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SG Undersea Cable System:

Terminal Transmission Equipment

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Terminal transmission equipment has been developed for the SG cable system that, compared to similar equipment for land analog facilities, makes more efficient use of the transmitted bandwidth and provides superior continuity of service. Although economy of development effort dictated the use of existing equipment and conventional design techniques wherever possible, many new designs were required to achieve the desired features. Means for protecting the undersea repeaters from gross signal overload and a carrier generating scheme for hypergroup and wideband-line frequency-translation equipment are examples of new designs that proved particularly challenging. Duplication of higher-level multiplex equipment coupled with automatic changeover switching is the means used to obtain the desired service continuity. In this regard, much care was required to limit amplitude and phase differences between duplicate transmission paths to insure "hitless" maintenance changeover switching. Other features of the terminal include an on-site equalizer design and construction capability at the wideband line and supergroup levels, a separate 3-channel order-wire facility, individual supergroup signal limiters, and the ability to operate with 3-kHz as well as 4-kHz/spaced message channels. Mechanical design follows the current French standard for such equipment. CIT-Alcatel in France carried out the detailed design.

I. INTRODUCTION

The terminal transmission equipment (TTE) for the SG Undersea Cable System provides the vital interface between the inland telephone network and the undersea link. Interconnection to the domestic network is at the basic supergroup level; thus, the TTE consists of *frequency-di-*

vision multiplex and *wideband line equipment* (including a *directional filter* that provides a physical 4-wire to equivalent 4-wire conversion) (Fig. 1). The transmitting multiplex serves to frequency-translate fifty-plus basic supergroups, combining them to form what we call the "baseband." The receiving multiplex performs the inverse operation.

The wideband line equipment provides its customary functions of signal preemphasis and deemphasis, equalization, level adjustment, and the like. Following the conventional equivalent 4-wire undersea cable terminology, the terminal stations at opposite ends of the system are designated A and B. Low-band transmission in the A-to-B direction is at baseband frequencies directly. In the opposite direction, the high band is formed by one further stage of frequency translation of the baseband, which takes place in the wideband line equipment.

The principal system parameters influencing TTE design are summarized below:

(*i*) Nominal frequency band (corresponding to 4000 3-kHz voice channels):
Low band 800 to 13,300 kHz,
High band 16,700 to 29,300 kHz.

(*ii*) Possible extension to:
Low band 500 to 13,900 kHz,
High band 16,100 to 29,500* kHz.

(*iii*) Operation with either 3- or 4-kHz voice channels, or a combination of the two.

(*iv*) Design load per channel: −13 dBm0.

(*v*) Terminal noise contribution (both stations): No more than 250 pW0p (24.5 dBrnc0) in the worst channel, with the system fully loaded and with all transmission levels at their nominal values.

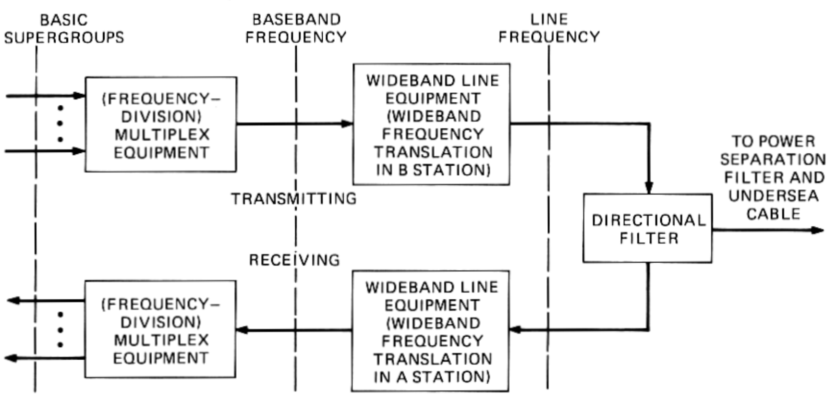

Fig. 1—Summary diagram of the SG terminal transmission equipment.

* Experience gained with the first SG system installation, TAT-6, has led to an upward translation in the extended high band by about 500 kHz (Fig. 4b).

Of course, 3-kHz spaced channel operation is common on long-haul undersea cable routes. It has also been traditional that undersea system design loads be higher than those for similar inland carrier systems for, among other reasons, the potential application to them of speech concentrators such as TASI or CELTIC.

The reason for nominal and extended frequency bands is quite simple. During development, it was not possible for us to be sure of the exact transmission band that would ultimately be achieved. This depends on the degree to which repeater gain can be trimmed to match cable loss at the band edges, and on the degree of success of mop-up equalization in the ocean-block equalizers.[1] We chose to design for the extended bands to encompass the largest bandwidth that optimistically could be achieved, so that the TTE would never restrict channel capacity of the overall system.

Conceptually, we were guided in the design of the TTE for the SG system by two main principles:

(*i*) The available frequency band should be used to the fullest.

(*ii*) The failure of an active device should not cause a loss of service of more than the equivalent of one supergroup.

In addition to the capability of 3-kHz operation, the first principle resulted in a unique multiplex frequency allocation that, in turn, required development of new modulation equipment. The second principle, one of reliability, we achieved largely through automatic protection switching between duplicated equipments.

II. FREQUENCY ALLOCATION

The frequency plan for the SG system was chosen primarily to achieve efficient use of the available transmission band and secondarily to minimize the degree to which standard multiplex equipment and techniques of other undersea and inland systems would have to be modified. For example, the ease with which new carrier frequencies could be produced was a factor in our plans. From the outset, our desire to achieve a high traffic-band efficiency factor (defined as the ratio of the actual frequency spectrum devoted to traffic to the total transmission band) forced us to reject standard CCITT* or Bell System frequency plans developed for inland carrier systems of comparable or greater bandwidth than the SG baseband, e.g., 12- and 60-MHz CCITT international systems and the L4 and L5 systems.[2,3] The traffic-band efficiency factor for the 12- and 60-MHz terrestrial systems is 0.89 and 0.78, respectively, and

* The International Telegraph and Telephone Consultative Committee.

that of the basic Bell System mastergroup itself is only 0.87, whereas that for the SG plan is greater than 0.95.*

2.1 Baseband assignment

The SG baseband comprises six *hypergroups* (HG) numbered 1 through 6 in ascending frequency, as shown in Fig. 2. The term *hypergroup* is British Post Office (BPO) terminology that refers to an arbitrary number of supergroups† assembled in a contiguous frequency band. Hypergroup 1 is direct-formed by supergroup translating equipment (Fig. 3). Positions of the 14 supergroups are those of supergroups 3 through 16 of the standard CCITT 4-MHz system, or equivalently, those of the CCITT basic 15-supergroup assembly.[4–6] Hypergroups 2 to 6 each contain 10 supergroups and together occupy the band 4032 to 16,424 kHz. They are formed in two steps of frequency translation. First, a *basic hypergroup* is formed by supergroup translation (CCITT supergroups 4 through 13), and then by hypergroup translation (Figs. 3 and 2, respectively).

Note that all the carrier frequencies are odd multiples of 124 kHz, a desirable feature from the point of view of carrier generation. Thus, the conventional 8-kHz gap between supergroups within hypergroups, which permits through-supergroup connection, is preserved between hypergroups as well. One exception is the HG 1–HG 2 gap of 4 kHz, an offset

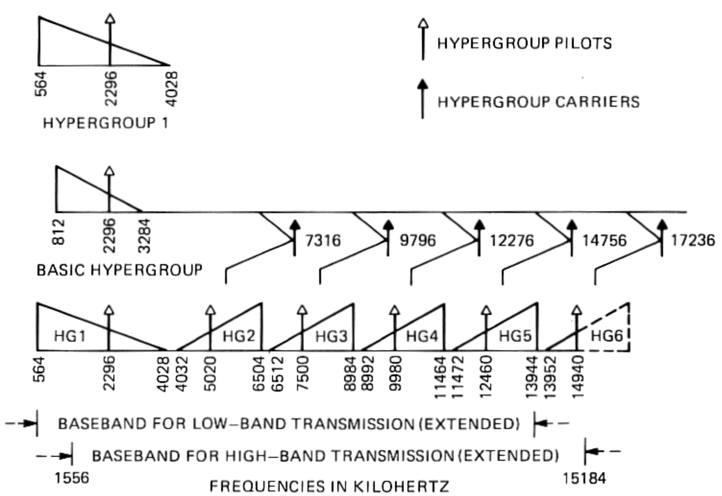

Fig. 2—Frequency allocation—SG basebands.

* At present, the line-to-terminal cost ratio of terrestrial carrier systems relative to their undersea cousins naturally leads to frequency allocations that, while not optimum in traffic-band efficiency, nevertheless achieve an overall efficiency due to less severe terminal filtering needs which facilitate pilot monitoring, automatic gain regulation, and circuit distribution (e.g., blocking and reinserting of large bundles of voice circuits).

† Each supergroup corresponds to 60 4-kHz or 80 3-kHz voice channels.

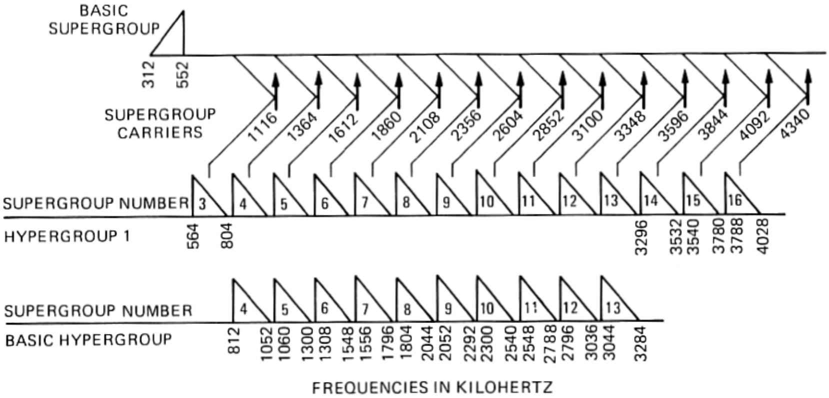

Fig. 3—Frequency allocation—basic hypergroup (and hypergroup 1).

needed to retain the 124-kHz integral multiple characteristic of hypergroup carriers. A secondary advantage of this choice is that all hypergroup carriers fall between voice channels for either 3- or 4-kHz spacing, thereby easing carrier leak requirements.

Several comments are in order concerning the makeup of hypergroups. First, we did not retain supergroup 3 in the basic hypergroup primarily to ease design complexity of, and reduce group-delay distortion caused by, the hypergroup modulator band filter, which must reject the carrier and upper sideband while passing the lower sideband. Next, we included supergroups 14 to 16 in HG 1 (but not in the basic hypergroup) to ease design of the HG 2 modulator band filter, which must reject the basic hypergroup band (because of leakage across the modulator) in addition to carrier and upper sideband. Furthermore, our choice of a 10-supergroup basic hypergroup limits to five the number of new designs of hypergroup translation units.

Although we have spoken of the SG baseband, one can, in fact, distinguish two slightly different spectra as evidenced in Fig. 2. The low-band baseband is simply hypergroups 1 through 5, whereas the high-band baseband includes hypergroups 2 through 5 plus part of hypergroups 1 (supergroups 7 through 16) and 6 (supergroups 9 through 13). The latter allows sufficient separation between the wideband-translation carrier frequency of 31,620 kHz and the upper edge of the high band at line frequency so that design of the associated modulator band filter is easily realizable. Note that this carrier is also an odd multiple of 124 kHz.

In summary, we believe that the SG frequency allocation is a good compromise between the objectives of efficient use of bandwidth and minimum development of new frequency-translating and carrier-generating equipment.

2.2 Order-wire and supervisory-tone band assignment

The order-wire and repeater supervisory-tone band assignments[1] are shown in Figs. 4a and 4b, for the low and high bands, respectively. One can see that both assignments fall within those of the multiplex, so that particular channels in hypergroup 1, supergroup 16, i.e., (1, 16) and (4, 5) in the low band and (1, 16) in the high band, cannot be used for commercial traffic.

2.3 Pilot assignment

A *hypergroup pilot* is inserted at the input of each transmitting hypergroup at a frequency of 2296 kHz, midway between supergroup 9 and 10, to facilitate measurement. (Line-frequency assignment of these pilots is given in Figs. 4a and 4b.) Due to its near-central location within each

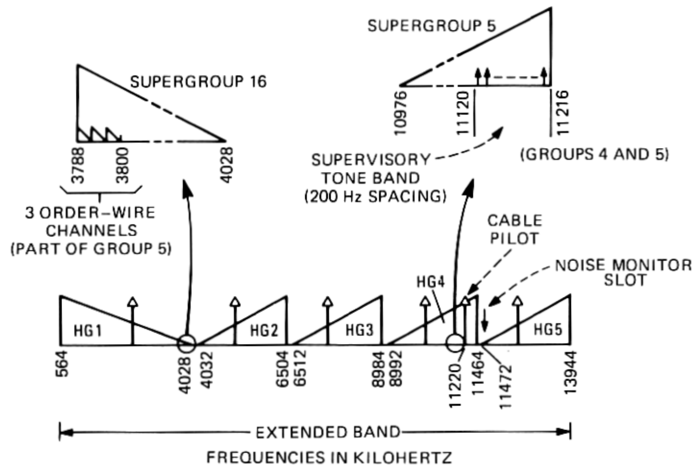

Fig. 4a—Frequency allocation—low band.

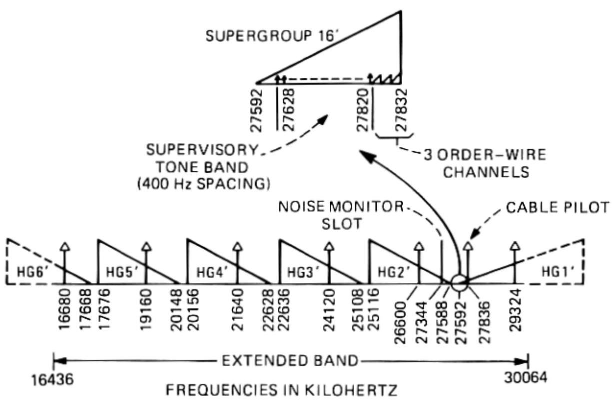

Fig. 4b—Frequency allocation—high band.

hypergroup, it should be representative of the overall transmission level of the hypergroup.

There are no separate assignment of *line* (or *system*) *pilots*, i.e., those which provide information about the behavior of the wideband link (wideband line plus undersea). Instead, the HG 2 and 5 pilots provide this function by being monitored at the input of the transmit and output of the receive wideband line equipment. This is illustrated in Fig. 5.

One additional pilot in each direction of transmission, the *cable pilot*, is inserted and measured as close as practical, from a transmission standpoint, to the undersea system to furnish information about the behavior of only this part of the wideband link. The cable-pilot frequency in the low and high bands was chosen to be near that of the supervisory tones and to fall between supergroups.

The power level of all pilots is −20 dBm0.

III. CONFIGURING THE TTE FOR RELIABLE OPERATION

3.1 Reliability criterion

As mentioned before, the layout of the TTE is such that failure of an active component will not involve loss of more than the equivalent of one supergroup of traffic (80 3-kHz or 60 4-kHz channels). The object of this section is to examine the ramifications of this principle on the configuration of the TTE; in particular, the extent of equipment duplication and automatic changeover switching.

3.2 Features common to transmit and receive

Generally speaking, the supergroup equipment itself (including supergroup signal limiters, modulators, and equalizers, all of which are discussed later) need not be duplicated to meet the above criterion. On the other hand, failure of a supergroup carrier would affect five or more supergroups. Thus, supergroup carrier generators are completely duplicated with automatic protection switching at the outputs for each in-

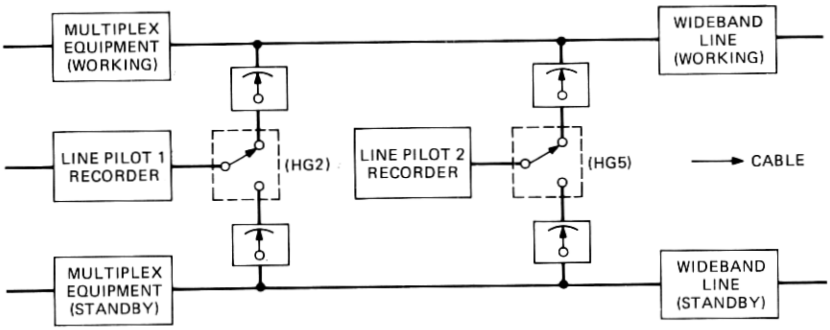

Fig. 5—Line-pilot monitoring (transmit and receive).

dividual carrier. Of course, duplicate sources of the master oscillator frequency of 124 kHz are required.

Referring to Fig. 6, we see that the transmission path between supergroup couplers* and the directional filter is duplicated. In the transmitting direction, this involves hypergroup translation and wideband line equipment. The same is true in the receiving direction but with the addition of hypergroup regulators. The duplicated paths in each direction are called *Path I* and *Path II.* At any one time, the particular paths that connect the directional filter to the supergroup equipment are referred to as *working* and the others as *standby.* If a working path fails, the two are interchanged.

Naturally, hypergroup and wideband translation carrier generators are duplicated, and are referred to as *generator* 1 and *generator* 2.† Connection to the translating equipment is not the same as to the supergroups, because hypergroup and wideband line equipment is itself duplicated and protected by automatic changeover switching. Duplicate generators for each hypergroup carrier can be connected to the transmission paths in the combinations shown in Table I by means of patch links.

The 2296-kHz hypergroup pilot supply is duplicated. Pilot supplies are connected to the transmission paths by means of patch links that allow combinations similar to those in Table I.

The directional filter unit (which includes the receiving path-splitting coupler) is passive but, because a failure here could affect the entire wideband path, we considered it prudent to provide a "built-in" spare which can be quickly interchanged manually for the working unit, albeit not without momentarily interrupting traffic.

3.3 Special transmitting features

Working and standby hypergroup pilots on the transmitting side are monitored at the output of the wideband line equipment just after the changeover switch but prior to the directional filter (Fig. 6). The changeover logic control recognizes pilot *failure* as a change in amplitude from nominal of between 2 and 3 dB. Failure of a working pilot initiates a path changeover provided there is not a concurrent standby pilot failure. Additionally, an alarm inhibit capability is provided on an individual hypergroup pilot basis which, if operated, removes that particular pilot from consideration by the changeover logic.

The cable pilot is introduced throuh a passive coupler after the transmit changeover switch but prior to the directional filter (Fig. 6),

* The couplers themselves are passive and therefore not duplicated.

† Roman numerals I and II are reserved for the duplicated transmission paths protected by automatic changeover switching. All other duplicated equipment is designated 1 and 2.

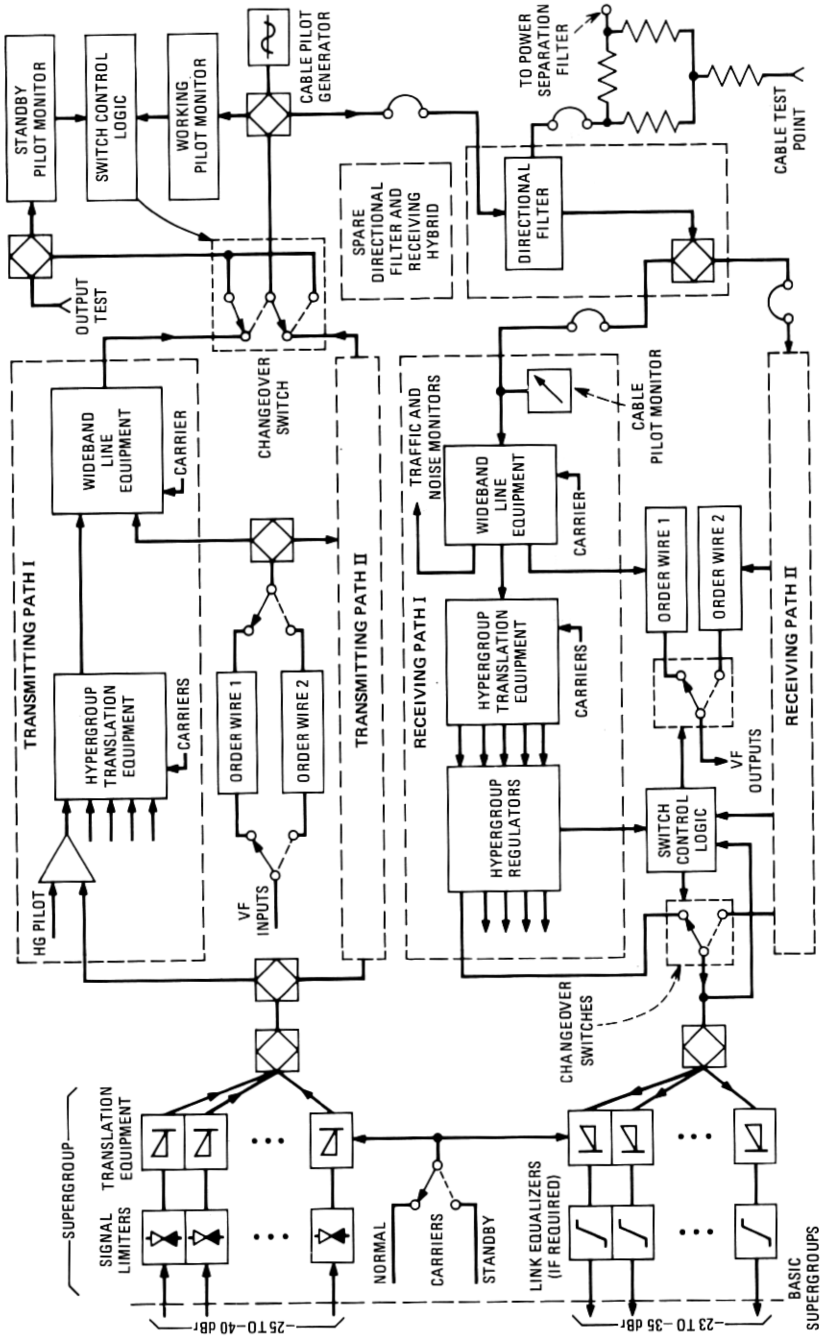

Fig. 6—Overall configuration of the SG terminal transmission equipment.

Table I

Combination No. 1 (normal operation)	Combination No. 2 (source and load paralleled)
Generator 1 → Path I Generator 2 → Path II	Generator 1 ⇉ Path I Generator 2 ⇉ Path II
Combination No. 3 (interchange of source)	**Combination No. 4 (two loads from single source)**
Generator 1 ↘ Path I Generator 2 ↗ Path II	Generator 1 → Path I Generator 2 ↘ Path II

thereby assuring that its level is independent of all adjustments in the transmitting paths.

3.4 Special receiving features

In the receiving terminal, the cable pilot is monitored just after the directional filter and path splitting coupler so that its level is independent of receiving path adjustments.

Although there is a receive changeover switch for each hypergroup, all are activated simultaneously by the receive path-changeover-logic-and-control unit when it detects a fault affecting even one hypergroup. There are minor advantages to individual hypergroup changeover switch operation, but we felt they are more than counterbalanced by the complexity of maintenance that would result if some working hypergroups were on Path I while others were on Path II.

Inputs to the receiving changeover-logic-and-control unit are from five sources:

- (*i*) and (*ii*) Hypergroup pilot level at the output of Paths I and II regulators.
- (*iii*) and (*iv*) Gains of Paths I and II regulators.
- (*v*) Working hypergroup pilot levels just beyond the changeover switches.

Switching occurs for either of the following conditions:

- (*i*) At a changeover switch output, the absolute difference between measured and nominal pilot level becomes greater than 1 dB, whereas at the standby path regulator output the corresponding difference is less than 1 dB.
- (*ii*) The difference in gain of corresponding Path I–Path II regulators is more than about 2½ dB, in which case the path whose regulator is providing the smaller correction becomes the working path.

Just as for the transmitting changeover switches, the receiving switches themselves are not duplicated, but pilot monitoring beyond the switches measures their performance as well. Individual pilot-alarm-inhibit capability is also provided.

3.5 *Final comment on TTE configuration*

The preceding description of TTE duplication and changeover switch operation brings to light the high degree of interdependence of multiplex and line terminal equipment. This is in contrast with most inland systems where multiplex and line terminals constitute separate families of equipment having little in common except impedance and transmission level at their interface. The intimate character of the association is underscored by the lack of separate line pilots in the SG wideband equipment.

IV. WIDEBAND LINE EQUIPMENT

The wideband line equipment (WLE) provides transmission between the multiplex and the terminal *power separation filter.*[7] Figure 7 is a simplified block diagram of the WLE. Aside from the conventional line functions of amplification, preemphasis, deemphasis, equalization, and the like, the SG WLE is designed to:

(*i*) Monitor performance of the undersea link.

(*ii*) Initiate changeover switching, in event of a failure, between duplicate terminal transmission paths.

(*iii*) Protect the undersea repeaters from high-level signal overload.

(*iv*) Provide adjustment capability to compensate for (*a*) that part of the shallow-water cable loss change with seasonal temperature, which is not equalized by temperature-controlled repeaters,[1] and (*b*) that part of transmission aging of the undersea link, which is not compensated for by shore-controlled equalizers.[1]

In some cases, accomplishing these functions provided us with interesting design problems that we had not encountered during development of terminals for earlier undersea systems.[8,9]

4.1 *Amplitude and phase equality of duplicated paths*

We have designed the changeover switching in such a way that maintenance switching (i.e., that which does not result from a transmission path failure) will not even momentarily disturb transmission more than a negligible amount.* To appreciate how this is accomplished, refer to the schematic in Fig. 8. If the amplitude and phase of the signals on each path are equal, closing of contacts B1 and B2 has no effect. Subsequent opening of contacts A1 and A2 (in either order) will interchange paths and loads without disturbance.

To evaluate the influence of path amplitude and phase differences, consider the following. The ratio in decibels of power delivered to the load in two cases, (*i*) separate paths (P_0) and (*ii*) parallel paths (P_1), is

* So-called hitless switching.

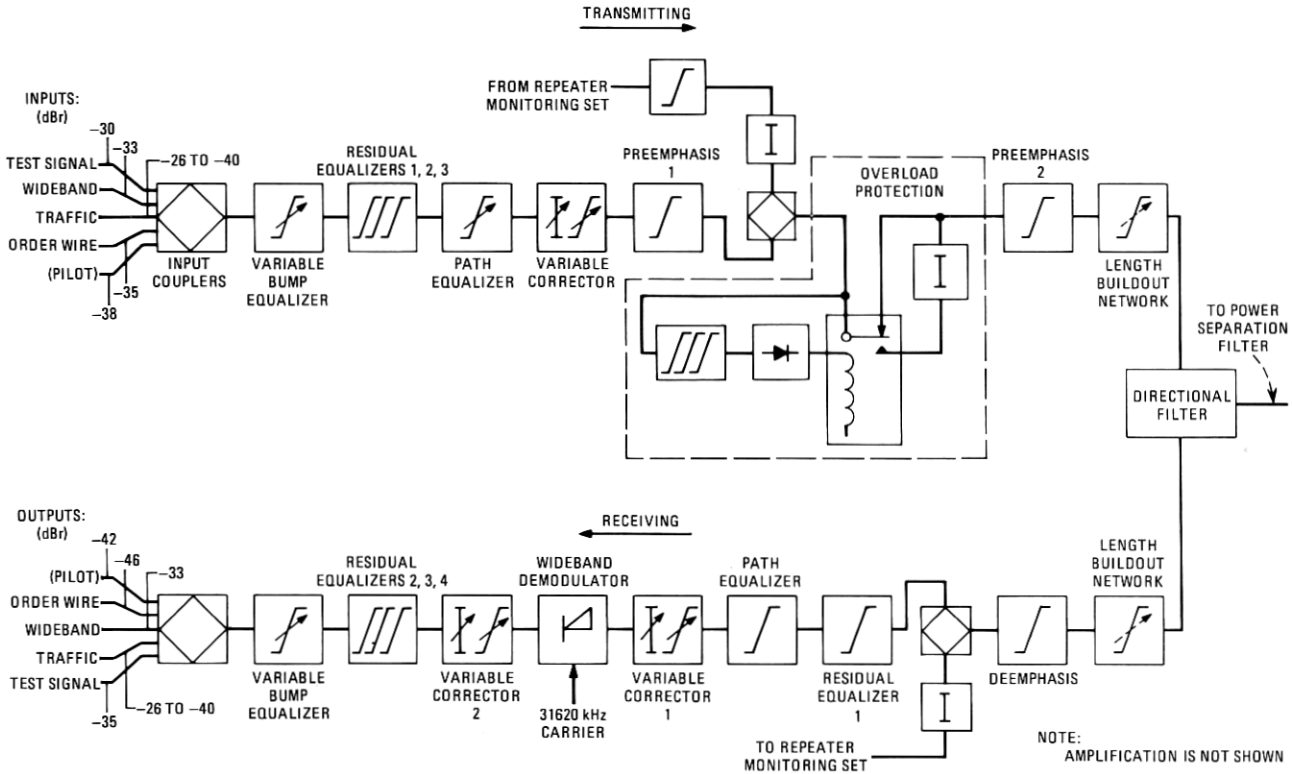

Fig. 7—Wideband line equipment-A station (B station is similar except frequency translation is in the transmitting line and only one preemphasis network is used).

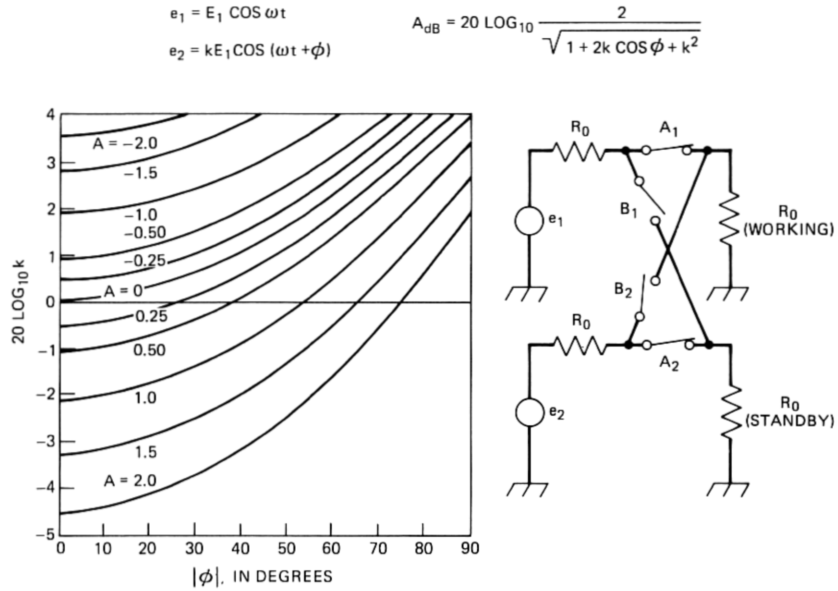

Fig. 8—Effect of path amplitude and phase differences on changeover switching.

$$A = 10 \log_{10} \frac{P_0}{P_1} = 20 \log_{10} \frac{2}{\sqrt{1 + 2k \cos \phi + k^2}},$$

where k and ϕ are defined in Fig. 8. In that figure, contours of constant A are plotted as functions of k and ϕ. One sees that, provided ϕ is not too large, the change in magnitude at paralleling is less than that for complete transfer. For example, if $|20 \log k| < 0.5$ dB and $|\phi| < 30°$, A is always less than about half a decibel. The phase disturbance at paralleling is

$$\tan^{-1} \frac{k \sin \phi}{1 + k \cos \phi},$$

and is always less than for complete transfer.

4.2 Protecting repeaters from signal overload

The peaks of a sufficiently high signal voltage applied to an SG repeater can, in time, cause a change in current gain of the output transistor. We decided, therefore, to limit to a safe value the maximum signal that can be applied to the undersea link from the terminal. This function is accomplished by the *wideband overload protection unit,* shown schematically in Fig. 7. The wideband signal is monitored at the output of the last active circuitry in the transmitting line and shaped with an equalizer before it is amplified and measured by a pseudo-quadratic detector. Should the detected signal exceed a predetermined threshold, a high-loss pad is switched in series with the transmission path. The ideal frequency weighting in the detection path would be one so that a change in spectral density* of the signal at the input of the overload protection unit has the same effect on the mean power of the signal at the detector as it does at the output transistor in the highest level repeater in the link.

To avoid insertion of the pad for a momentary signal overload, the time constant of the detector is approximately 1 second. On the other hand, once the pad is inserted, it can only be reset manually.

We anticipate that operation of this unit will be extremely rare, because of the action of the supergroup limiters (described in Section 5.1.3), and probably due only to an equipment failure or adjustment error within the TTE itself. (Operation of the overload protection unit in the working transmitting line would, of course, cause changeover to the standby path.)

4.3 Pilot generation and measurement

As explained in Section 2.3, hypergroup and cable pilots serve to monitor operation of the multiplex, line, and undersea links, to initiate automatic protection switching, and to control the gain of receiving hypergroup regulators.

In principle, hypergroup and cable-pilot generators are identical designs, i.e., a quartz oscillator generates a stable frequency that is amplified and clipped to assure level stability. The signal is then filtered to remove harmonics and other spurious energy that could disturb traffic. The generator output is monitored (displayed on a front-face meter) and fed to a test jack so it can be checked with external equipment. An alarm is initiated for changes from nominal of a sufficient amount.

Pilot measuring units are also similar. A narrow-band 2296-kHz quartz filter is located at the input of those units monitoring the basic hypergroup (and hypergroup 1) pilot, and is followed by amplification and detection. On the other hand, for those units monitoring hypergroup pilots at baseband frequencies (except HG 1), this circuitry is preceded by a demodulator whose carrier frequency was chosen to restore the pilot to 2296 kHz. For the cable-pilot measuring units, a demodulator is not used; instead, a narrow-band quartz filter at cable-pilot frequency (11220 and 27836 kHz in the low and high bands, respectively) precedes amplification and detection. For all units, the pilot level is displayed on a front-face meter. A test jack provides access for an independent check of pilot level, and an alarm is initiated for sufficiently large level changes from nominal.

* Peak-to-mean-power ratio remaining constant.

4.4 Traffic and noise monitors

A continuous indication of undersea system noise is furnished by a unit connected near the output of the receive wideband line equipment that measures noise in a frequency slot, which is about the bandwidth of a voice channel, and is located between two supergroups in the neighborhood of the supervisory-tone band. Refer to Figs. 4a and 4b. The measuring apparatus itself consists of a quartz filter centered at 4276 kHz (A terminal*) and at 11,468 kHz (B terminal) followed by amplification and a pseudo-quadratic detector. Noise power is displayed on a meter whose scale is ±7 dB. Preceding this apparatus in the measuring path is a variable attenuator of ±10 dB in 1-dB steps. Fixed levels are such that a zero meter reading can correspond to noise in the range of about 28 to 48 dBrnc0. An alarm is initiated if the measured noise power exceeds the nominal value (zero meter reading) by more than 5 dB.

Also connected near the receive wideband line output is a traffic measuring unit similar to the noise measuring unit except that it is broadband (because it measures the complete traffic band) and is not alarmed. An attenuator adjustment on the front face (0 to 15 dB in 5-dB steps) permits the zero meter reading to correspond to 8, 13, 18, or 23 dBm0. (4200 channels at −13 dBm0/channel corresponds to a broadband power per band of 23.2 dBm0.)

Traffic as well as noise measurements are necessary to monitor an analog transmission system such as SG whose signal-to-noise performance is intermodulation rather than overload limited.

4.5 Alarm and maintenance features

As we have seen, behavior of the transmission link is monitored by means of pilot, noise, and traffic measurements. Pilot generating and measuring apparatus and noise measuring apparatus give visual indication of variations from nominal and initiate alarms when variations exceed specific limits. Upon initiation, alarm lamps on the front face of a unit and at the top of the bay containing that unit are lit, and the alarm is extended to the station alarm equipment which is expected to provide audio as well as visual indications. In this way, a technician is directed to the source of the trouble. A two-position switch on the face plate of the unit, when in the *cutoff* position, inhibits the station alarm as long as the source of the alarm remains. When the trouble is cleared, the alarm is reactivated until the switch is returned to the *normal* position. Finally, an output from pilot, traffic, and noise measuring units can be connected to a chart recorder (12 recorders are provided in a separate bay). This arrangement permits a continuous record to be obtained, when and if it is desired.

* The A station noise monitor is positioned after wideband translation to baseband.

4.6 Principle of primary frequency comparison

From the point of view of carrier generation, an undersea cable link often acts as an interface between national frequency standards. To insure that the frequency offset between terminals is within performance limits (no more than 2 parts in 10^8 for an SG link), it is necessary to compare master oscillator frequencies (primary frequency supplies). Comparison between the two terminals is accomplished in the following manner. Let us designate:

f_g—primary frequency (nominally 124 kHz) (from which all TTE carrier frequencies are derived) at the A terminal.

f'_g—Similarly at the B terminal.

N_1f_g, N_2f_g—Carrier frequency for hypergroups 2 and 5, respectively, at the A terminal ($N_1 = 59$, $N_2 = 119$).

$N_1f'_g, N_2f'_g$—Similarly for the B terminal.

f_1—Basic hypergroup pilot frequency (nominally 2296 kHz) at the A terminal.

f'_1—Similarly for the B terminal.

f_t—Wide-band translation carrier (nominally 31,620 kHz) at the A terminal.

f'_t—similarly at the B terminal.

The A terminal transmits the HG 2 and 5 pilots at line frequencies of $(N_1f_g - f_1)$ and $(N_2f_g - f_1)$, respectively. At the B terminal, each is demodulated by the corresponding hypergroup carriers, $N_1f'_g$ and $N_2f'_g$ to obtain $f_1 + N_1(f'_g - f_g)$ and $f_1 + N_2(f'_g - f_g)$. The frequency difference between these recovered pilots, $(N_2 - N_1)(f'_g - f_g)$, is displayed directly on an analog meter (pointer movement proportional to the frequency difference) at the B terminal. Additionally, an A terminal reference frequency is made available in the B terminal, which is the difference frequency between received HG 2 and 5 pilots at line frequency, i.e., $(N_2f_g - f_1) - (N_1f_g - f_1) = (N_2 - N_1)f_g$, nominally 7440 kHz.

A similar arrangement provides a frequency-difference display and a B terminal reference signal in the A terminal, even though additional frequency translations by f_t and f'_t are involved.

4.7 Equalizers

We can make the following distinctions with regard to wideband line equalizers:

(*i*) Fixed equalizers meant to achieve the best overall signal-to-noise ratio for an ideal system in the sense of one with no undersea misalignment.

(*ii*) Equalizer networks designed and fabricated on site during commissioning[10] to compensate for actual misalignment measured after completion of installation.

(*iii*) Adjustable equalizers which, during commissioning, can be used to achieve the best overall signal-to-noise ratio for an actual link with undersea misalignment, and, after commissioning, can be used to compensate for transmission changes resulting, for example, from temperature changes on the continental shelves and, in conjunction with the shore-controlled equalizers,[1] from cable aging.

The terminal equalization plan is discussed in more detail in a companion article.[10]

4.7.1 Fixed equalizers

In the category of fixed equalizers are the *line buildout*, *preemphasis*, and *deemphasis networks*, and the *path equalizers*. The line buildout networks in the transmit and receive paths are fixed for each terminal in that the effective electrical length to the first repeater from the terminal is equal to three-quarters of the loss of a nominal repeater section. In this way, flexibility is maintained in placement of the first repeater, while at the same time reasonably standard terminal equalization is preserved.

Path equalizers compensate for small misalignment unavoidably introduced in the wideband path, by interconnecting cabling and the like, and differences between nominally identical paths.

Given the nominal line equipment, the preemphasis network (transmit) provides the calculated loss shape to optimize overall s/n as mentioned in Section 4.7, item (*i*), above. The deemphasis network (receive) compensates for the preemphasis loss shape as well as for that of the last section of undersea cable (which is not compensated for by the gain of a repeater).

4.7.2 Equalizers fabricated during commissioning

To achieve final alignment of an SG link in a minimum of time after installation, we developed a *residual equalizer unit*. In a single unit, up to five bridged-T[11] networks can be mounted and connected in tandem. The frequency-loss characteristic of each network can be a bump, dip, or slope of wide ranging selectivities. Several such units are used in both transmit and receive paths (Fig. 7). A kit of components (inductors, capacitors, and resistors) covering specific ranges of values, as well as other hardware, is supplied with the WLE. After link misalignment has been measured, bridged-T networks are designed (with the aid of a computer) and constructed on site, and inserted into the wideband line.

4.7.3 Adjustable equalizers

Both broad- and fine-grain equalization capability is provided by the front-panel-adjustable networks which facilitate initial performance optimization and subsequent realignment following undersea loss variations. Broadband adjustment at line frequency is provided in both the transmit and receive paths by a so-called *variable corrector* that contains four types of circuits: slope, curvature, flat, and $\sqrt{f}$. At the frequency of maximum excursion (e.g., the peak of the curvature shape), each is adjustable in 0.3-dB steps over a range of ±3 dB (slope and curvature) or ±6 dB (flat and $\sqrt{f}$). A second type of variable corrector, used only in the receive path, provides additional flat and $\sqrt{f}$ adjustable gain range.

Among other functions, the variable correctors must be able to compensate for certain fault conditions in the undersea link, i.e., those whose effect on transmission is not so severe that service cannot be maintained, albeit at reduced performance, until repair operations commence.

A *variable bump equalizer*[12] permits narrow-band adjustment in the vicinity of a series of discrete baseband frequencies related by geometric progression. Selectivity is such that adjustment at one of these frequencies involves negligible change at adjacent ones. Because of the slightly different basebands, 16 bumps are available in the low band, but only 12 in the high-band direction of transmission.

4.8 Order-wire facilities

The line terminal is equipped with three order-wire circuits, each terminated at voice frequency with a unit permitting two- or four-wire operation and signaling. The frequency-translation circuitry is distinct from the regular multiplex equipment. Each channel undergoes translation to 24 to 28 kHz, as in the French Post Office (PTT) Type 70 12-channel equipment,[13] before the three are contiguously assembled at 60 to 72 kHz, the bottom quarter of the standard group baseband. The final two stages of translation correspond to placement in group 5 of supergroup 16 (see Figs. 4a and 4b).

The order-wire equipment is duplicated; in the transmit direction, either equipment can be connected by a manual switch to the transmitting paths. In the receiving direction, order-wire signals are selected from the working path through an automatic switch controlled by the receive changeover logic. See Fig. 6.

One of the three channels is equipped as a local order wire (i.e., for exclusive use between terminals), with an operator panel containing headset jacks plus ring and call-cutoff pushbuttons.

V. MULTIPLEX EQUIPMENT

The multiplex portion of the TTE is located between supergroup distribution frames and the wideband line equipment (Figs. 1 and 6). It includes supergroup and hypergroup translating equipment (STE and HTE) with the associated carrier generators, hypergroup regulators, supergroup limiters (transmit), and supergroup equalizers (receive). Typically, this circuitry constitutes a link between domestic inland facilities (at basic supergroup) and the wideband line equipment (at SG system baseband).

Design of the multiplex equipment allows it to operate with 3- or 4-kHz spaced channels, with a per-channel load of −13 dBm0 in either case.

The supergroup and hypergroup frequency assignments have already been discussed in Section II. Refer to Figs. 2 and 3.

5.1 Supergroup equipment

5.1.1 Frequency translation

Supergroup translation equipment is derived from standard PTT domestic equipment,[14] which already conforms to CCITT recommendations,[6] but special care was given to reduce carrier leaks. Unfortunately, supergroup carrier frequencies, which are multiples of 4 kHz, do not necessarily fall between channels when operating with 3 kHz spacing as they do with the more conventional 4-kHz spacing. The disturbance level of an ensemble of spurious tones must be less than −65 dBm0/channel, so we felt it prudent to hold the power of a single spurious frequency to no higher than −70 dBm0.

Performance requirements for the supergroup translating equipment are summarized below:

(*i*) Carrier-leak, ≤ −70 dBm0 transmitting, ≤ −40 dBm0 receiving.*

(*ii*) Thermal and intermodulation noise (for +6.0 dBm0/supergroup loading), ≤30 pW0p (15.3 dBrnc0) transmitting or receiving.

(*iii*) Return loss at all ports, ≥25 dB.

(*iv*) Crosstalk ratio (single frequency) ≥85 dB.

5.1.2 Carrier generation

The supergroup carrier generating equipment is of conventional design, a harmonic generator (fed from a 124-kHz master oscillator) driving a parallel string of LC bandpass filters, each selecting the appropriate harmonic for a particular supergroup, followed by a gain-regulated drive amplifier. Suppression of unwanted carrier frequencies at each output is greater than 80 dB. As mentioned in Section 3.2, the supergroup carrier

* Receive carrier leaks fall outside the transmission band.

generating equipment is duplicated, with a changeover switch at the outputs for each carrier. Signal detection permits automatic changeover operation and alarm initiation in case of failure in the working equipment.

5.1.3 Supergroup signal limiters

Application of sufficiently high-powered signals to analog transmission systems will cause excessive intermodulation noise[15] that interferes with traffic and, in a severe case, causes overload which can result in the loss of all traffic. To prevent this situation from occurring on the SG system, we decided to equip each input of the transmitting STE with a signal limiter (Fig. 6). The limiter is transparent (fixed attenuation) to signals in the normal operating range. Should the applied signal exceed preset amplitude limits, however, a controlled amount of attenuation is introduced in a variable loss network in the signal path.

Two monitoring circuits are used to control loss insertion, (*i*) a peak level monitor, and (*ii*) a mean-power level monitor. Refer to Fig. 9. Response of the peak monitor is relatively fast but consistent with maintaining within acceptable limits the generation of unwanted wideband energy. In practice, operation and restoration times of about 1 and 5 ms, respectively, are used. Response time of the mean-power monitor is, on the average, much slower than this, but depends on the magnitude of its overload, i.e., the higher the overload the shorter the response time.

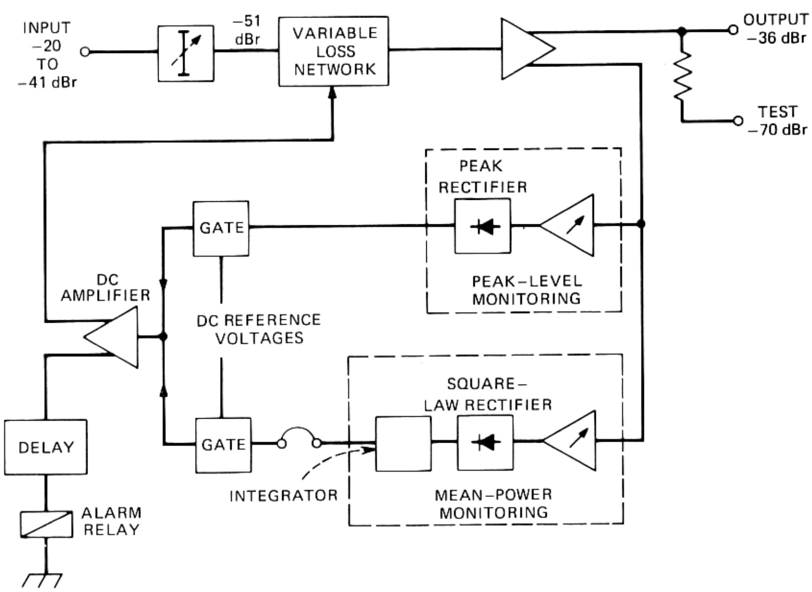

Fig. 9—Supergroup signal limiter.

To allow for differing types of traffic and the actual performance of the undersea link, the operating point of the peak and mean-power limiter circuits are separately adjustable by means of attenuators in each amplifier/detector input. The dc output of each monitor is compared with a reference voltage. When exceeded, the difference voltage is applied (after amplification) to the variable loss network; the larger the difference voltage, the greater the loss increase. A second output from the dc-amplifier energizes an alarm indicative of limiter operation, but a delay network suppresses the alarm if the limiter is activated only momentarily.

An input attenuator to the limiter unit is adjusted at the time of installation for differences among administrations with regard to transmission level at the supergroup input.

The supergroup signal limiter used in the SG terminal is a slight modification of the British Post Office (BPO) limiter[15] as manufactured by GEC, Ltd, and is constructed under SOTELEC 70 equipment practice to conform to the remaining TTE equipment manufactured by CIT-Alcatel of France.

5.1.4 Narrow-band-elimination filters

To assure a clear slot between particular supergroups for subsequent insertion of hypergroup and cable pilots, and to facilitate undersea noise monitoring, narrow-band-elimination filters centered at 308- and 556-kHz are inserted between signal limiter and modulator in certain transmitting supergroups, and between demodulator and equalizer in the corresponding receiving supergroups.

5.1.5 Supergroup link equalizers

Although the primary means of compensating for undersea misalignment in the terminal are the residual equalizers in the WLE, we decided nevertheless to have available for use a supergroup-link equalization capability if needed to satisfy the CCITT recommendation regarding amplitude distortion,[16] viz., no greater than ± 1.5 dB relative to a midband frequency which itself must be ± 0.1 dB of nominal. When used, an equalizer is placed after the supergroup demodulator as shown in Fig. 6.

A simplified circuit diagram of the equalizer is given in Fig. 10. It is essentially an amplifier whose gain in the 312- to 552-kHz band is determined by damped resonant R-L-C circuits inserted as shunt elements in the feedback network. Up to five such circuits per amplifier can be used. Just as for the residual wideband line equalizer, a specific kit of components is provided for on-site construction, during commissioning, of the feedback and other gain controlling elements.

A sophisticated computer program is used to determine the number

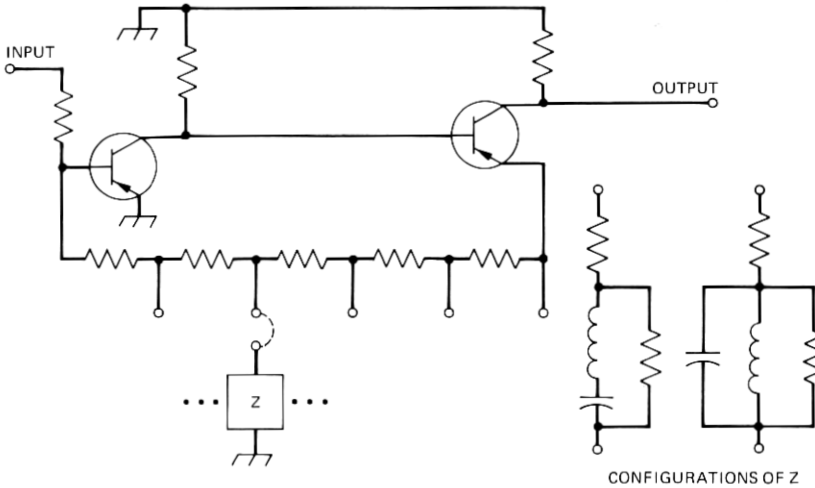

Fig. 10—Supergroup-link equalizer.

and configuration of the feedback circuits and the value of all variable components. The program uses an iterative trial-and-error process which continues until the computed link gain after equalization is within a specified tolerance. If equalization proves particularly difficult, e.g., for those supergroups near the edge of the wideband, a second amplifier can be placed in tandem with the first.

5.2 Hypergroup equipment

5.2.1 Frequency translation

A new design of hypergroup translating equipment is justified for use with undersea systems to achieve high traffic-band efficiency. Moreover, the tight phase and amplitude difference constraints made the new design an interesting one.

Most subassemblies of the HTE are of conventional design. Negative feedback amplifiers are made up of transistor pairs, the modulators use fast diodes in a ring configuration between ferrite core transformers, and the filters are LC type using ferrite inductors and mica capacitors. Solder-adjustable resistive pads permit level alignment. Coupling of the hypergroups is at a low input impedance amplifier on the transmit side and at a low output impedance amplifier on the receive side.

A departure from conventional practice was the addition of a series LC circuit at the input of each carrier amplifier. Tuning the capacitor permits adjustment of carrier phase over a sufficient range to compensate for phase differences between duplicate HTE paths for each hypergroup.

Performance requirements for the hypergroup translating equipment are summarized below:

(*i*) Carrier leak, ≤ −55 dBm0 at transmitting, ≤ −40 dBm0 at receiving.
(*ii*) Thermal and intermodulation noise (for +16.0 dBm0/hypergroup loading), ≤20 pW0p (13.5 dBrnc0) transmitting or receiving.
(*iii*) Return loss at all ports ≥25 dB.
(*iv*) Crosstalk ratio (single frequency) ≥85 dB.

5.2.2 Carrier generation

Design of the hypergroup (and wideband) carrier generating equipment was particularly challenging. The conventional scheme of harmonic generator followed by selective filters was not capable of producing sufficient carrier purity because the ratio of carrier frequency to master oscillator frequency is so large. (In the extreme case of the wideband carrier, the ratio is 255.) Furthermore, it was necessary to maintain the phase difference between corresponding carriers from the duplicated generators to within a few degrees to be consistent with hitless changeover switching between transmission paths as well as hitless manual patching at the duplicated generator outputs, whose combinations are illustrated in Table I.

The arrangement chosen to do the job is shown in Fig. 11 in block form. Notice the harmonic-generator, selective-filter combination is still present, but the desired harmonic of 124 kHz is only used to phase-lock

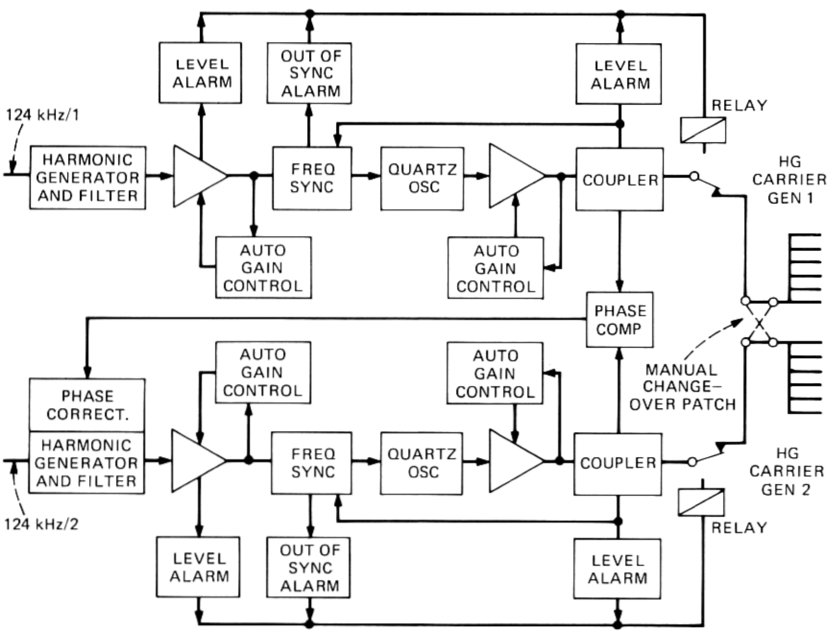

Fig. 11—Hypergroup carrier generation.

a quartz oscillator which is the actual carrier source. The necessary carrier purity is achieved by means of a first-order low-pass filter within the phase-locked loop whose cutoff frequency is only a few Hertz (except during capture). This arrangement produces, in effect, an extremely narrow-band-pass filtering action at the carrier frequency.

A phase comparator monitors the difference between corresponding generators and controls a corrector which automatically compensates phase deviations.

Performance requirements for the hypergroup (and wideband) carrier generating equipment are summarized below.

(*i*) Frequency stability of the master oscillator is preserved.
(*ii*) Output level stability: ±1 dB.
(*iii*) Carrier-to-noise ratio: at least 100 dB in 3-kHz band.
(*iv*) Phase difference between duplicate generators: <5 degrees.

5.2.3 Hypergroup regulators

The hypergroup regulator is a conventional design, i.e., an amplifier whose gain is pilot-controlled. A narrow-band quartz filter in the regulation loop extracts the hypergroup pilot from the traffic band at the amplifier output. This signal is then amplified, rectified, and compared to a dc reference voltage. The resulting difference signal controls the temperature of a thermistor located in the feedback path of the amplifier. The regulator has a compression ratio greater than 10 over an input range of ±2.5 dB about its nominal gain.

Lamps on the front panel of the unit indicate when regulation exceeds ±1 dB and ±3.5 dB, and the latter can be transferred to the station alarm, as is the loss-of-pilot alarm which is initiated if the amount of regulation exceeds 7 dB. Input and output test points are also provided on the front panel.

VI. MECHANICAL ARRANGEMENT

The SG system terminal transmission equipment is produced under a mechanical specification standardized in France under the name SOTELEC 70,[17] whose basic elements are the *frame,* a simple mechanical support for *shelves* which contain a number of plug-in *units.* This total arrangement constitutes a *bay.* Units are provided with a front face plate on which are located labeling, test points, meters and other indicators, and in-service adjustment facilities. The rear face supports a connector that mates with its shelf-mounted partner. Mechanical locking is assured either by the connectors themselves or by a screw on the face plate. All shelves are the same width and depth, but their height can be a multiple of a modular unit of 44.5 mm.

Interconnection of units within a shelf (and occasionally between shelves) is done at the rear. Input and output access to a shelf is through vertical terminal strips, one on each front side of the shelf.

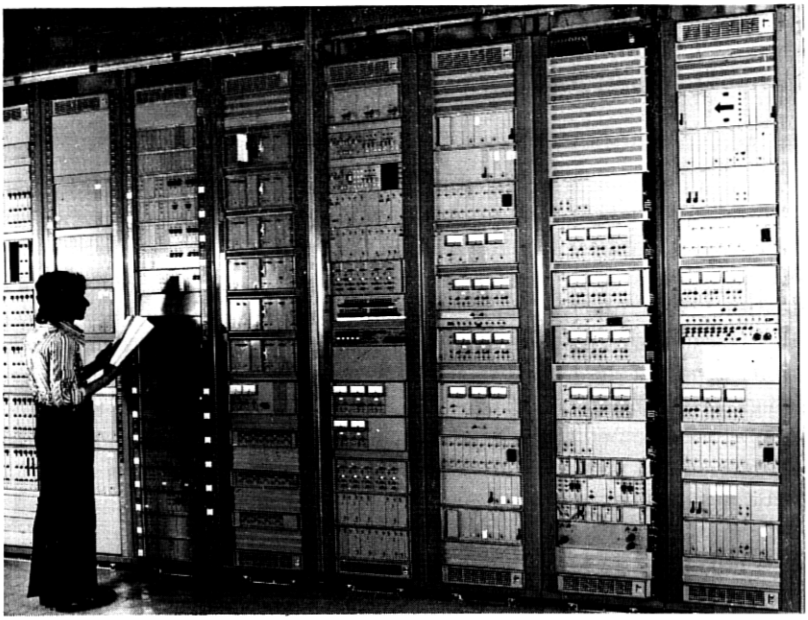

Fig. 12—Typical bay lineup of SG terminal transmission equipment.

A frame supports the shelves, and is in turn held to a base fixed to the floor. Wiring between shelves generally follows along the inside of the vertical frames and connects to the terminal strips.

A typical bay line-up for a terminal is pictured in Fig. 12. Although variations from this bay layout are possible, one must be careful to limit length differences of many intra-bay cabling runs in order to preserve phase equality of duplicate paths. The high degree of functional interdependence of line and multiplex terminal equipment dictates that they be physically close.

VII. CONCLUSIONS

Achieving and maintaining maximum use of the undersea link have been our prime objectives from conception through production of the SG terminal transmission equipment. Accomplishing these ambitious objectives has led in some instances to complex designs whose development has been challenging because of, on the one hand, technological difficulties associated with the relatively high frequencies used (compared to earlier undersea system designs), and on the other the multiplicity and diversity of required functions. In four years it has been necessary to plan for and then design, develop, and produce no fewer than 263 different types of units. Undertaking the work in this interval constituted a wager that could only be won by exerting an all-out effort.

Everyone who has participated in this task confidently believes that the SG terminal transmission equipment will render all the service we have the right to expect from it.

VIII. ACKNOWLEDGMENTS

Many individuals from organizations on both sides of the Atlantic were involved in TTE development from planning through installation as part of the first SG system implementation, TAT-6. Representatives from the Network Planning Department of the British Post Office Telecommunications Headquarters, the National Center for Telecommunications Studies and the Submarine Branch of the French Post Office, the Ocean Cables group of the Long Lines Department, American Telephone and Telegraph Company, and the Undersea Systems Department of Bell Laboratories helped guide development, but the lion's share of the work was carried out most commendably by members of Compagnie Industrielle des Télécommunications (CIT-Alcatel) in France.

REFERENCES

1. C. D. Anderson, W. E. Hower, J. J. Kassig, V. M. Krygowski, R. L. Lynch, G. A. Reinold, and P. A. Yeisley, "SG Undersea Cable System: Repeater and Equalizer Design and Manufacture," B.S.T.J., this issue, pp. 2355–2402.
2. F. H. Blecher, R. C. Boyd, F. J. Hallenbeck, and F. J. Herr, "The L-4 Coaxial Systems," B.S.T.J., *48,* No. 4 (April 1969), pp. 821–839.
3. F. C. Kelcourse and F. J. Herr, "L5 System: Overall Description and System Design," B.S.T.J., *53,* No. 10 (December 1974), pp. 1901–1933.
4. Recommendation G338, "4-MHz Valve Type Systems on Standardized 2.6/9.5 mm Coaxial Cable Pairs," Volume III.1 of CCITT Green Book.
5. Recommendation G343, "4-MHz Systems on Standardized 2.1/4.4 mm Coaxial Cable Pairs," Volume III.1 of CCITT Green Book.
6. Recommendation G233, "Recommendations Concerning Translating Equipments," Volume III.1 of CCITT Green Book.
7. E. T. Calkin, I. Golioto, W. J. Schatz, R. E. Schroeder, D. S. Shull, "SG Undersea Cable System: Undersea System Power," B.S.T.J., this issue, pp. 2497–2522.
8. R. L. Lynch, J. L. Thomas, and C. A. Von Roesgen, "SF System: Shore Terminal Facilities and Fault Location," B.S.T.J., *19,* No. 5 (May–June 1970), pp. 721–748.
9. A. Blanchi, M. Dubois, R. Salvador, and H. Soulier, "La Liaison Sous-Marine Marseille-Alger II," L'Echo des Recherches, July 1973.
10. D. N. Harper, B. O. Larson, and M. Laurette, "SG Undersea Cable System: Commissioning: Final System Alignment and Evaluation," B.S.T.J., this issue, pp. 2547–2564.
11. O. J. Zobel, "Distortion Correction in Electric Circuits with Constant Resistance Recurrent Networks," B.S.T.J., July 1928, pp. 438–534.
12. J. Oswald and C. Chalhoub, "L'Égalisation," Câbles et Transmission Ann., *16,* No. 3 (July 1962).
13. G. Duval, J. Grollemund, and J. C. Duval, "Organes Fonctionnels de Ligne Avec Appel à Fréquence Zéro," Câbles et Transmission Ann., *25,* No. 4 (October 1971).
14. G. Laguerie, M. Louboutin, and M. Knapp-Ziller, "Modulation de Groupe Secondaire, etc.," Câbles et Transmission Ann., *25,* No. 4 (October 1971).
15. N. P. McKay, "Wideband Signal-Limiters," P.O.E.E.J., *62,* Part 4, January, 1970.
16. Recommendation M46, "Bringing International Group, Supergroup, etc., Links into Service," Volume IV.1 of CCITT Green Book.
17. G. Laguerie, M. Lagarde, and J. Menu, "Structure Mécanique du Matérial SOTELEC 70," Câbles et Transmission Ann., *25,* No. 4 (October 1971).