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SPECIFICATION FOR FOUR 9.2-KM-LONG. OPTO-MECHANICAL TUBES FOR DEEPSEA ELECTRO-OPTICAL SEAFLOOR CABLE

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Abstract

This document is a manufacturing specification for a opto-mechanical tube which will contain and protect 12 optical fibers in a 35-km-long electro-optical seafloor cable. The cable will supply power- and data support to a deepsea sensor array which contains more than 200 photomultiplier tubes, and which is designed to detect and characterize ultra-high-energy neutrinos as they enter the earth from outer space. The array will be deployed to an ocean depth of about 4800 meters, and will be buoyed to a height of about 350 meters above the deep seafloor. The deployment site will be about 30 km off the Western tip of the island of Hawaii. Critical characteristics of the seafloor support cable system include:

Total cable length (km) --------- 35 (minimum)
Number of cable sections -------- 4 (maximum)
Number of optical fibers -------- 12
Type of optical fibers ---------- Single Mode

I.D./O.D. of tube (mm) ---------- 1.930/2.337
No. of electrical conductors ---- One
Type of armor ------------------- Steel, contrahelix

Cable diameter (mm) ------------- About 11.7 mm
Cable strength (kg) ------------- > 10,000
Free length in seawater (km) ---- > 22

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SPECIFICATION FOR:

FOUR 9-KM-LONG, OPTO-MECHANICAL TUBES,
FOR DEEPSEA ELECTRO-OPTICAL SEAFLOOR CABLE

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1.0 INTRODUCTION

This specification describes an opto-mechanical tube which will serve as the axial core in a deepsea electro-optical (E-O) seafloor support cable. In a total length of about 35 km, the cable will provide electrical power from a shore station to a deepsea optical array. It will also transmit command signals over a fiber optic data link from shore to the array, and will transmit fiber optic data from the array to shore. The array will be located some 30 km offshore at a depth of 4800 m.

Alternative sketches of the E-O shore cable design are shown in Figures (1) and (2). The principal purpose of this document is to describe and specify the axial opto-mechanical metal tube in this cable, the optical fibers and void filler contained by that tube, and the final fiber/tube geometry and physical performance within the cable.

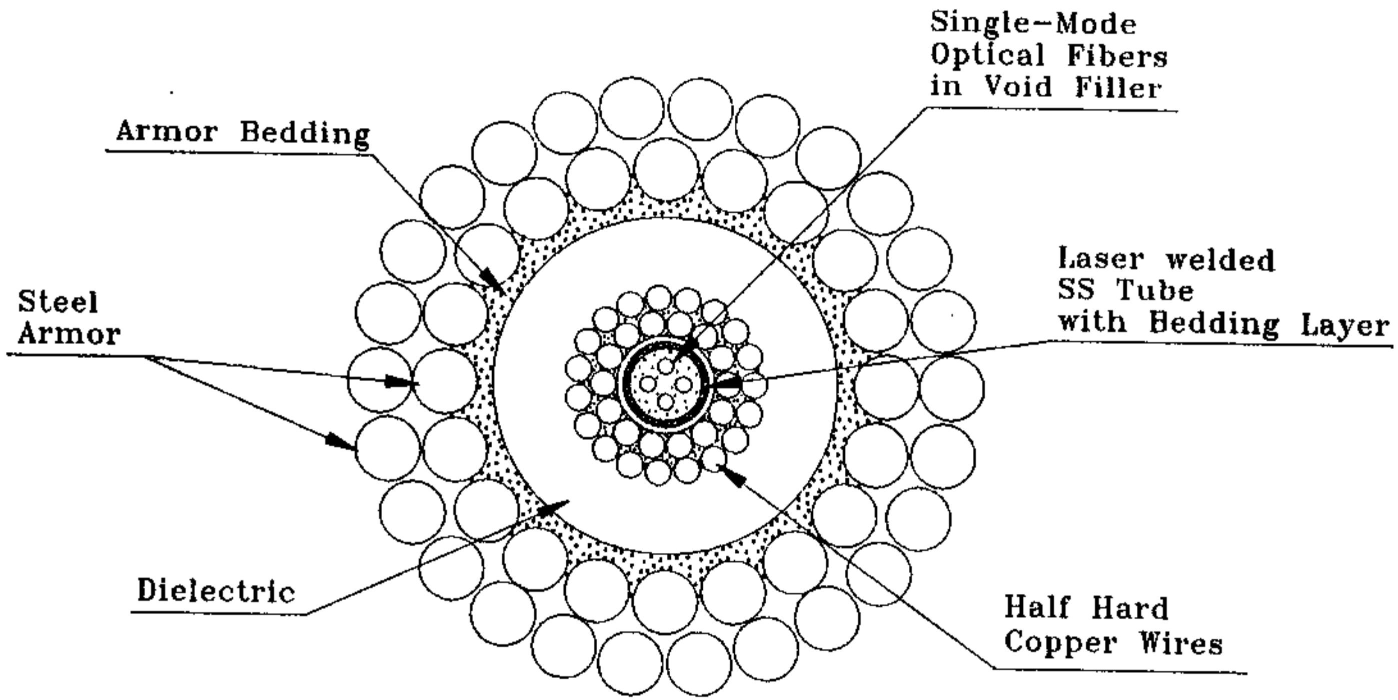
The seafloor cable system will operate DC with a seawater return. The axial metal tube will contain 12 single-mode optical fibers within a void-filling gel. The tube will be formed from a work-hardened tape of Type 304 stainless steel. During the forming process, the tube will be laser welded at a larger diameter, then immediately drawn down (in line) to the specified diameter. The laser-welded tube will contain and hermetically seal the optical fibers. These fibers will share the tube's interior space with a cushioning and void-filling gel.

The tube is designed to remain circular and unbuckled under a combination of deepsea hydrostatic pressure, tensile strain and radial pressure derived from "squeezing" of the cable core by the helical armor. Except for a small tensile component, the optical fibers should experience only isotropic (i.e., hydrostatic) stresses. After deployment, the cable will lie in a slack condition on the seafloor, and hydrostatic stresses will dominate.

This specification is written to support a sole source procurement from Laser Armor Tech (LAT), 10581 Roselle Street, San Diego, California 92121 (619-453-0670). That company developed the laser-welded opto-mechanical tube process, and is the only U.S. source having this capability. Laser Armor Tech has licensed its metal-tubing process to companies in Japan and West Germany, but remains as the only company which has fully demonstrated the ability to produce multi-fiber tubes in multi-kilometer lengths.

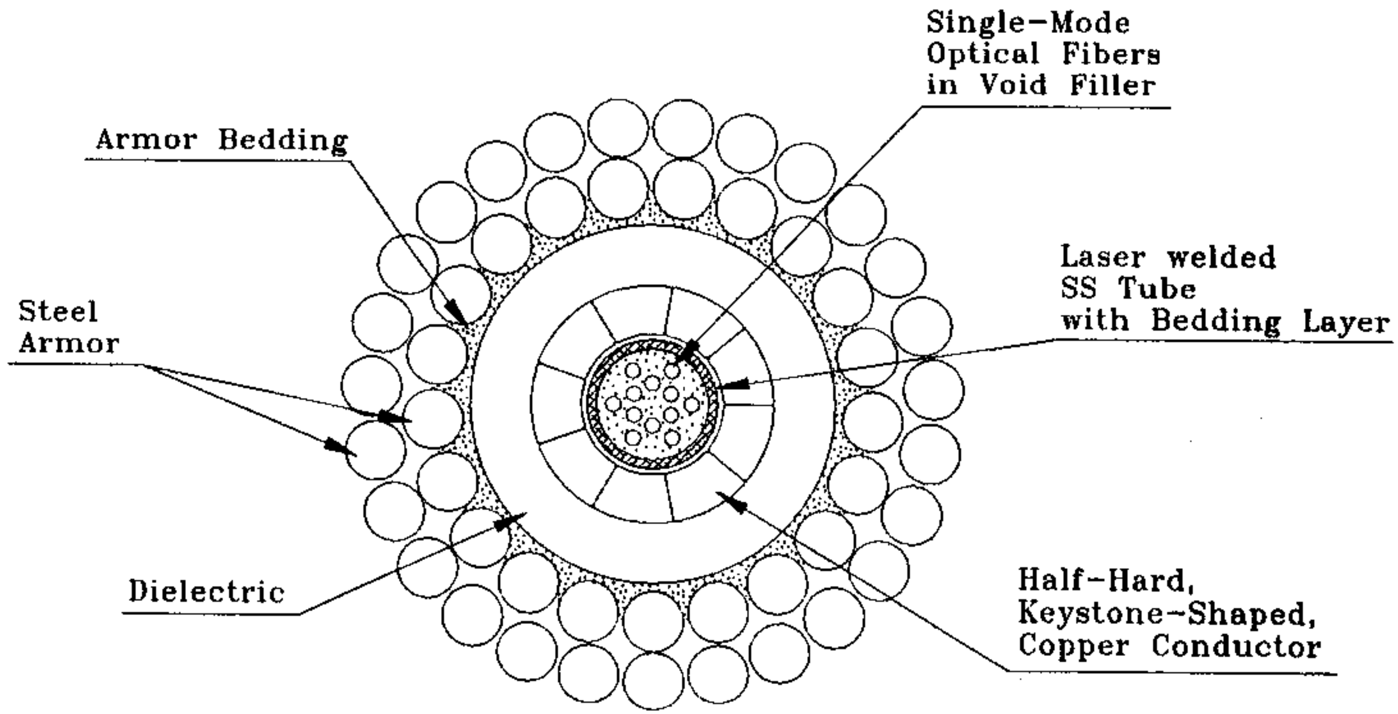
2.0 SPECIFICATIONS

To the point that they describe the in-cable geometry planned for the metal-tubed optical fibers, Figures (1) and (2) are made



E-O Seafloor Cable With Metal-Tubed Optical Fibers.
(The DUMAND version contains 12 single-mode fibers.)

Figure (1)



E-O Seafloor Cable With Keystone Conductor Wires

Figure (2)

a formal part of this specification. Table (1), which describes and specifies the 12 optical fibers to be hermetically sealed within the tube, is also made a part of this specification.

The material of the tube shall be Type 304 stainless steel, precisely cut to form a tape which will allow the industrial processes described below. At the time it is introduced to the tube-forming process, the tape shall have been worked to at least a quarter-hard temper. The tube forming steps will include:

(1) Pulling the tape through a die to form a closed tube, while;

(2) Pumping the void filler and 12 optical fibers through the die as the tube is being formed, while;

(3) Laser welding the tube's longituduinal seam to form an enclosure which---except for the ends of the tube---is hermetic, while;

(4) Immediately drawing down the welded tube in an in-line operation to precisely form a smaller, void-filled, hermetically-sealed tube with the dimensions shown below. (As a goal---described later---the completed fiber/tube unit will have a three-quarters-hard temper.)

# of Tubes	=	4		
Fibers/Tube	=	12		
Tube Length	=	> 9,200 meters		
Tube O.D.	=	2.337 mm	± 0.025	mm
	=	0.092 in	± 0.001	in
Tube I.D.	=	1.930 mm	± 0.025	mm
	=	0.076 in	± 0.001	in

The tube will be filled with a SynchoFox void filling gel*. At least 80% of the non-fiber voids within the tube must be filled with thisgel, and all residual voids must be localized (i.e., they must not be long and filamentary). It is the goal of this specification that all voids within the welded tube are to be at least 98% filled.

After a tube has been drawn down to the O.D. noted above, it is critical that its optical fibers not be in a state of axial compression. Such compression can force optical fibers into small-radius helices, and can induce microbending losses. To guard against this, as much as 0.1% residual tensile strain will be allowed when the fibers and tube are in this final condition.

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* Manufactured by Syncho Chemical Corporation, 24 DaVinci Drive, Bohemia, New York 11716. Section 2.2.4 describes the performance expected for this (or any) void-filling material.

Fiber Parameter	Units	Parameter Value
1. Fiber Type	--------	"SL" Single Mode
2. Splices Allowed	--------	None
3. Proof Stress Proof Strain	kg/sq-cm --------	At Least 14,000 At Least 2.0%
4. Mode Field Diameter	μm	8---10
5. Fiber Diameter	μm	125 ± 3
6. Buffer Type	--------	UV-Cured-Acrylate
7. O.D. of Buffer(s)	mm	0.25---0.40
8. Water Absorption	--------	< 1%
9. Concentricity A. Core/Fiber B. Fiber/Buffer	 μm μm	 < 1.5 < 15
10. Single Mode Cutoff	μm	1.19--1.27
11. Attenuation A. 1.30---1.35 μm B. 1.53---1.57 μm	 dB/km dB/km	 < 0.35 < 0.25
12. Dispersion	ps/km/nm	< 3 at 1.33 μm
13. Index Difference	--------	0.37% at 1.33 μm
14. Microbend Sensitivity	--------	See Text.

(A) If no ranges or limits are stated, dimensions are nominal.

(B) Proof stress/strain must be applied for at least 1 second.

(C) Buffer water absorption must be less than the indicated percentage of the fiber/buffer's dry weight after 24-hours exposure to 30°C at 100% relative humidity.

(D) Attenuation can be as measured on "zero tension" laboratory spool. Attenuation must also be measured on shipping reel. Both sets of attenuation data must be supplied with fiber.

Table (1). Specification For Optical Fibers In The DUMAND Deepsea Electro-Optical Shore Cable.

As a specified checkpoint to ensure this strain balance, the Technical Coordinator must review and approve---before fabrication of the metal-tubed optical fibers begins---all tensile conditions of the fabrication process. This includes, but is not limited to, tube pulling and drawing forces, fiber back tensions, void filler flow rates and sliding frictions expected during system assembly. (It is recognized that these conditions are a fundamental basis for the company's proprietary manufacturing technique. The review will take place at the company facility, and no data of a "manufacturing recipe" type will be taken away from that facility.)

2.1 Optical Fibers

Table (1) describes and specifies the optical fibers which are to be purchased by LAT and assembled into the metal-tubed system. Detailed specifications for this purchase must be given prior approval by the Technical Coordinator. (TELEFAX communication of this information to the Technical Coordinator is recommended to expedite this phase of the contract.)

Table (1) speaks of "Type SL" optical fibers. This citation refers to the type of fiber used in "SL" transoceanic optical communications. It does not necessarily mean that ATT Type "SL" fibers must be used. Depending on the results of cost and performance competition, the fibers used to complete this contract may be purchased by LAT from any of several U.S., Japanese or European sources.

As a goal, the buffer jacket for each of the 12 optical fibers is to be given a permanent and unique color which does not degrade fiber performance in any measurable way. As a minimum, a sufficient number of color codings will be used so that no more than 2 optical fibers shall share the same color code.

Past experience with the Laser Armor Tech process has shown that insertion of optical fibers into such void-filled, welded tubes normally results in either no increase or a very slight reduction of fiber attenuation. Followon cabling operations normally reduce fiber attenuation---but not usually below the values measured for the as-purchased fibers. The attenuation values specified on the next page for the tubing process allow a very small increase in attenuation during the metal tubing and cabling processes.

The "as-tubed" attenuation values shown on the next page are to be measured at the completion of the tubing/drawing process---on a reel ready for shipment to specified destination. For completeness, the table also shows the attenuation levels which will be specified for the E-O cables.

The lengths of the optical fibers are not specified here, except that they must be sufficient to allow the manufacture of fiber/tube units with finished lengths of at least 9200 meters.

Manufacturing State	Fiber Attenuation (dB/km)	
	1300--1350 nm	1530--1570 nm
Optical fibers, as delivered to Laser Armor Tech.	< 0.35	< 0.25
In completed opto-mechanical tube, on shipping reel.	< 0.38	< 0.29
In completed electro-optical cable, on shipping reel.	< 0.39	< 0.31

2.1.1 MICROBEND-INDUCED ATTENUATION

The fibers purchased for the metal tubing operation must have low susceptibility to microbends. That is, each fiber must show little or no attenuation increase when it is subjected to small-radius bending at essentially zero tensile stress. The maximum allowed fiber responses to such bending are shown in the following table.

Type Of Test	Mandrel O.D. (mm)	# Of Wraps	Wavelength (nm)	Maximum Excess Loss (dB)
Microbend	32	1	1550	0.5
Macrobend	75	100	1300	0.1
Macrobend	75	100	1550	0.5
Ref: "FOTP-62: Optical Fiber Macrobend Attenuation", EIA Standard EIA-455-62, Electronic Industries Association, 2501 I Street N.W., Washington, DC 20006 (May 3, 1988).				

These values are reported to be the microbend/macrobend performance levels required for selection of ATT "SL" optical fibers for use in that company's transoceanic electro-optical cables. Satisfaction of this performance level must be certified by the fiber supplier.

2.2 Manufacturing Options

The contractor may wish to propose technical changes to this specification; for example, of the types described in this section. If such changes are made, they must be approved (by signature) by the contract Technical Coordinator. Such approval can be given by TELEFAX.

2.2.1 Composition Of Metal Tube

This metal is specified to be Type 304 Stainless Tube. Other metals will be considered, if requested by the contractor. Examples of such candidates include Type 316 or 316L stainless steel, inconel or titanium.

2.2.2 Dimensions Of Metal Tube

No increase of tube O.D. will be permitted. A smaller tube diameter is desirable, especially if it can be obtained without reducing the tube thickness (currently 0.2 mm or 0.008").

2.2.3 Temper Of Metal Tube

As presently specified, the metal tube can have a temper as low as half hard. A higher temper (at least three-quarter hard) is very desirable, since it will give the completed metal tube a higher elastic strain limit.

2.2.4 Void Filler And Void-Filling Fraction

The contractor may wish to request a different void-filling material. Approval of such a request will depend upon (1) proof of long-term compatibility of the void filler with the optical fibers, (2) reduced manufacturing risk, and (3) evidence that a higher void-filling fraction can thereby be obtained in the final tube. It is highly desirable that the cross section occupied by the optical fibers and void filler in the tube approach 100%.

2.2.5 Goals And Standards For The Metal Tube

Level Of Performance	Tube I.D. (mm)	Tube O.D. (mm)	Tube Wall Thickness (mm)	Final Temper (hardness)
Specification	1.930	2.337	0.203	> 1/2
Desirable	Decrease	Decrease	Increase	Increase to 3/4
Unacceptable	Increase	Increase	Decrease	Decrease

3.0 TESTING

It is the intention of this specification that all tensile materials and all optical fibers are to be subjected to sufficient testing to support rational planning for followon cabling operations, as well as for cable deployment operations.

3.1 Testing Of Metal Tapes And Tubes.

It is extremely important that the temper, ultimate stress and elastic stress limits be determined for the stainless steel in the metal tubed fibers. This performance is to be measured at both the tape and tube levels of manufacturing. The following tests are required. Machine strain-vs-load plots are to be obtained, properly annotated for later interpretation, and saved for incorporation into the specified Data Report. For each test specified in the table on this page, both the tested sample and an identical (but untested) sample will be set aside for delivery to the Technical Coordinator.

Test To Be Performed On:	Type Of Tensile Test
SS Tape, Before Tubing Process	Strain-vs-load to tape failure; 5 samples from each end of each tape batch. (A "tape batch" is a wider tape from which several tapes are slit for the tubing operation.
SS Tube, After Welding But Before Draw Down	Strain-vs-load to tube failure; 5 samples from each end of each tube.
SS Tube, After Draw Down.	Strain-vs-load to tube failure; 5 samples from each end of each completed tube.
	Strain-vs-load from no-load to 50% of ultimate load; 10 cycles each for 2 samples from each end of each completed tube.

3.2 Testing Of The Optical Fibers.

For each optical fiber, optical attenuation measurements are to be made with an optical time domain reflectometer (OTDR), operated single mode and at wavelengths of 1300 and 1550 nm. Permanent records---properly annotated as to date, operator, fiber identity, test conditions and machine settings---are to be maintained for each OTDR measurement run. (These will later be incorporated in the Data Report.) OTDR attenuation measurements are to be made for each fiber at 1300 and 1550 nanometers after completion of the manufacturing phases noted below and on the next page.

(a) Fiber manufacturer's optical attenuation data. (These data are specified in order to ensure that they are obtained from the fiber manufacturer, that they are held safely by the tubing company, that that they are available as a basis for evaluation of the tubing operation, and that they are incorporated in the contract Data Report.)

(b) When the fibers are received at the contractor's facility, but before they are either (1) transferred to process reels or (2) fed into the metal-tubing process.

(c) On process reels, ready for incorporation into the metal-tubing process.

(d) After metal tubing and draw down, on the process takeup reel and before transfer to any shipping reel.

(e) On the shipping reel and ready for shipping to the contract destination.

The purpose of this optical measurement requirement is to carefully track the attenuation history of each fiber through the entire metal tubing process. Depending on the number of reel transfers to be made, it can require as few as two or as many as four OTDR measurement sets to be made at the metal tubing plant.

4.0 DELIVERABLES AND DELIVERY SCHEDULE

This contract will result in nine deliverables, as described below.

ITEM #1 ITEM #2 ITEM #3 ITEM #4	Each of these first four deliverables consists of a 9200-meter length of metal-tubed optical fibers, as described elsewhere in this specification. Each tube contains 12 optical fibers (also described elsewhere), and the continuous length of each tube and all fibers must be at least 9200 meters.

Each reel will have a minimum core diameter of at least 18 inches (45.7 cm), and it shall be constructed to secure and protect the optical fibers from (normally rigorous) shipping shocks and loadings. As an independent constraint, the minimum tube curvature induced by the reel must be large enough that the tube suffers no permanent yielding (i.e., it must not take a "set").

At least 10 meters of the inside end of the tube must project either through the reel's core into the interior of the core or out the side of the reel into a protected zone. At no point along its entire length shall the tube be allowed to suffer a radius of curvature less than 12 inches (30 cm).

The shipping reel is to be mounted on a pallet in such a way that its axis of rotation must remain in the horizontal plane. In other words, it must not be possible for gravity forces to cause the tube to slide along the reel's core.

ITEM #5 ITEM #6 ITEM #7 ITEM #8	These four ITEMS represent a separate Data Report for each 9200-meter fiber/tube unit. Three copies of each data report will be delivered. Each will contain, as a minimum:

(1) A complete manufacturer's description of both the composition and test performance of the 12 optical fibers, as they were received at LAT. The company is to make a serious effort to obtain a complete set of performance data from the fiber manufacturer.

(2) All test data obtained during tensile and optical testing of components during manufacture of the opto-mechanical tube. (See Sections 3.1 and 3.2.)

ITEM #9 All samples---both tested and untested---resulting from tensile testing of the stainless steel used to form the fiber/tube units. (See Section 3.1.)

Items (5) through (9) are to be Air Mailed to the University of Hawaii Technical Coordinator for this contract. Items (1) through (4) will be shipped by Air Express to the company which wins the contract to build the DUMAND E-O cable. The address of this company will be supplied to LAT at least two weeks in advance of the delivery date for Item #1 of this contract.

4.1 Delivery Schedule.

ITEM #1	Within 12 Weeks After Receipt Of Order.
ITEM #2	Within 14 Weeks After Receipt Of Order.
ITEM #3	Within 15 Weeks After Receipt Of Order
ITEM #4	Within 16 Weeks After Receipt Of Order.
ITEM #5	Within 4 weeks after shipment of ITEM #1.
ITEM #6	Within 4 weeks after shipment of ITEM #2.
ITEM #7	Within 4 weeks after shipment of ITEM #3.
ITEM #8	Within 4 weeks after shipment of ITEM #4.
ITEM #9	Within 4 weeks after shipment of ITEM #4.

5.0 TECHNICAL COORDINATOR

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