weighting function that gives equal weight to the deviations at the standard frequencies which are in-band but away from the band edges and that gives zero weight to the deviations at the other standard frequencies has been found to give satisfactory results.

Two of the factors which are considered when making the equalization decision are (*i*) the misalignment of the last repeater in the block being laid and (*ii*) the misalignment of the first repeater in the next block. Figure 1 shows typical misalignments of first and last repeaters, with the equalizer causing the sharp changes between these adjacent repeaters and an assumed linear change over the remainder of the repeaters in a block. The misalignment of the last repeater in the block being laid cannot be changed by switching the equalizer. This misalignment is computed from the block deviation and the system data book value of the loss between the outputs of the repeaters on either side of the equalizer for the equalizer reference setting. The misalignment of the first repeater in the next block equals ± the block deviation for the equalizer reference setting and can be computed for any other equalizer setting by using the equalizer added loss due to switching. The question of which sign (±) becomes evident upon considering which band is involved, and the facts that (*i*) gain always gives a positive block deviation and (*ii*) during cable laying the output of the repeater nearest shore is always taken as the point of zero misalignment for both directions of transmission. Hence, during cable laying a system gain in both bands will give a positive misalignment in the shore-to-ship band and a negative misalignment in the ship-to-shore band.

After the equalization decision has been made and about two hours before the equalizer must go overboard, a transmission test is made, the equalizer stepping control equipment is used to switch the 14 networks, followed immediately by another transmission test. These two transmission tests are compared to verify that the transmission change does represent the desired new equalizer setting. The transmission and switch control leads are then transferred to the next equalizer in the system, and the two leads on the equalizer to be laid are sealed. Testing is then begun from the shore through the next equalizer.

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