SF System:

Ocean Cable and Couplings

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An SF armorless coaxial cable design having lower loss than its predecessor, the SD design, has been developed. Its basic construction is similar to that of the SD Cable. However, its larger diameter, along with lower loss polyethylene and higher conductivity inner conductor copper, provides a substantial decrease in attenuation.

A new coupling design has also been developed. The armorless version of the coupling design provides an improvement in return loss between cable and repeater and smaller deflection of the plastic parts under load. The armored version of the coupling provides improved isolation of the steel and beryllium copper parts.

I. INTRODUCTION

This article covers the design of the cable and of the coupling used to join the cable to the repeater or equalizer. Other articles in this issue give the details of the SF System, repeater, and power circuitry.

To provide 800 two-way, 3-kHz voice-frequency message channels, frequencies in the range from 500 kHz to 6 MHz are used. The cable design must provide a transmission medium in this frequency range whose loss, stability and uniformity allow the repeatered system to meet modulation and noise requirements for a span of 4000 nautical miles.

If SD Cables were used for the broader band SF System, its 6 MHz loss at 10°C. and zero pressure would amount to 24,000 dB (6.0 dB/nm). To compensate for this loss, the large number of repeaters required would degrade the modulation performance and increase both the overall system cost and the possibility of failure. Higher voltage would also be needed. To minimize the number of repeaters required for the desired increased channel capacity and to optimize system cost, a lower loss cable is dictated.

II. ARMORLESS DEEP SEA CABLE

Traditionally, deep sea cable designs have been made as small as possible to permit the maximum amount of cable to be loaded on board the cable ships. For example the C. S. LONG LINES, designed specifically for laying armorless cable, can carry approximately 2000 nautical miles of SD Cable which has a diameter over its jacket of 1.25 inches.

To arrive at the desired cable design, therefore, the following general objectives were established at the start of the development program.

(*i*) Decrease the loss of the cable as much as possible.

(*ii*) Increase the size of the structure with respect to the SD design as little as possible.

(*iii*) Obtain the maximum loss advantage from component materials.

(*iv*) Minimize changes in existing SD production facilities.

(*v*) Provide adequate mechanical strength for laying in water as deep as 4,000 fathoms.

(*vi*) Provide sufficient strength for recovering cable with the additional weight of one repeater from depths of 3000 fathoms.

(*vii*) Provide resistance to mechanical and environmental hazards equivalent to that of earlier designs.

The deep sea SF design, shown in Fig. 1, meets these objectives. It consists of virtually the same components as its SD Cable predecessor; namely, an inner steel strand strength member, encapsulated by a copper inner conductor; a low density solid polyethylene dielectric; a longitudinally overlapped copper outer conductor; and a high density poly-

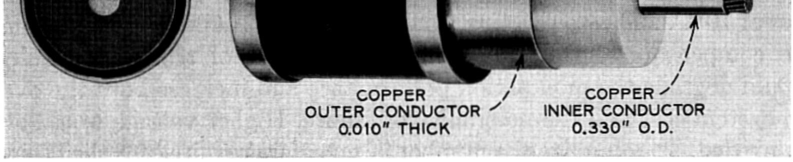

Fig. 1—Armorless ocean cable.

ethylene outer jacket. The major differences between the two deep sea cable designs are that the diameter over the dielectric of the SF Cable is $1\frac{1}{2}$ inches instead of 1 inch; the conductivity of the copper inner conductor of the SF Cable is higher; and a polyethylene dielectric material having a lower dissipation factor at 6 MHz is used. Because of its larger diameter, only about 1100 nm of SF cable can be carried by the C. S. LONG LINES.

The SD inner conductor was retained based on the following considerations. The weight in water of the SF Cable (2000 pounds per nautical mile) is virtually equivalent to that of the SD Cable. Although the drag forces of the SF Cable are larger than those for SD, the strand has sufficient strength for recovering SF Cable at depths up to 3000 fathoms at normal slow recovery rates.

To provide a higher strength cable which could be reliably recovered in depths exceeding 3000 fathoms, it would have been necessary to increase the number and/or diameter of the strand wires because the practical limit in tensile strength of the individual wires had been reached. Either of these approaches would enlarge the strand diameter and require extensive modification of existing manufacturing facilities.

Since there are relatively few locations in the Atlantic or Pacific Oceans where the depths exceed 3000 fathoms, it appears reasonable to accept the restriction that the cable can only be recovered from these depths when the weather conditions are ideal and the recovery rate is kept very low to minimize the drag force.

Having established the diameter over the dielectric as $1\frac{1}{2}$ inches, the inner conductor could have been enlarged slightly to achieve the optimum conductor diameter ratio for minimum attenuation. However, the reduction in loss achieved by this action was judged insufficient to offset the cost of modifying existing manufacturing facilities. The possibility of achieving some material cost savings by reducing the inner conductor copper thickness was also considered. The basis for this approach is the fact that 500 kHz is the bottom frequency for the SF System and 100 kHz is the bottom frequency for the SD System. Because of the skin effect phenomenon, the signal current at the higher frequency flows closer to the outer surface of the copper conductor. The conductor therefore does not have to be as thick to provide satisfactory transmission at 500 kHz. A thinner conductor, however, is mechanically weaker. A comparison of the mechanical difficulties likely to be encountered in producing and handling such an inner conductor, with the savings in materials cost indicated that the disadvantages outweighed the advantages.

III. ARMORED SHORE END CABLE

In most ocean cable systems about one or two percent of the total length is located in depths where protection against chafing on a rocky bottom or against breakage by trawlers or ships' anchors is needed. Because of these potential hazards a plow has been developed to bury the shallow water portions of cables. Where plowing is not feasible, armored cables are used. These designs are similar to the SD armored shore end cables. Figures 2a and 2b show single- and double-armored SF Cable. In these cables, the composite inner conductor is replaced by a solid copper wire and the strength of the cable is provided by outer armor wires.

The armored shore end cables are subject to many of the requirements of the deep sea cable designs. In this case, the jacketed cable diameter is $1\frac{1}{4}$ inches instead of $1\frac{3}{4}$ inches to minimize the overall armored cable size. However, the inner conductor diameter is reduced so that both

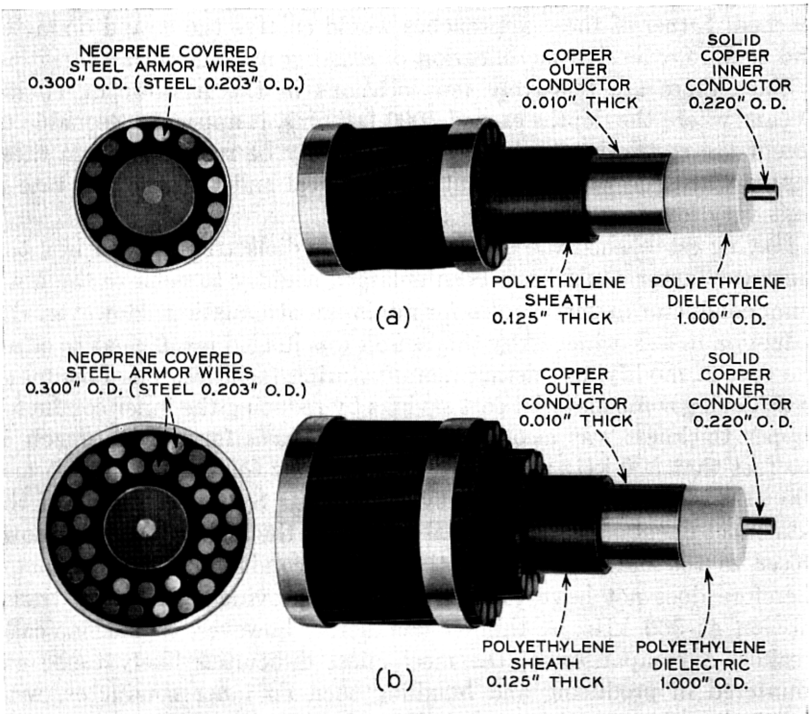

Fig. 2—(a) Single-armored ocean cable, and (b) double-armored ocean cable.

the shore end and deep sea SF Cables have the same characteristic impedance. One or two layers of neoprene-jacketed armor are placed over the basic coaxial structure, depending on the type of ocean bottom, the environmental conditions and the mechanical hazards anticipated.

IV. SHIELDED CABLES

Cable immediately adjacent to a terminal station requires shielding protection to reduce the effect of external electromagnetic disturbances on the system. Figures 3a and b show the two designs of shielded, armored cable. Normally the single armored structure is used, but where anchor damage is expected the double armored structure is used.

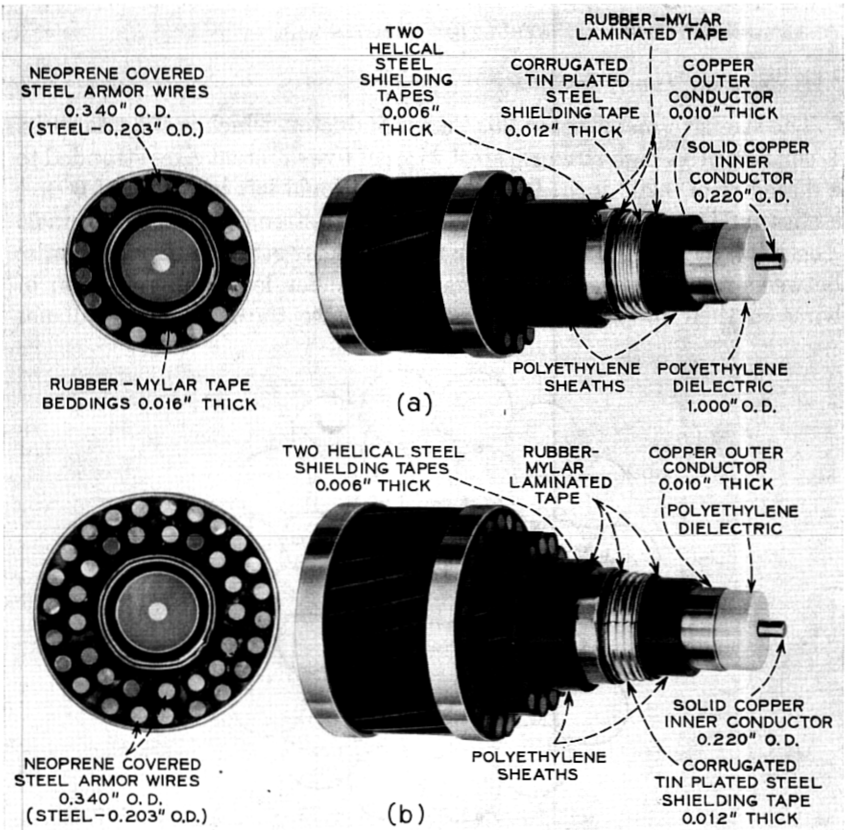

Fig. 3—(a) Shielded single-armored ocean cable, and (b) shielded double-armored ocean cable.

The earlier SD shielded design used four helically applied and one longitudinal soft iron tape. Although this design provides satisfactory electrical shielding, potential wrinkling of the steel tapes during mechanical handling of the cable and a possible subsequent reduction in the life of the cable were considered undesirable. As a result, a modified design (see Fig. 3) was used for the SF Cable. It consists of a corrugated longitudinal steel tape with a soldered seam replacing the unsoldered longitudinal tape used in SD. Over this structure two helically applied steel tapes with opposite directions of lay are applied. Cushioning of the coaxial is provided by beddings of rubber-mylar tape applied under, between and over the steel tapes. The change in shielding structure results in considerable improvement in cable-handling characteristics.

V. ARMORLESS CABLE CONSTRUCTION DETAILS

5.1 *Composite Inner Conductor*

The strength member for this inner conductor, which is shown in Fig. 4, consists of 41 high strength steel wires of five different sizes stranded to a diameter of 0.292 inch. It has a unidirectional left hand lay of $6 \pm \frac{1}{4}$ inches and is a compact fill, achieving a tensile strength of 16,000 pounds. The relatively long 6 inch lay for this diameter strand is a compromise between minimization of torsional twist under load and retention of wires in their proper stranded position. Since the lay length will not

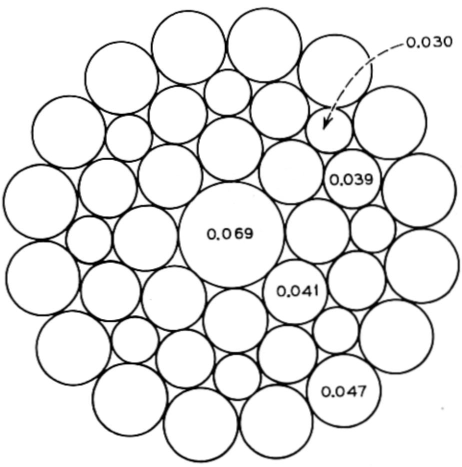

Fig. 4—41-wire steel deep sea cable center strand (average ultimate individual strength is 300,000 psi and the approximate breaking strength is 16,000 pounds).

remain uniform unless enclosed while under stranding tension, the copper shell which is the coaxial inner conductor is formed around the strand in a tandem operation.

The uniformity of the cable strength is controlled by placing a tolerance of ±0.0005 inch on the five sizes of wire diameters comprising the center steel strand and a ±7 percent tolerance on their tensile strength. In addition, the diameter of the completed strand is closely maintained and adequate fill of the strand cross section is achieved by placing a tolerance of ± 0.008 inch on the algebraic summation of diameter deviations for the individual wires comprising the strand. To assure that the inner conductor copper and the steel strand act as a single unit the minimum depth of penetration of the copper between the individual steel outer layer strand wires is 0.005 inch.

The 0.023 inch thick oxygen-free copper shell is formed from annealed tape into an oversize tube, the longitudinal seam of which is sealed by a continuous weld in an inert gas atmosphere. The oversize tube is then swaged down tightly onto the steel strand, partially filling its outer interstices. Oxygen-free copper is specified for ease and reliability of welding. The diameter of the finished composite inner conductor is 0.330 inch. The average conductivity of the copper raw material is 101.7 percent as compared to the International Annealed Copper Standard which is generally accepted as 100 percent. For SD Cable, the average conductivity was 101.4 percent.

5.2 *Dielectric*

To achieve the desired cable attenuation characteristics, a dielectric material must possess good electrical properties which are not degraded by processing, mechanical handling, or severe environmental conditions. The material must also be capable of adhering to the inner conductor surface when extruded. This adhesion assists in preventing interfacial voids and assures adequate longitudinal shear transfer from external forces to the center strength member.

Although the existing SD Cable polyethylene had good mechanical properties, its dielectric loss at 6 MHz was considered excessive for use in the SF System. Since in general, the dielectric loss is a direct function of frequency, the magnitude of the loss is more important at the upper end of the band where the contribution of dielectric loss to the total loss of the coaxial is significant. Through the cooperation of the polyethylene raw material suppliers, a low density, high molecular weight material having a dissipation factor of less than 80 microradians at 6 MHz was obtained. A contributing factor to this low loss was the substitution of

Ethyl Antioxidant 330 [1, 3, 5 trimethyl—2, 4, 6 tri (3, 5—ditert butyl—4 hydroxy-benzyl) benzene] in place of Santonox[R] [4, 4′ thiobis—2 tertbutyl—5 methyl phenol] for the thermal antioxidant. The dielectric material was closely controlled during manufacture to assure uniformity of product. The result was a material which met the dissipation factor requirements shown in Table I. The dielectric constant also was closely controlled to a requirement of 2.285 (+ 0.0002 or − 0.0003).

Table I—Dissipation Factor Requirements

Frequency in MHz	Dielectric Loss in Microradians		
	Minimum	Nominal	Maximum
0.1	35	45	55
1.0	56	61	66
6.0	74	79	84

The low density, high molecular weight polyethylene is pressure extruded over the inner conductor slightly oversize and is then shaved to a precise dimension of 1.500 ± 0.001 inch at a temperature of 20°C. The eccentricity of inner conductor is limited to 0.005 inch.

5.3 *Outer Conductor*

Experience with the overlapped longitudinal outer conductor on SD Cable indicated that this type of structure is electrically superior to helical tapes and is adequate mechanically with proper restrictions placed on bending radii. Consideration was given to reducing the copper thickness for SF Cable below the 0.010 inch thickness previously used, since from an electrical standpoint thinner copper would suffice. Theoretical and experimental evidence, however, showed that reducing the thickness would aggravate the problem of buckling of the outer conductor even though the cable was bent around larger sheaves and cable drums than were used for the SD Cable. The 0.010 inch thick copper outer conductor was therefore retained because it performs satisfactorily when completed cable is bent around a minimum diameter of 9 feet. To assure that the cable will provide the desired mechanical performance, short lengths of each 10 nm section of cable are required to withstand 50 reverse bends at the 9-foot diameter without experiencing outer conductor failure.

As shown in Fig. 5, an annealed electrolytic, tough pitch copper tape 5.000 ± 0.005 inches wide and 0.010 ± 0.0002 inch thick is formed

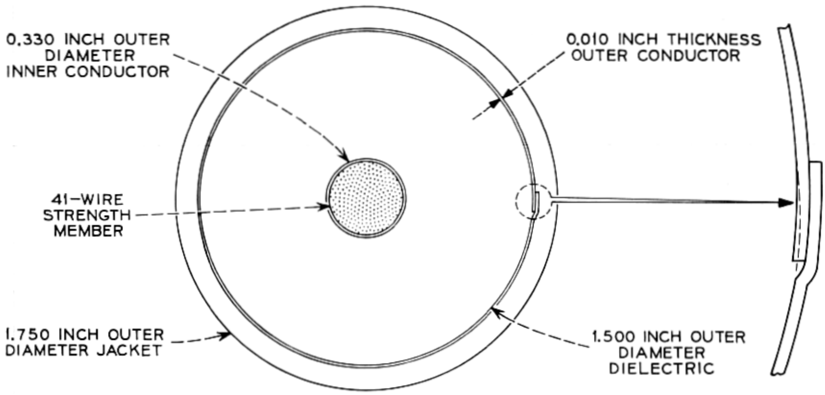

Fig. 5—Cross section of armorless ocean cable.

tightly around the shaved core by a forming mill to provide an overlapped longitudinal seam. The air space between the core and tape at the seam overlap is practically eliminated by the formation of a knee in the overlapping tape edge by the final forming roller. Since the outer conductor is not constrained after formation, this operation is performed in tandem with the jacket application which provides the necessary constriction.

5.4 *Jacket*

Several jacket materials were investigated including the high density black polyethylene jacket used in the SD Cable. Since none of the newer materials examined were significantly better than the SD jacket polyethylene in limiting outer conductor buckling when the cable was bent over sheaves or in abrasion and environmental stress crack resistance, it was decided to use the SD type jacket for SF Cable. This material is a high density, high molecular weight black polyethylene which is extruded over the outer conductor of the coaxial to a thickness of approximately $\frac{1}{8}$ inch. The carbon black is added to minimize deterioration from photo-oxidation during periods of storage and shipment. The eccentricity of the jacket is restricted to 20 mils and the outside diameter tolerance is 1.750 ± 0.010 inch.

5.5 *Cable Loss Characteristics*

In the SD Cable design, emphasis was placed on providing a structure having a loss which is not only predictable but stable. In the case of the SF Cable design, both of these requirements are of even greater importance. For example, in a 4,000 nm system, the SF Cable loss at 6 MHz is about 16,000 dB (4.0 dB per nautical mile). An overall loss deviation of 0.1 percent is 16 dB, which is sufficient to cause system problems. Therefore to minimize these problems, the attenuation is controlled within close tolerances during manufacture and laying by providing equalizers at 192 nautical mile intervals in the system. If, however, the loss of a cable section and the gain of the associated repeater has frequency characteristic deviations which are not readily compensated and are not stable with time, serious system misalignments can occur. Consequently, the effect of all parameters on the cable loss must be evaluated and tight tolerances on material and finished cable characteristics established to avoid system problems.

Nineteen repeater sections are connected together to form a 192 nm ocean block. Each repeater section consists of 10 nm of cable and a repeater. Between any two ocean blocks, two one-nautical-mile lengths of cable and an equalizer are installed to provide means for reducing the misalignment of the system. The equalizer primarily corrects for unpredictable changes in loss encountered during laying. In the cable factory, an objective of ±1 dB at ±6 MHz, 10°C. and zero pressure is placed on the cumulative loss of the nineteen sections manufactured for an ocean block when compared with specified cable loss for the ocean block.

In general, variations in conductor dimensions, dielectric constant or copper conductivity are reflected in a percentage change in loss characteristic which is constant over the transmission frequency band. A variation of outer conductor thickness however has a small effect on the cable loss up to about 1.3 MHz and no effect at higher frequencies as shown in Fig. 6 for a ±0.0002 inch thickness change. This results from the conductor being electrically thin at the lower frequencies.

Another parameter which has a sizeable effect on the cable loss is the dissipation factor. The effect of a ±5 microradian change is shown in Fig. 7. Here the increased importance of dissipation factor at higher frequencies is apparent.

Table II presents the tolerances on important characteristics and indicates the magnitude of their combined accumulated effect on total cable loss in percent. On a root sum square basis the deviations at 6 MHz are ±0.24 percent, which represents a maximum misalignment of about 2.0 dB for an ocean block. It, therefore, is apparent that in order to satisfy the desired overall requirement every effort must be made to achieve the nominal value and to keep the excursions from that value to a minimum. The average percent deviation of the loss of manufactured

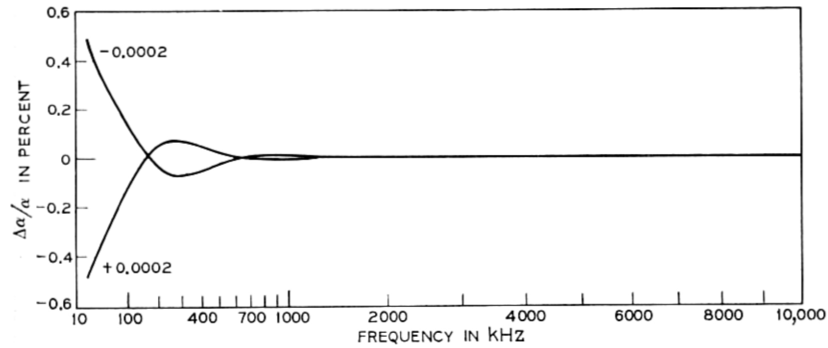

Fig. 6—Effect of a 0.0002 inch change of outer conductor thickness on attenuation of 1.5 inch cable (nominal thickness is 0.0100 ± 0.0002 inch).

product from design for the Florida-St. Thomas and TAT-5 SF Systems are shown in Fig. 8. Minor adjustments in section lengths are made in the factory when required to keep the total loss of an ocean block well within the objective.

5.6 *Derivation of the SF Design Loss Characteristic*

The loss characteristic of the SF Cable was predicted by: (*i*) reduction of average SD Cable loss data to primary and (*ii*) secondary constants, and recalculation of the loss after modification of parameters affected by the changes in inner conductor conductivity, core diameter, and dissipation factor of the dielectric.

Measurements made on experimental cables produced in the pilot

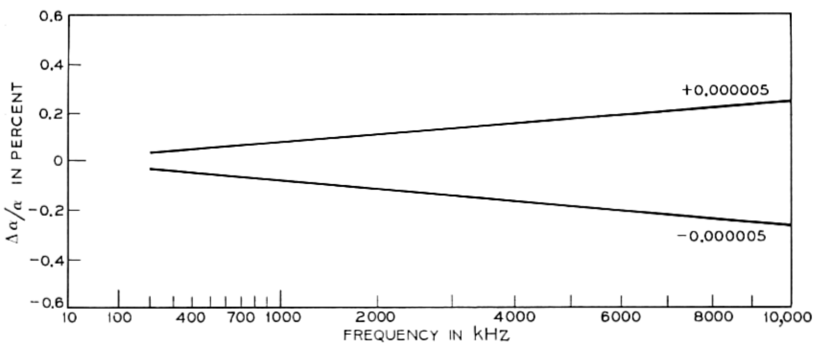

Fig. 7—Effect of a 0.000005 radian change in dissipation factor on attenuation of 1.5 inch cable. (nominal value is 0.0000079 ± 0.000005 radians).

TABLE II—SF DEEP SEA CABLE—PERCENT CHANGE IN TOTAL CABLE LOSS RESULTING FROM TOLERANCES ON CABLE CHARACTERISTICS

Characteristic	Dimensions & Permissible Tolerance	Effect of Tolerance on Cable Loss in Percent	
		0.5 MHz	6 MHz
Inner conductor diameter	0.330 inch ± 0.001	±0.051	±0.048
Diameter over dielectric	1.500 inch ± 0.001	±0.055	±0.054
Thickness of inner conductor	0.023 inch ± 0.0005	0.00	0.00
Thickness of outer conductor	0.010 inch ± 0.0002	±.023	0.00
Dielectric constant	2.285 $\begin{Bmatrix} +0.002 \\ -0.003 \end{Bmatrix}$	+.044 −.066	+.044 −.066
Dissipation factor 0.1 MHz	0.000045 ± 0.000010		
0.5 MHz*	0.000055 ± 0.000010*	±.111	
1 MHz	0.000061 ± 0.000005		
6 MHz	0.000079 ± 0.000005		±.188
Conductivity of inner conductor	101.7 ± 0.3%	±.121	±.118
Conductivity of outer conductor	101.2 ± 0.3%	±.024	±.026
	Algebraic summation	±.440	±.489
	RSS	±.192	±.241

* Interpolated from values specified at 0.1 and 1.0 MHz.

laboratory were then used to refine the predicted loss characteristic and to project the loss data to 6 MHz. The temperature coefficient of attenuation and the pressure coefficients were also determined from measurements made on the experimental cables.

The dissipation factor of the experimental product was derived from the loss measurements. The following formula for dissipation factor

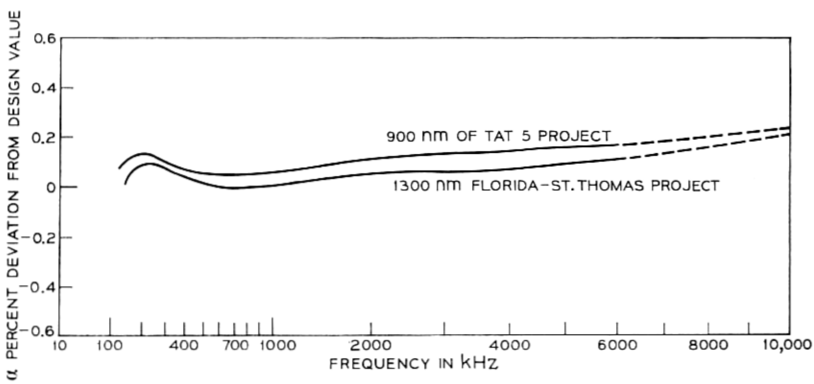

Fig. 8—Per cent deviation of attenuation from design value.

was derived from data at 10°C, zero pressure

$$F_p = 56.36 + 46.07 \log (1 + f_{\text{MHz}}/3) \text{ microradians.}$$

5.7 *Other Areas Investigated*

The increase in diameter of dielectric from 1.0 to 1.5 inches created some uncertainty as to whether the large volume of polyethylene could be extruded in one operation at a reasonable line speed without producing retraction voids or excessive deformation. Since these defects are dependent upon the rate at which the extruded core is cooled, the relationship between line speed, water trough lengths and temperatures was investigated and a suitable time-temperature curve was developed. The overall length of the experimental extrusion line used to establish these parameters was such that good cores could only be achieved at a line speed of about 5 to 8 feet per minute. Based on these experimental data, it was estimated that a speed of 12 to 15 feet per minute could be achieved if the SD manufacturing facilities in the existing cable plants were used to produce SF Cable. This estimate proved correct in actual practice.

A review of the minimum diameter to which the cable can be bent repeatedly without rupturing the outer conductor was necessary because of the larger cable diameter. The minimum diameter to which SD Cable could be bent is 72 times the diameter of the cable core. Applying the same factor to SF, the minimum-bend diameter is 9 feet. Tests as discussed previously, confirmed that this requirement will provide equivalent outer conductor life expectancy to that obtained on SD Cable. Therefore, the minimum diameter of all reels, coils, cones, sheaves and drums was specified as 9 feet.

VI. CABLE COUPLINGS

Since the cable must be connected to a repeater, means for accomplishing this had to be devised. The device had to provide a mechanical transition from the cable strength member to the repeater housing, and a waterproof connection for the coaxial transmission path. Both had to be accomplished without degrading the inherent mechanical strength and electrical performance of the cable.

A special coupling assembly was therefore designed and requirements compatible with those for the cable were established, as given below:

(*i*) Metallic materials were to be beryllium-copper compatible with the repeater housings.

(*ii*) All beryllium-copper parts were to be capable of an in-line pull of 50,000 pounds.

(*iii*) A gimbal was to be provided, with a minimum angular displacement capability of 45° from its normal axis in any direction of bending.

(*iv*) The coupling was to be capable of carrying a repeater through 180° excursions over specified bow sheaves and cable drums at laying and recovery tensions.

(*v*) The return loss measured in the transmission path extensions (pigtails) midway between the cable and the repeater was to be greater than 30 dB over the frequency range between 0.5 and 6 MHz.

(*vi*) The inception of corona noise was to occur at a voltage greater than 4500 volts dc when measured in a 48 kHz band with a 6.8 microvolt threshold.

(*vii*) Reliable bonds between the parent and injected polyethylene material were to be achieved in dielectric restorations at junctions of cable and the pigtail extension to the coupling components.

6.1 *Armorless Coupling*

The initial coupling design used in the Florida to St. Thomas SF System is shown in Fig. 9. During the manufacture of this system, the

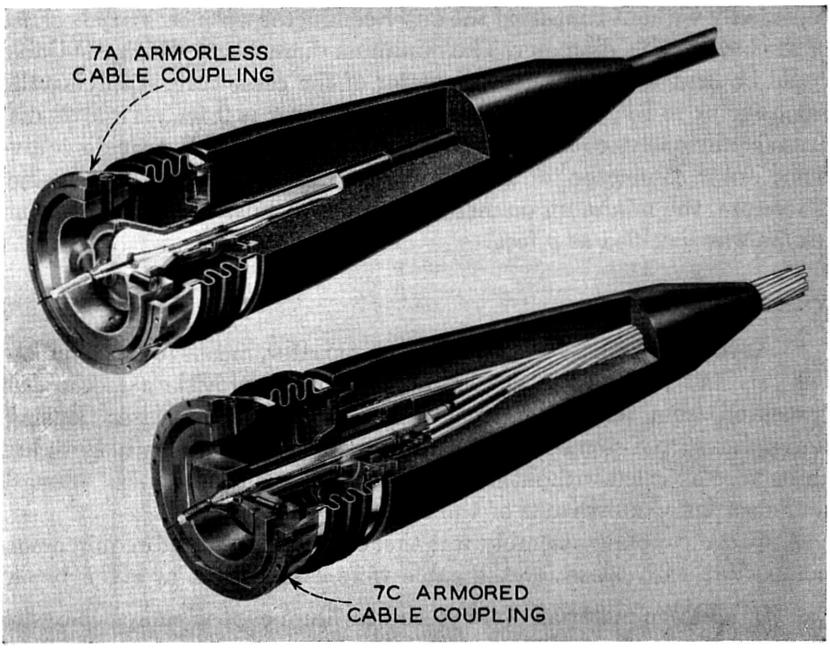

Fig. 9—7A and 7C coupling.

design was modified to improve the reliability of the outer conductor and jacket connection. The latest design is covered by Figs. 10 through 15 inclusive.

The coupling is supplied as piece parts which are assembled and joined to the cable in the cable manufacturing plant. Terminated cable sections and repeaters are then loaded separately on shipboard and joined together prior to laying the cable.

The heart of the deep sea cable coupling is a beryllium-copper termination cone assembly and a ceramic anchor which are assembled and molded with polyethylene, as shown in Fig. 11, to form the anchor molding assembly. This assembly is attached to the cable by inserting the inner conductor with an end portion of strand exposed into the extension tube until the steel wires flare out in the termination cone. Epoxy is then injected into the cone through the small fill tube and cured, thus anchoring the strand. The copper inner conductor is soldered to the end of the extension tube and this junction is bridged by several turns of tinned copper wires soldered at each end to provide a back-up connection. The cable and anchor mold assembly dielectrics are joined by molding. The tapered portion of the anchor mold assembly seats in the matching taper of the beryllium-copper cone housing shown in Fig. 12, and is pinned to prevent rotation of the core under load. The supported tapered cone provides a surface area which results in low unit pressures on the polyethylene during laying and recovery. In addition to the mechanical advantage offered by this shape, it has an electrical advantage since the return loss of the unit is better than 40 dB over the frequency band involved.

Calculations based on the projected surface area indicate that under maximum load conditions the average polyethylene stress is 2400 psi which is well below the stress found acceptable for the earlier SD System 5A coupling. Laboratory tests of deflection, defined as combined movement of ceramic anchor and anchor molding assembly, under constant tensions of 3000 and 12,000 pounds are shown in Fig. 13. The deflection noted after 100 hours at the lighter load is less than 0.010 inch which is considered negligible. At the 12,000 pound load, which simulates expected maximum sustained cable recovery loads, an acceptable deflection of 0.027 inch is noted after 21 hours, which is considerably longer than required for the normal recovery operation.

The outer conductor is restored by brazing a preformed copper insert to the outer conductor of the cable and welding it to the cone housing. Beryllium-copper pins (Fig. 14) in the housing prevent a preformed jacket flange from rotating. A collar (Fig. 15) prevents the

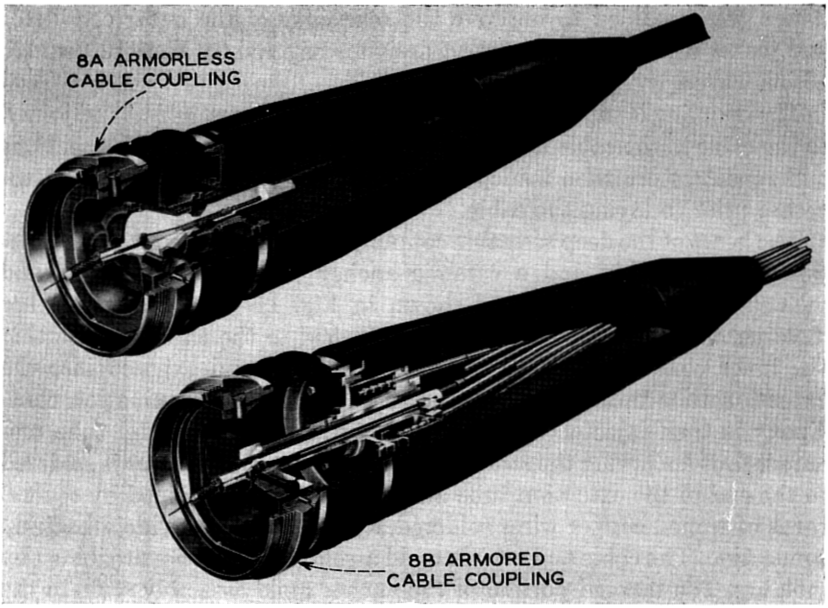

Fig. 10—8A and 8B coupling.

flange from retracting when the cable is under tension. The jacket between the flange and the cable is then restored by molding.

The pigtail is joined to the anchor mold assembly by crimping and soldering the center conductor to the fill tube and restoring the dielectric by molding (Fig. 14). The cone housing cap, pigtail cap and braid are then assembled on the coupling, and the pigtail is formed into a coil which is heat treated to give it a permanent set. The coupling is completed by assembling the gimbal ring, gimbal housing, rubber boot and bellows. The boot serves to minimize stresses in the molded joints and the bellows serve to restrict the entrance of shells, sand and rocks into the area of the moving parts.

The initial outer conductor and jacket restoration designs of the coupling differed somewhat from the present one. During installation of the Florida to St. Thomas SF System, jacket retraction, or "milking," was observed with resultant outer conductor breakage. Although satisfactory temporary remedies were employed for this system, the design was modified to assure that the core, outer conductor and jacket act as a single unit when the cable is subjected to torsional and tensile forces.

The use of bolts to connect the coupling to the repeater was carried

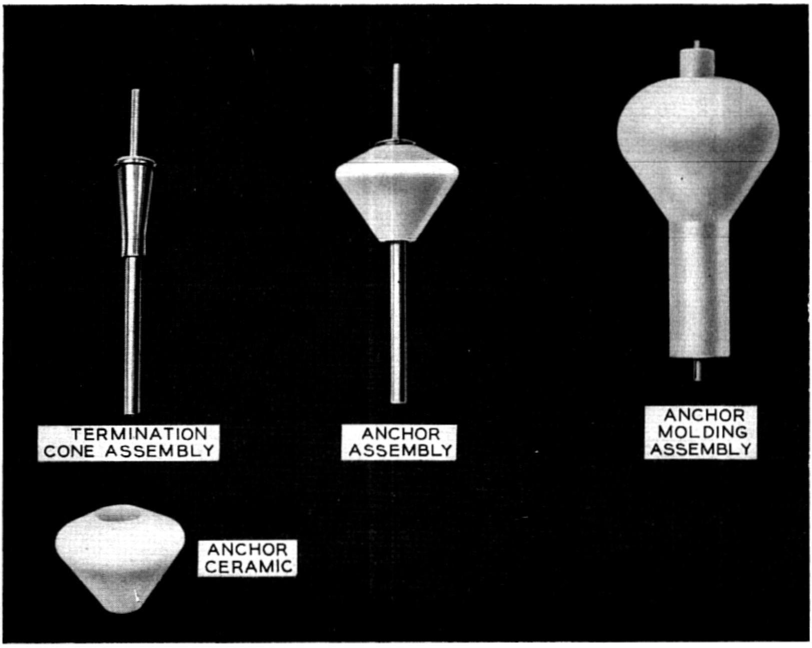

Fig. 11—Anchor molding assembly.

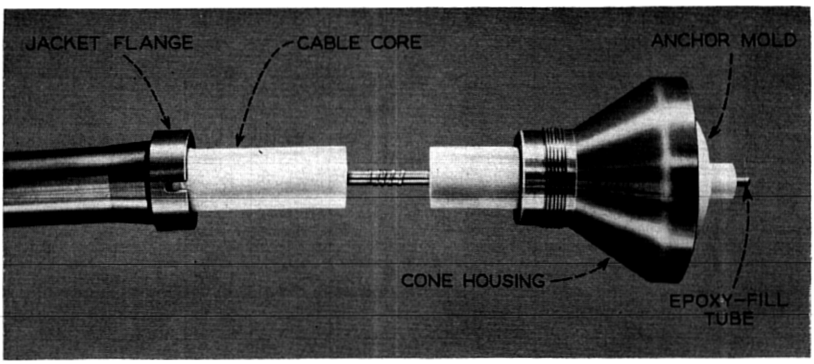

Fig. 12—8A coupling inner conductor restoration.

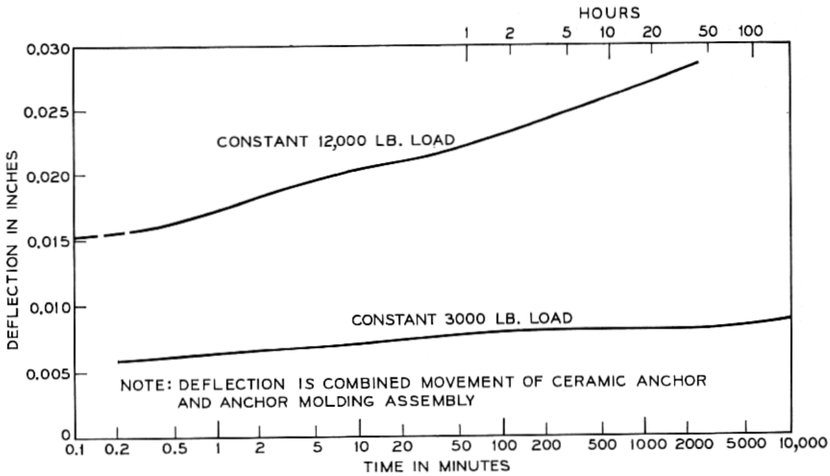

Fig. 13—Tension-loading 8A coupling anchor.

over from the SD coupling design to the initial SF design. Because of possible stress corrosion, these have been replaced by a major thread on the coupling and support housing. The large thread bearing surface minimizes stress concentrations and consequently any potential stress corrosion. Tests in the laboratory and at sea have shown the validity of the final design. The results during the installation of TAT-5 confirm this.

6.2 *Armored Coupling*

For this coupling assembly (see Figs. 10, 16 and 17), the single or inner layer of armor wires are unlayed and the end of the cable is prepared

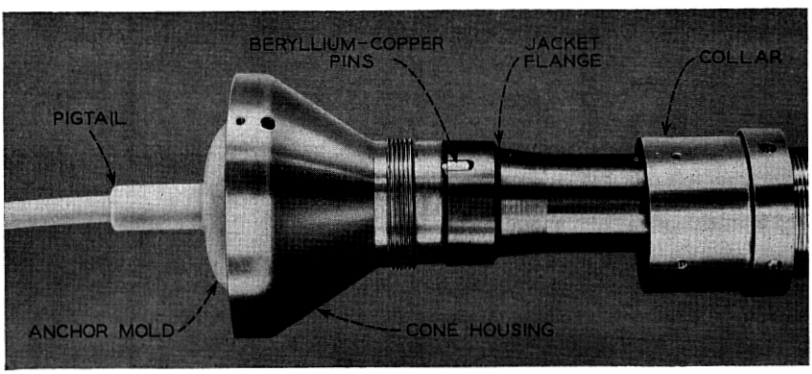

Fig. 14—8A coupling pigtail mold.

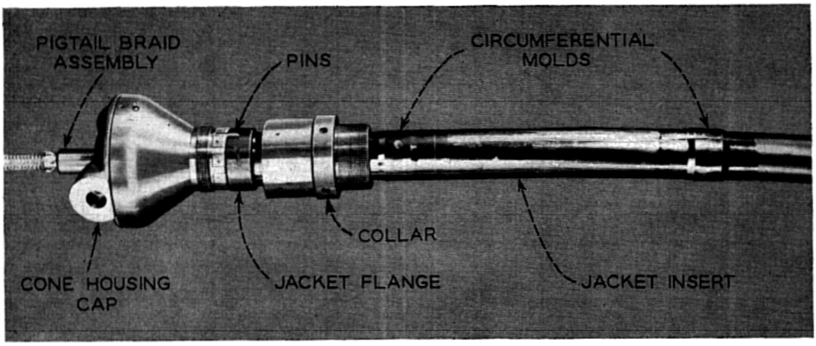

Fig. 15—8A coupling jacket restoration.

to expose the solid copper inner conductor. The core diameter is shaved; the pigtail conductor is attached directly to the cable conductor; and the insulation is restored by molding. A round copper nut with pigtail cap and braid attached is slid over the pigtail onto the shaved portion of the cable dielectric. The pigtail is then formed into a coil and given a permanent set by the application of heat. Outer conductor restoration is accomplished by slitting it into narrow longitudinal strips and brazing the strips to the round nut. A preformed jacket flange extending from the parent jacket to the end of the round nut is molded to the parent jacket. A collar screwed onto the round nut prevents longitudinal jacket movement (Fig. 16). A sub-assembly (Fig. 17) consisting of the gimbal armor support and slotted armor ring previously placed on the cable is positioned near the cable end. The armor wires are relayed and their

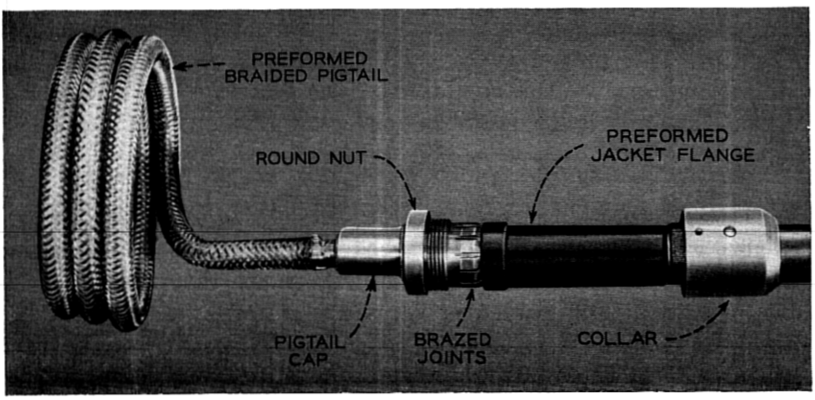

Fig. 16—8B coupling attachment of outer conductor and positioning.

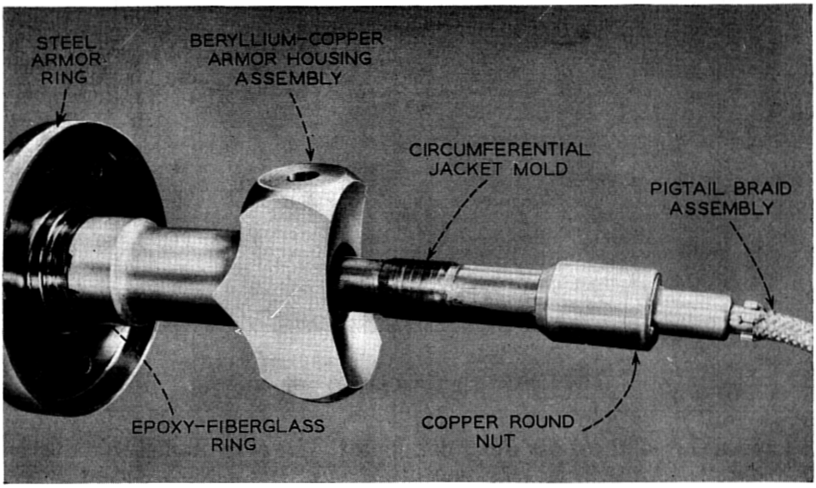

Fig. 17—8B coupling completed assembly of jacketed coaxial.

sleeved ends are placed in the proper slots on the armor ring and lashed down. The completed assembly is shown in Fig. 10.

The possible galvanic cell between the beryllium copper piece parts and the steel is eliminated by having the armor wires in direct contact with the steel armor ring, isolating this ring from the beryllium copper strength members of the coupling by the use of a nylon sleeve and epoxy-fiberglass rings. Additional corrosion protection is obtained by filling the space which the armor wire connections occupy with polyethylene-polybutene compound.

In the original coupling design, corrosion isolation was achieved by individually isolating the steel armor wires from a beryllium-copper armor ring. This proved to be only partially successful. An interim modification improved this condition for the Florida to St. Thomas SF System. The latest design described above, however, was used in TAT-5.

6.3 *Dielectric Molding*

Dielectric restorations are required at times during cable manufacture and also when couplings are attached to the cable. When joining two polyethylene parts, it is of prime importance that reliable bonds between injected and parent polyethylene material be obtained. To achieve these bonds it is necessary to have the parent polyethylene, the injectate, and the conductor in the molding area considerably hotter than the melt point of the polyethylene. These temperatures must be sustained a sufficient length of time to permit the bond to take place. Cooling must be gradual and injection pressure must be high enough and maintained long enough to prevent retraction voids and undesirable levels of internal stress. The mold must be designed to vent air, have dual diametrically opposite injection ports to minimize conductor eccentricity, and be coated with a material such as Teflon to prevent sticking. Purging the mold with the injectate improves the possibilities of good bonding because the surfaces of parent polyethylene will be washed and the temperature of the conductor will be raised to an adequate level.

All molds must be instrumented so that the complete molding cycle, including preheat, injection, and cooling is recorded. By providing the proper control equipment, it is then possible to repeat the process once a satisfactory cycle is established, since the cycle can be confirmed by chart recordings.

Operators and machines are subjected to qualification routines to assure the consistent reproduction of the proper molding cycle. The quality of a joint is determined by microtoming it to produce a thin wafer which is examined, tested in tension and heat treated. Flexing the joint around a small mandrel is also used as a criterion.

VII. SUMMARY

The purposes of this development were to provide a cable having a lower loss than the SD Cable, to better accommodate the increased frequency range of the SF System, and to provide an improved repeater to cable coupling arrangement. The tight overall system transmission requirements made it necessary to achieve the predicted cable loss frequency characteristic within narrow limits. To assure this result, tight limits had to be placed on allowable variations in material characteristics and rigid in-process controls had to be imposed. It was also necessary to design couplings which would permit the system to be laid and recovered without difficulty. The experience extending through TAT-5 indicated that the efforts were successful.

VIII. ACKNOWLEDGMENTS

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