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SG Undersea Cable System:

Commissioning: Final System Alignment and Evaluation

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A comprehensive line-up and test program called commissioning was developed for the SG Undersea Cable System. The program provides instructions for measurement, alignment, and evaluation of various performance parameters of the system. Equalization, optimization of signal-to-noise ratio, and system alignment are the primary objectives of commissioning. Measurement of performance parameters such as differential gain and phase, phase jitter, and impulse noise count distribution with threshold level are included in the test program. This paper describes the commissioning process, interspersing both a general description of procedures and selected test results from the TAT-6 link.

I. INTRODUCTION

Commissioning, a British Post Office term, is the test and adjustment program (or process) performed on a newly installed undersea cable link before it is placed in service. The cable system is measured and aligned, and its performance is optimized. This process starts during installation and continues until the terminal-to-terminal link is ready to be released for service. The bulk of the effort takes place after cable laying[1] is finished; that is, after the final splice, and can take several weeks to complete. This paper describes the commissioning process for the SG system. General descriptions of the test program and illustrative data from the TAT-6 link are provided. Fault localization reference data, although part of commissioning, are not discussed.

Successful completion of commissioning means that the cable and terminal transmission equipment (supergroup-to-supergroup) are equalized, signal-to-noise ratio is optimized over the transmission bands, and the terminal equipment is adjusted so that service may begin. Accurate commissioning test data are vitally important because these data are used also to:

(*i*) Determine link operating performance.
(*ii*) Compare actual with computed performance.
(*iii*) Provide initial data so that future link performance may be evaluated.
(*iv*) Obtain reference data for maintenance purposes.

Incidentally, the SG system differs from the SF and SD systems[2,3] in that the undersea link transmission can be adjusted from the terminal, by means of shore-controlled equalizers.[4] Five sectors, each approximately 650 nautical miles (nmi) long, were created in the TAT-6 link by using four shore-controlled equalizers. Undersea link transmission is separately adjustable for four of the five sectors using these equalizers (discussed in Section IV); terminal adjustments affect the entire link.

II. THE TRANSMISSION LINK

The system is designed to provide at least 4000 three-kHz channels (from supergroup to supergroup) over ocean distances of up to 4000 nmi. Associated with the undersea single-cable link are two-wire to four-wire terminals located at opposite ends of the link[5] (see Fig. 1). The two terminals are defined "A" and "B" terminals, respectively. At line (cable) frequency, the A terminal transmits in the low band or A-to-B direction, 0.8 to 13.9 MHz, and receives in the high band or B-to-A direction, 16.5 to 30.0 MHz; the B terminal is complementary. A 31.62-MHz conversion frequency is used to translate the high-band baseband, 1.6 to 15.1 MHz, to line frequency at the B terminal and re-establish the baseband at the A terminal. The low-band baseband and line frequencies are identical. These frequency ranges individually and collectively are termed wideband.

Each terminal is composed of separate transmit and receive sections that are used to provide the four-wire supergroup connection to the domestic network external to the terminal. Towards the undersea link, transmit and receive signal paths are combined in a directional filter furnishing the two-wire match with that link. To achieve reliability, major parts of the terminal are duplicated; this feature increased the amount of data-taking and record-keeping needed for commissioning.

For commissioning, the terminal-to-terminal link can be thought of as being made up of three nested links as shown in Fig. 1:

(*i*) Wideband-to-wideband link (wideband link).*
(*ii*) Hypergroup-to-hypergroup link (hypergroup link).†

* The undersea link is part of the wideband link.
† A hypergroup is an ordered frequency-contiguous set of supergroups (see Ref. 5).

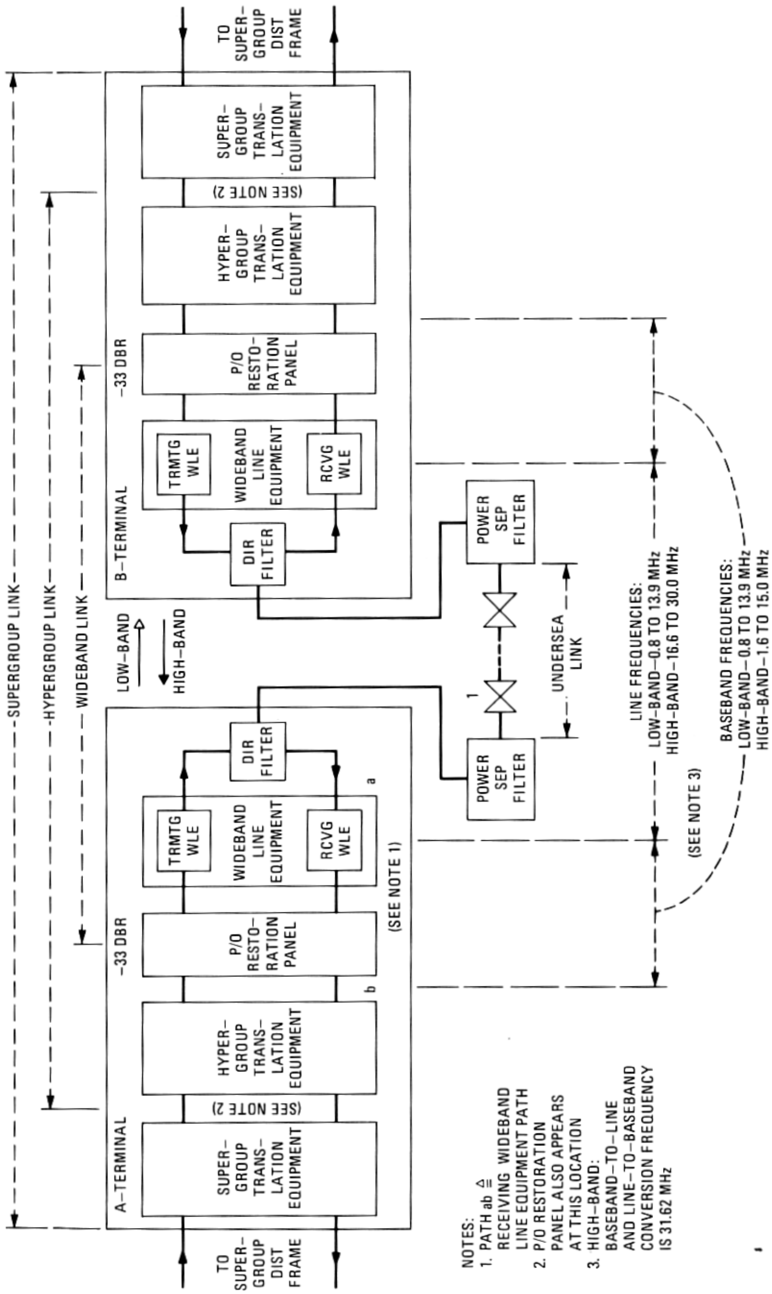

Fig. 1—SG undersea cable system.

(*iii*) Supergroup-to-supergroup link (supergroup link).

Following any necessary adjustments in the undersea link using the shore-controlled equalizers, measurements and adjustments proceed from the wideband to hypergroup to supergroup links.

The wideband/hypergroup interface is the restoration panel.* This interface is a −33 dBr† nominal flat-level point, for both transmit and receive. Transmission measurements between restoration panels in the two terminals define the misalignment of the wideband link which is due primarily to the long undersea section.

III. COMMISSIONING TEST PROGRAM

Development of the commissioning test program is a process that requires data and other information from virtually all areas of cable system development such as repeaters and equalizers,[4] terminals,[5] cable,[6] and power separation filter.[7] Use of specialized test equipment developed for the SG system, such as the cable laying test set, the data translator, and the repeater monitoring set, is integrated into the test program[1] as is the use of a modern table-top computer system.

The commissioning test program is divided into four categories of tests. The four groups of tests are carried out sequentially, each succeeding category building more or less upon the results of its predecessors:

(*i*) Undersea link tests—between cable laying operations.
(*ii*) Shore preparation tests—prior to final splice.
(*iii*) Line-up tests—after final splice.
(*iv*) Reference and special tests—follows link alignment.

3.1 Objectives

Even though the four groups of commissioning tests are done sequentially, it is more illuminating to consider the line-up tests, (*iii*), as being central to commissioning. Most preceding tests, (*i*) and (*ii*), are preparatory to line-up. Most subsequent tests, (*iv*), are designed to provide information that can be used to maintain the lined-up link status or confirm the engineering design of the system. Equalization, optimization of the signal-to-noise ratio (s/n) over each baseband, and terminal adjustments (including pilots) are the major objectives of the line-up procedures.

Transmission data from the line-up tests, however, cannot be referenced in level unless various transmission path gains (or losses) of the terminal, the power separation filter, and the shore section‡ are measured

* The restoration panel provides a manual patching arrangement used to accomplish alternative traffic routing in the event of an undersea transmission failure.
† dBr is equivalent to dB TLP (TLP is transmission level point).
‡ The shore section is the cable between the terminal and the repeater closest to the terminal.

or computed beforehand. For example, the transmission gain of path *ab,* Fig. 1, is measured.

Prior to the shore preparation tests, undersea system tests are made to determine (or estimate) performance parameters such as warm-up time and cable aging.* Figure 2 shows the TAT-6 warm-up characteristic at high-band supervisory tone frequencies (approximately 27.7 MHz) after power turn-up. Most of the gain change occurs over the two continental shelves and takes place within about 10 hours. The change is due largely to internal warm-up of temperature-controlled repeaters.[4] Obviously, it is important that equalization be based on nonchanging data taken after this 10-hour warm-up period.

After the line-up tests are completed, reference and special tests are performed. The objective of the reference tests is to obtain for future comparison initial supervisory tone, pilot, and transmission measurements (made at discrete frequencies between supergroups). Identical measurements can be made in the future without service interruption, thereby providing an excellent way to monitor changes in undersea link transmission.

The objective of the special tests is to obtain by direct measurement such engineering parameters as change in system gain with line current, differential gain and phase, phase jitter, and impulse noise count distribution, to name a few. Figure 3 shows the measured TAT-6 high-band

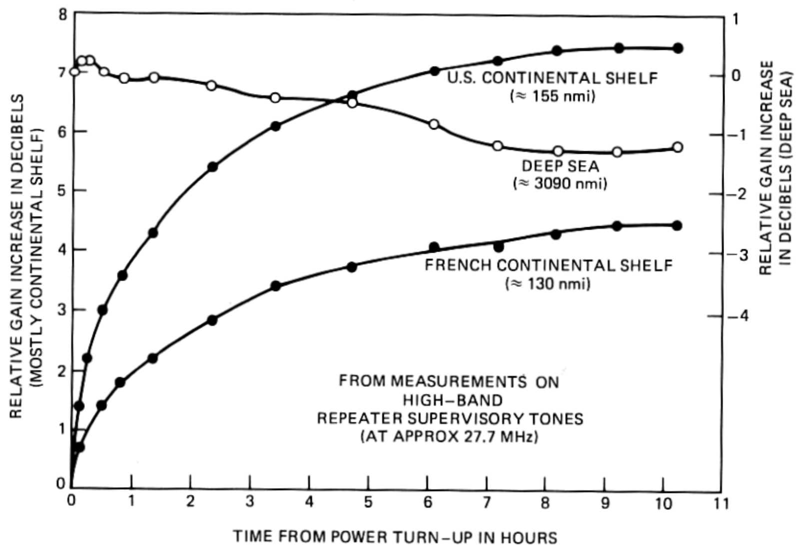

Fig. 2—TAT-6 high-band warm-up characteristic following power turn-up from cold start.

* Warm-up time is the relatively short-term interval required to reach transmission stabilization following power turn-up from a cold start. Cable aging is the long-term cable transmission change with time (Ref. 8).

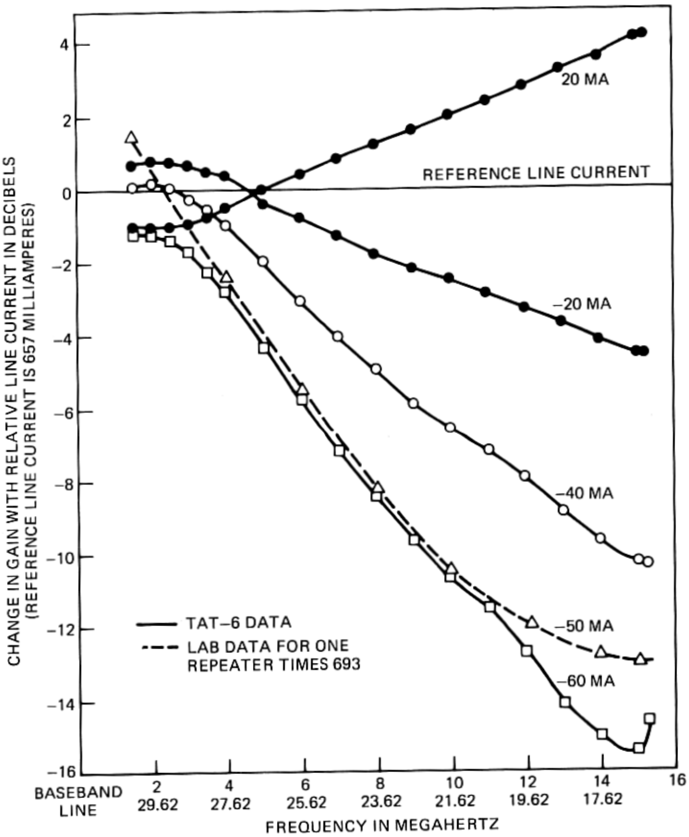

Fig. 3—TAT-6 high-band change in gain with line current.

change in gain as line current is stepped from the nominal 657 milliamperes. Measured gain-change data correlated well with laboratory data on a single repeater scaled by 693 (the number of repeaters in TAT-6). In the event of a shunt fault in the undersea link, there is always the possibility that changes in line current, along with other adjustments, could be used to modify undersea misalignment so that some service could continue until repair was possible. The other engineering parameters listed above are discussed in Section VI.

3.2 Methodology

The lengthy commissioning test program must be grounded in well-defined procedures no more complicated than absolutely necessary, making use of:

(*i*) Standard data forms.
(*ii*) Standard definitions.
(*iii*) Standard list of test frequencies.

Considerable effort was put into developing individual, but standardized, data forms for the various commissioning tests. The forms, in general, represent a method of entering data, and intermediate and final results as a function of frequency. Short equations are provided on the forms, as necessary, to describe how the measured data should be handled to compute an intermediate or final result. These equations can be used as a computer program instruction for keyboard entry into the table-top computer system mentioned previously. A general-purpose program called UTILITY was written to implement this capability. In summary, the computer system served several purposes. It provided:

(*i*) Speed of data manipulation and computation.
(*ii*) Data storage.
(*iii*) Plotting.
(*iv*) Analysis of on-site tests not specifically listed in the test program.
(*v*) Backup, since the computer can be used to compute results based on data from either station.
(*vi*) Supergroup equalizer design (Section 4.4).

Finally, attention was paid to historical and practical ways of defining submarine cable link transmission subpaths to optimize the testing process. Commissioning test frequencies covering the wideband portion of the SG system were chosen to be compatible with the use of the cable laying test set.[1] Defined transmission subpaths and the testing frequencies were integrated into the standardized test forms.

IV. EQUALIZATION

4.1 The equalization process

During installation of the undersea link, residual misalignment is substantially compensated for at the end of laying each ocean block using the associated ocean-block equalizer (OBE).[4] A buildup of misalignment unequalizable in the OBEs invariably occurs, accumulating along the length of the undersea link. This end-to-end residual misalignment is compensated for (to the extent possible) in two ways:

(*i*) By adjustment of undersea link levels on a sector basis using the shore-controlled equalizers.
(*ii*) By terminal equalization adjustments.

4.2 Undersea link adjustment

Four shore-controlled equalizers (SCE),* which divided the undersea link into five sectors, were deployed to compensate for transmission changes due to cable aging[8] over the life of TAT-6 (see Section I). How-

* The shore-controlled equalizers are controllable from the Green Hill Station, with SCE 1 being closest to that station.

ever, sufficient aging (added loss) had occurred over the five-month installation interval to justify a reoptimization of SCE settings following the final splice.

The average transmission level* of each of the four sectors beyond SCE 1 was adjusted to the extent possible to the average level of Sector 1. Since only broadband equalizer shapes are available in the SCEs, the selected settings are a compromise. In the low band only SCE 1 needed readjustment; in the high band, SCE 1, SCE 2, and SCE 3 were reset. Figures 4a and 4b show undersea link levels versus distance at two typical frequencies, 19 and 26 MHz, before and after SCE adjustment.

4.3 Terminal equalization—wideband

4.3.1 The plan

The terminal wideband equalization plan is illustrated in Fig. 5. Equalizer networks are discussed in more detail in Ref. 5. For the ideal situation (no equalization required), *line buildout* (LBO) *networks* are used to build out shore section loss to 3/4 of a cable section (3.83 nmi†) to conform to SG system design. In addition, the transmit combination of *shore section,* LBO *networks, pre-emphasis network,* and *path equalizer network* is designed to shape the flat-level signal coming from the inland network to a computed characteristic which provides optimum s/n in the undersea link. The receive part of the terminal at the other end of the undersea link is complementary, restoring the shaped signal to a flat level for transmission to the inland network.

In the real world, however, remaining misalignment, principally in the undersea link, will require terminal equalization. Additional transmit terminal signal shaping will also be needed to optimize s/n in the undersea link, since most levels end up being nonideal. Terminal equalization is carried out in three phases:

(*i*) Wideband equalization, transmit end only (before optimization of wideband s/n).

(*ii*) Wideband equalization, receive end only (after optimization of wideband s/n).

(*iii*) Supergroup equalization, where required.

Transmit-end equalization (before s/n optimization) is accomplished using *residual equalizer networks, adjustable corrector networks,* and *adjustable bump equalizer networks.* Normally, most of the transmit-

* The average level of an undersea sector is the average of the level averages of individual blocks in that sector. (The undersea link levels were determined on a broadband basis during cable laying. Subsequently, level can only be measured at supervisory tone frequencies, essentially one frequency in each band. This latter level information is interpolated to other frequencies by fitting an equation of the form $a\sqrt{f} + bf$ to the data.)

† The shore section is between 1/4 and 3/4 of the nominal repeater spacing (5.1 nmi of 1.7-inch cable).

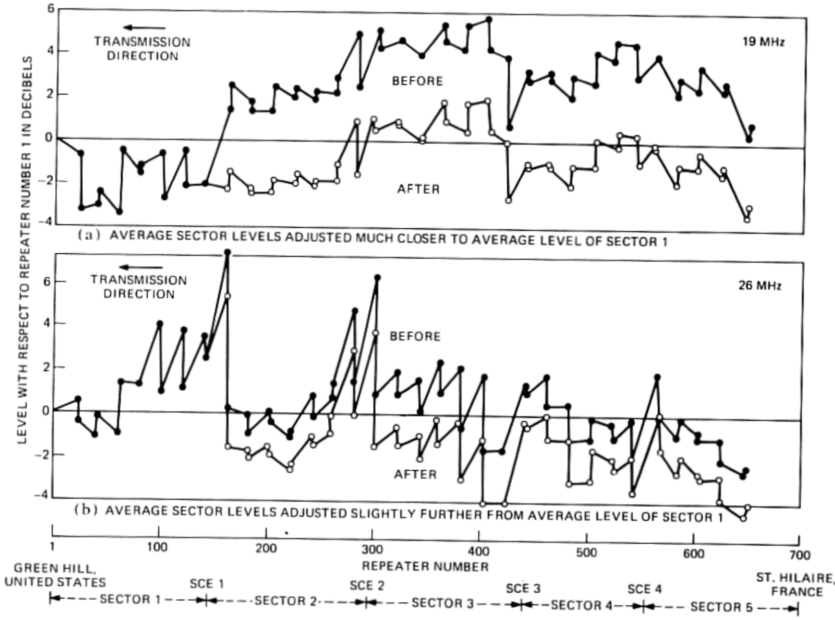

Fig. 4—TAT-6 lengthwise level distribution at 19 and 26 MHz before and after SCE adjustment.

end misalignment (and receive-end misalignment also) is equalized with the residual equalizer networks.

The residual equalizer networks are of the bridged-T type, custom-designed during commissioning using a previously written computer program. For TAT-6, a data link from Green Hill to the Bell Laboratories computer at Holmdel was utilized. Residual networks are built from a stock of high-quality components at the terminal sites and tested there for circuit integrity and transmission performance before being installed in the terminal.

Adjustable corrector equalizer networks are wideband networks of four types, each front-panel-adjustable around a nominal setting:

(*i*) Attenuator.
(*ii*) Square-root-of-frequency.
(*iii*) Slope.
(*iv*) Curvature.

Following s/n optimization (details are discussed in Section V), the remaining misalignment (including level changes introduced by s/n optimization) is equalized in the receive part of the terminal. Networks identical to those mentioned above are used to implement receive-end equalization. Figures 6a and 6b show that the remaining misalignment in the low and high bands, respectively, after terminal equalization is

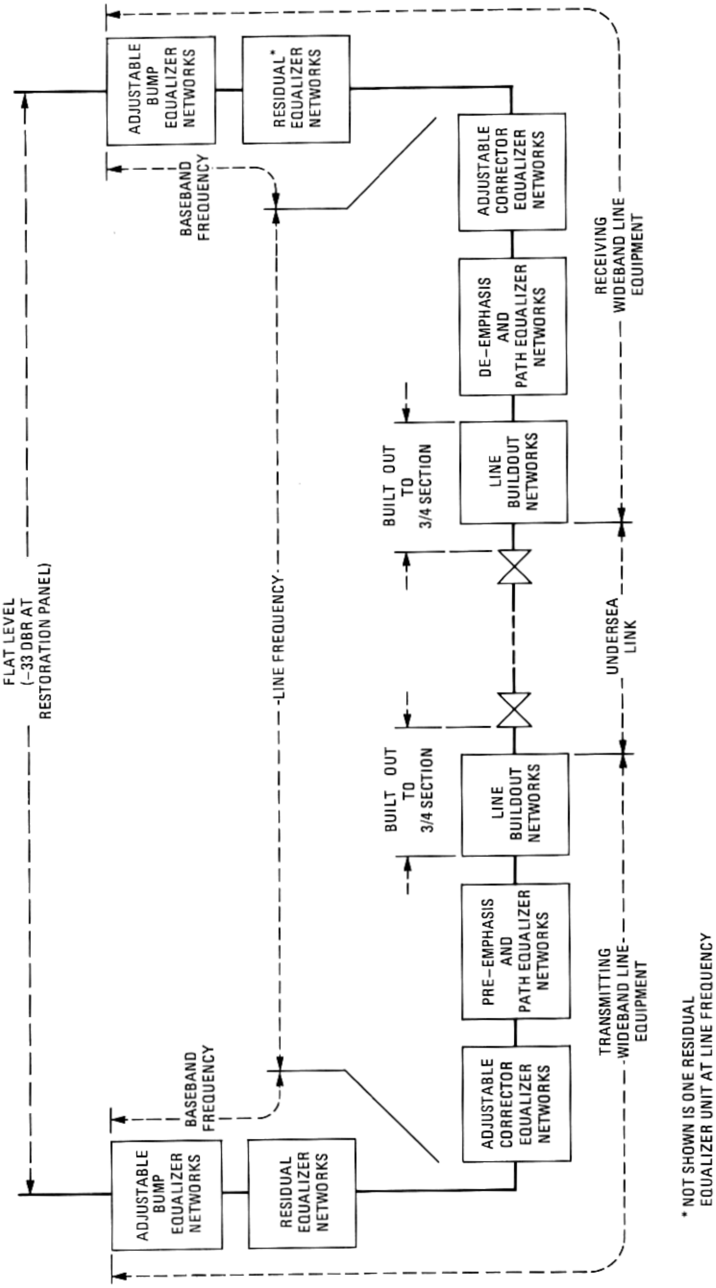

Fig. 5—Terminal wideband equalization plan.

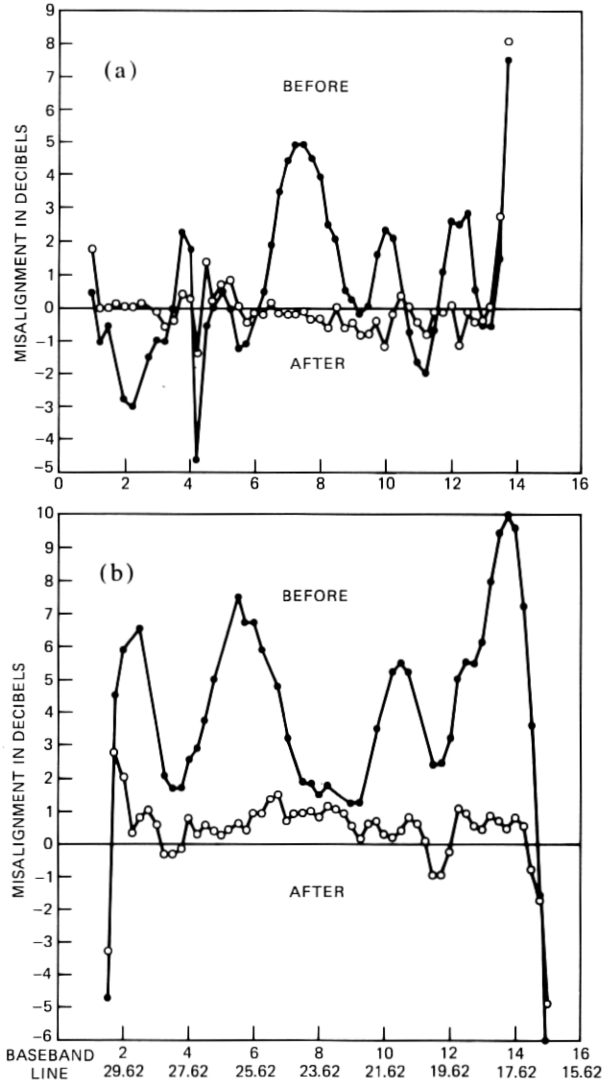

Fig. 6—TAT-6 misalignment before and after terminal equalization. (a) Low band. (b) High band.

for the most part within ±1 dB, except near the band edges. Band-edge misalignment is more conveniently equalized at the supergroup level (discussed in Section 4.4).

4.3.2 Transmit-end equalization

Normally, one-half of the wideband undersea misalignment is equa-

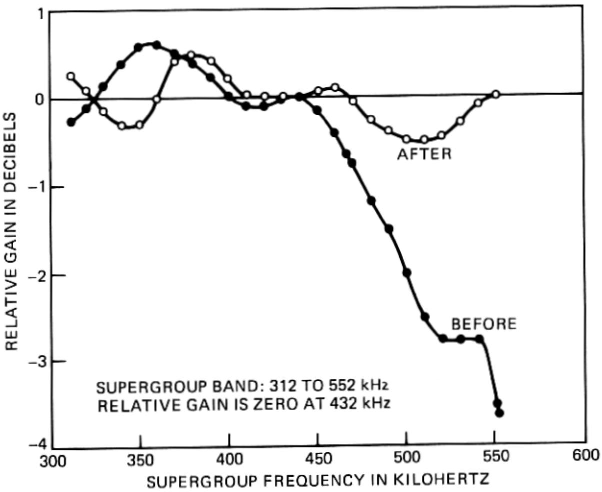

Fig. 7—TAT-6 low-band hypergroup 1, supergroup 4 response before and after supergroup equalization.

lized at the transmit end of the link. Assuming uniform misalignment with distance, this division of equalization should minimize the noise penalty due to misalignment. On TAT-6, however, misalignment is not uniform with distance. Because wideband average level versus frequency had been computed in preparation for the SCE adjustment procedure, it seemed more appropriate to decide the extent of transmit-end equalization by comparing the following three parameters:

(*i*) Average level.

(*ii*) End-to-end misalignment.

(*iii*) Estimated obtainable equalization from residual equalizers.

The final transmit-end equalization decision is obviously a compromise based on computations and experience. This equalization decision is too detailed to be discussed here.

4.4 Terminal equalization—supergroup

Supergroups are equalized individually only if the magnitude of the differences in transmission between the center of the band, 432 kHz, and the rest of the band, 312 to 552 kHz, exceeds 1.5 dB.[9] Supergroup equalization, where required, is carried out after final wideband equalization.

Supergroup equalization is accomplished in the *receive supergroup equalization unit.* For the fifty-some supergroups in each band of TAT-6, at most four band-edge supergroups in each band required equalization, plus two in-band supergroups in the low band. Figure 7 shows how the relative low-band misalignment in hypergroup 1, supergroup 4 (812 to

1052 kHz at line frequency) was equalized at supergroup frequency. An approximate +0.6 to −3.6 dB misalignment range was equalized to within ±0.5 dB.

V. OPTIMIZATION OF WIDEBAND SIGNAL-TO-NOISE RATIO

Optimization of the wideband s/n in the SG system is accomplished by changing one or more of the adjustable corrector or bump equalizer networks in the transmit terminal. This changing reshapes the broadband undersea transmission levels (additional signal shaping). The adjustment process is semi-empirical in that it determines, mostly by trial and error, whether or not a particular equalizer adjustment improves or degrades performance. The test signal load is broadband Gaussian white noise. (Test signal power is varied step-wise to define the maximum s/n at the frequency of test.) The process is actually one of obtaining undersea link levels versus wideband frequency for which the difference between the test signal noise load and the power sum of thermal noise and intermodulation distortion in narrowband test slots (the noise power ratio [NPR] in decibels) is a maximum.

For the TAT-6 link, NPR is measured in several narrow-band test slots in the low and high bands using a white noise test set. The wideband noise load, which is inserted at the transmit −33 dBr flat-level point on the restoration panel, is adjusted to be equivalent to a load of 4000 channels with an average channel power of −13 dBm0. A relatively narrow bandstop filter (part of the test set) is introduced to clear a slot in the transmitted noise load. The noise power which appears at the receive terminal restoration panel is measured at this slot frequency in an even narrower band (using test set filtering), both without and with the bandstop filter. The ratio of these two measurements is the NPR.

The final NPR data from the TAT-6 commissioning is given in Table I, including the equivalent 3-kHz channel noise in dBrnC0. Because of an unforeseen problem which resulted in higher-than-expected third-order intermodulation products, the desired NPR was not attained in

Table I — TAT-6 optimized noise power ratio and equivalent 3-kHz channel noise power

Low Band			High Band		
Freq (MHz)	Noise Pwr Ratio (dB)	3-kHz Ch Noise Pwr (dBrnC0)	Freq (MHz)	Noise Pwr Ratio (dB)	3-kHz Ch Noise Pwr (dBrnC0)
1.248	42.8	31.7	18.142	37.6	36.9
2.438	42.8	31.7	21.494	36.0	38.5
5.340	44.0	30.5	22.948	36.0	38.5
8.672	41.0	33.5	26.280	30.1	44.4
10.126	41.7	32.8	26.970	29.5	45.0
13.478	39.8	34.7	29.182	28.6	45.9

Table II — TAT-6 differential gain in undersea link

Low Band					High Band				
Freq (MHz)	Differential Gain in dB, dB Above Design Load: 2	4	6	8	Freq (MHz)	Differential Gain in dB, dB Above Design Load: 2	4	6	8
1.248	−0.1	−0.2	−0.3	−0.4	18.142	−0.1	−0.2	−0.3	−0.5
2.438	−0.05	−0.2	−0.15	−0.2	20.046	−0.1	−0.3	−0.4	−0.6
3.886	−0.05	−0.15	−0.3	−0.45	21.494	−0.1	−0.2	−0.5	−0.8
5.340	−0.1	−0.2	−0.4	−0.65	22.948	−0.1	−0.3	−0.5	−0.7
8.672	−0.2	−0.4	−0.8	−1.2	26.280	−0.1	−0.4	−0.7	−1.1
10.126	−0.25	−0.65	−1.15	−1.9	26.970	−0.2	−0.5	−0.9	−1.3
11.574	−0.1	−0.2	−0.4	−0.8	29.182	−0.1	−0.3	−0.5	−0.8
13.478	0.0	0.1	0.1	0.1					

Design load is 23 dBm0 per band.

the upper part of the high band.[4,8] In the low band, the attained NPR performance ranged from 3.8 to 8.0 dB better than the objective.

VI. SELECTED PERFORMANCE DATA—TAT-6

6.1 Differential gain—undersea link

Table II gives the differential gain of the undersea link as a function of relative signal load. For this test, a −20 dBm0 tone was inserted in a cleared slot in a broadband white noise test signal load. This test load was varied from 26 dBm0 (the design load) to 8 dB higher, with the difference between the received power of the −20 dBm0 tone at test loading and at design load being differential gain. The data show compression at all frequencies except near the top of the low band, where there is 0.1 dB of expansion. Maximum compression occurs near 10 MHz in the low band and 27 MHz in the high band. Below design load, it was determined that expansion (with respect to design load) was negligible.

6.2 Differential phase—undersea link

Figure 8 shows the differential phase of the undersea link in the high band as a function of signal load relative to high-band design load. A novel method making use of the repeater monitoring set (RMS) was used to measure differential phase. (The RMS is described in Ref. 1.) First, using standard techniques, a composite test signal was sent from the transmit end of the link:

(*i*) High band noise load amplitude modulated at 5 Hz to a depth of approximately 90 percent.

(*ii*) A tone of −20 dBm0 inserted in a cleared slot of the white noise load (the tone was not modulated).

The peak power (crest of modulation) of the modulated load is set at the desired test loading in the high band; the minimum power (valley of modulation) is approximately equivalent to no load. Second, at the re-

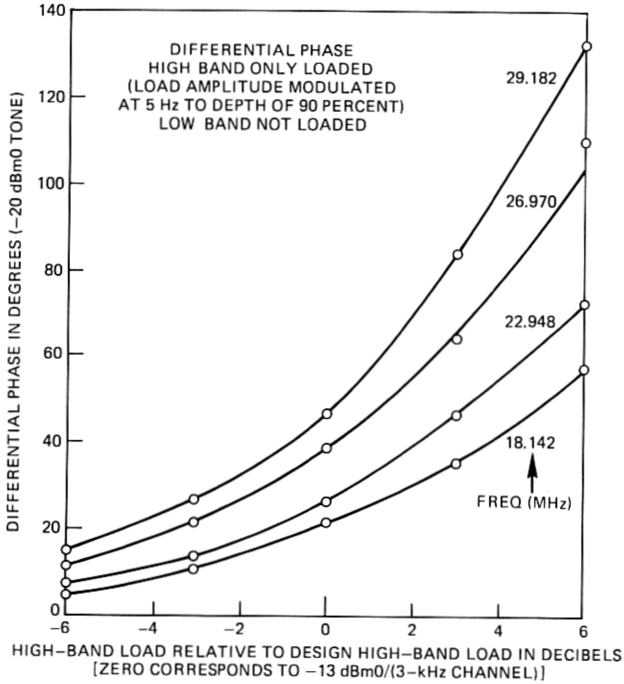

Fig. 8—TAT-6 high-band differential phase in undersea link.

ceive end of the link the composite signal is connected to the RMS. The transmit noise load is then reduced to essentially zero using an attenuator, and the RMS is phase-locked to the tone. Following this operation, the 50-Hz-wide, 100-kHz phase-locked loop of the RMS is opened. The transmit noise load is then reapplied.

The relative positions of the RMS reference 100-kHz signal and the phase-locked-loop 100-kHz error signal are monitored on an oscilloscope. Each of these signals is a square wave, and any movement of the error signal is easily calibrated in degrees. The difference between the position of the error signal at test loading power (crest of modulation) and no load (valley of modulation) is the differential phase of the undersea link. Drifting in the opened phase-locked loop is minimal, as can be observed on the oscilloscope by comparing the 100-kHz reference signal with the error signal at no load.

Maximum differential phase occurs at the top end of the high band, being 47 degrees at high-band design load and 133 degrees at 6 dB above this design load. The 133-degree figure has some relevance because undersea link highband levels will be increased from commissioning levels when the effect of third-order intermodulation products is reduced by terminal cancellation arrangements.[4,8]

Table III — TAT-6 measured phase jitter

Low Band			High Band		
Approximate Line Freq in MHz	Hyper-group—Supergroup	Phase Jitter in Degrees Peak-to-Peak	Approximate Line Freq in MHz	Hyper-group—Supergroup	Phase Jitter in Degrees Peak-to-Peak
1.0	1–4	0.8	16.9	6–11	1.2
4.2	2–13	0.8	19.8	5–12	1.2
7.5	3–9	0.9	22.2	4–12	1.2
10.2	4–9	1.1	24.9	3–13	1.4
13.5	5–5	1.1	26.7	2–10	2.4
			29.4	1–9	3.1

Measurements made in channel 1, group 1 of listed supergroup.

6.3 Phase jitter

Table III gives the measured phase jitter of the TAT-6 link. Phase jitter was measured in channel 1 of group 1 in a sufficient number of supergroups to characterize the low and high bands. Phase jitter is 0.8 degree peak-to-peak at the bottom of the low band and increases with frequency across the low- and high-band spectrum to approximately 3.1 degrees peak-to-peak.*

6.4 Impulse noise

Impulse noise power peaks exceeding approximately 12, 14, 16, and 18 dB above average (continuous) noise power were counted over 15-minute intervals for several supergroups to sample the low and high bands. Measurements were made at the channel level and supergroup level using different test instruments. The impulse noise count data were reduced to the fraction of time that signal peaks exceed peak amplitude threshold. Figure 9 shows these data for the low band at channel level.

Essentially, Fig. 9 confirms that the number of impulse counts measured at different peak amplitude thresholds follows a Gaussian distribution typical of thermal noise. The important observation from Fig. 9 is that, as long as the reduced data curves parallel that of thermal noise, the source of the impulses is indistinguishable from system noise and not due to non-Gaussian processes such as corona. The fact that the curves do not lie on the thermal noise curve is caused by several factors, the largest being (*iii*), which fortunately causes only a horizontal offset:

(*i*) Error in measurement.
(*ii*) Calibration of test instrument.

* The phase jitter data are believed to be pessimistic because the measurements were influenced by channel noise, particularly at the higher line frequencies.

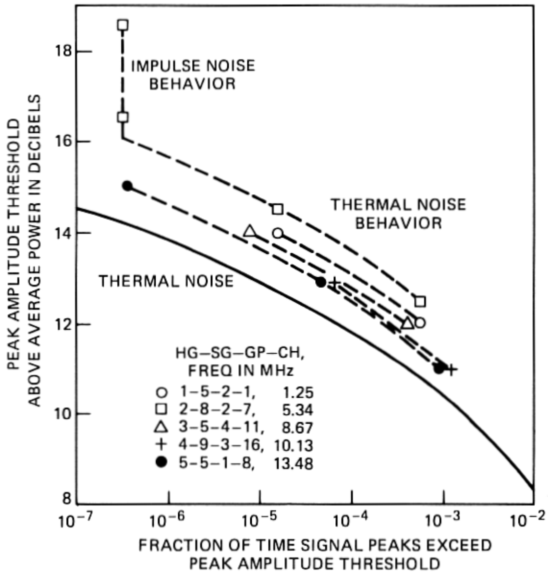

Fig. 9—TAT-6 low-band distribution of impulse noise count data.

(*iii*) Estimate of available number of time slots for which impulses could be counted.

The one indication of an impulse, a count exceeding two different threshold levels, may have been due to inadvertent terminal switching (probably caused by a carrier supply phase problem evident during the time that this test was made).

VII. COMPILATION OF COMMISSIONING DATA

Commissioning data are compiled in three areas, basically:

(*i*) Data books.

(*ii*) Punched paper tape.

(*iii*) Magnetic cassette tape.

The more important data from both stations are compiled at each station; therefore, duplication of data records is achieved. A separate data book is maintained for each of the four categories of tests mentioned in Section III. Each of the data books is sectionalized so that data from specific tests may be easily entered or retrieved.

The commissioning tests are generally run in sequence as directed in the test instructions, each succeeding test relying more or less upon the results of one or more previous tests. As the tests proceed day after day, the books are completed section by section, forming a permanent record of measured and computed data. Supplementing this record are selected

TTY punched tapes of measured data and magnetic cassette tapes. The printed page output from the computer system printer and graphs from the plotter are also entered into the data books where required. The punched tapes and magnetic cassette tapes are especially useful for comparison of data from identical tests separated in time, since these tapes provide an easy way to enter data into the computer.

Regarding residual equalizer design information, a complete record is kept in a separate book at each station:

(*i*) Identifying nomenclature.

(*ii*) Schematic (with element values).

(*iii*) Design and measured transmission.

(*iv*) Notes.

In addition to its record function, this book is used for maintenance purposes

VIII. ACKNOWLEDGMENTS

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