SPECIFICATION FOR:
36-KM-LONG, DEEPSEA,
ELECTRO-OPTICAL, COMMUNICATION CABLE

SEPTEMBER, 1990

ABSTRACT

This document is a manufacturing specification for a seafloor electro-optical (E-O) cable which will give power and telemetry support to the Deep Underwater Muon And Neutrino Detector (DUMAND) experiment. The cable described here will be fabricated in four sections; each having a nominal length of 9 km and each containing 12 optical fibers. These cable sections will be physically-, electrically- and optically joined to form a total cable length of approximately 36 km. The completed cable will be deployed to a water depth of approximately 4800 meters to support the DUMAND experiment. This document presents two "model" designs for the E-O cable---in terms of its component materials, dimensions, geometry, and tolerances. It also summarizes expected cable performance. The final purchase specification will be a composite of (1) this document, (2) modifications proposed by the winning bidder, and (3) a final (purchaser's) memorandum which will reconcile any differences between the first two documents.

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1.0 INTRODUCTION

This specification describes an electro-optical (E-O) cable which will furnish digital control signals and electrical power to a deepsea optical sensor array, while receiving digital data from that array. The cable is to be fabricated in four sections, each with a nominal length of 9+ km. The total delivered cable length must be at least 36 km. After delivery, the cable sections will be joined with electrical/optical/mechanical connectors, and will be deployed as a single linear unit.

The cable system is designed for one-time deployment down the steep and rocky slope of a volcanic island to a depth of 4800 meters. A junction box will be attached to the cable's sea end, and will be deployed at the same time. Connecting E-O cables will later be plugged into the junction box, using deepsea, make-and-break, optical and electrical connectors. These connections will be performed by a manned or unmanned submersible.

(1) The cable must be small, dense and rugged. These constraints are applied in order to reduce the impact of cable size and weight on the cost and risk of transport and deployment. They also enable the cable to better withstand bending stresses and abrasive forces on rocky seafloors.

(2) The cable must have high capacity in power transfer, depth capability, operating length and telemetry bandwidth. It will contain 12 single-mode optical fibers, and will operate DC with a single conductor and a seawater circuit return. The anticipated data rate will be in excess of 5 GB/second.

(3) The cabled optical fibers must be provided with near-total isolation from external stresses.

1.1 Overview Of The "Model Design" Cables

This specification document describes two "model" E-O cable designs. These have been thoroughly analyzed, and should meet or exceed all performance levels specified in this document. The cross sections of these cables are sketched in Figures (1) and (2). They differ only in having different structures for the electrical conductor (and in the effect that difference has on cable diameter).

MODEL #1	The single electrical conductor is a contrahelix of AWG-standard copper wires.
MODEL #2	The conductor is a helix of keystone-shaped copper units which fill 96% of the annulus.

These model designs are historically related to a series of E-O cables which were developed by the author at the Naval Ocean Systems Center and, more recently, at the University of Hawaii. In several of the earlier developments, am attempt was made to fit the model design structure to that of a standard oil well logging cable. In the initial (1983) development prototype, for example, the dielectric insulation O.D., the armor package, and the conforming of the armor to the insulation were taken directly from The Rochester Corporation's 1-H-375 oil well logging cable.

Cable manufacturers are invited to propose changes to either model design if they believe such changes can improve the cable's performance, reduce fabrication risks, and/or reduce purchase cost. Reasonable modifications to either model will be considered---but they must be fully justified, and the company must be able to show that it has successfully fabricated cables which are similar to any recommended design modifications.

The final purchase specification for this contract will be a synthesis of this document with acceptable changes recommended by the winning cable manufacturer. The result---documented formally by a University of Hawaii reconciliation letter---will be a "build to plan" specification, moderated by specifications on cable performance for such fundamental parameters as strength, conductor/insulation resistance and optical attenuation.

1.1.1 **FIBER TUBE.** Both of the model designs incorporate a welded, stainless steel tube which contains 12 optical fibers in a void-filling matrix. Four 9200-meter lengths of this opto-mechanical structure will be supplied to the cable contractor, together with complete data on the performance of the component optical fibers.

The cable manufacturer will extrude a thin elastomeric jacket around this opto-mechanical tube. The jacket will serve as a bedding layer for the served copper conductor units.

1.1.2. **ELECTRICAL CONDUCTOR.** The cable will contain only one electrical conductor, and can be operated AC or DC with a seawater return. Two design options are presented here as models for the conductor design.

MODEL #1. The electrical conductor is formed as a contrahelix of round copper wires. This design approach is relatively straightforward, and is well within the capabilities of any competent cable manufacturer. It has two serious deficiencies which will cause cable diameter, weight and stiffness to grow. First, the density of the copper wires within the conductor annulus is low (PI/4 packing factor). Second, the irregular outer surface of the copper wires increases voltage stress in the dielectric. These effects combine to force increases in the O.D.'s of the conductor, the dielectric and the armor package.

MODEL #2. Here, the conductor annulus is a single helix of keystone-shaped copper units. These fill the conductor annulus with higher (96%) efficiency. Also, the conductor's relatively smooth outer surface will decrease both voltage stress and minimum dielectric thickness.

The Model #1 design is more conventional and, therefore, will probably be more attractive to cable manufacturers. But as Tables (1) through (4) show, it imposes a serious growth penalty on cable diameter, stiffness and weight. The Model #2 design may be more difficult to build and will probably be more expensive. But it will have a major impact in reducing the size, weight and cost of the deployment system.

1.1.3. **DIELECTRIC AND ARMOR BEDDING LAYER.** The (void filled) conductor structure is jacketed with a tough layer of dielectric insulation. Around this layer is formed a taped or extruded layer of softer (initially uncured) elastomer which serves as a distortable bed for the cable's steel armor.

1.1.4. **ARMOR.** In the final assembly step, the E-O cable core is armored with a contrahelix of galvanized, plow steel wires (XGIPS or SXGIPS). Figures (1) and (2) show that the wires of the inner armor helix are pressed into the armor bedding layer. It is the intention of this specification that such bedding occur (without axial strain) at the armor closing die---helping to stabilize the geometry of the inner armor so that cable constructional stretch during initial loading cycles will be minimized.

1.1.5. **WHAT IS "OPTIMUM"?** The dimensions and geometry of the conductor/dielectric structure can be adjusted to give the cable an electrical resistance which (approximately) optimizes its operational performance. In the model designs presented here, this means that---for any pair of constraints on cable length and power transfer---we can choose a diameter (or thickness) for the conductor units which minimizes the diameter of the cable's E-O core.

Tables (1) and (2) compare electrical and physical performance of the model designs for 4 choices of conductor unit diameter or thickness. Note that the diameter of the inner and outer armor wires were arbitrarily held constant in this study. These data were used to select 0.5105-mm-O.D. (24 AWG) conductor wires for the Model #1 cable, and 0.75-mm-thick keystoned conductor units for the Model #2 design. (See Tables 3 and 4 for design details.)

These design choices need not give the lowest values for cable diameter. Usually, the selection is a "best" compromise among several conflicting constraints---conductor wire diameter (small), cable diameter (small but matched to a standard winch), and conductor/armor coverage (high, but not so high as to cause lockup at high cable tension.

1.1.6. **REQUIREMENTS FOR A RESPONSIVE BID.** The goal of this specification document is the successful procurement of a cable which responds to the "Model #2" design. In working toward this goal, it is also recognized that---given current capabilities and attitudes within the cable industry---such a contract may not (yet) be reasonable or even possible.

In the face of this possibility, it is still a requirement of this purchase document that cost and delivery time bids must be returned for both model designs. To the extent that any bid ignores the Model #2 cable design, it will be treated as "nonresponsive." A bid which rejects the Model #2 approach will be accepted without prejudice if (and only if) the reasons for such rejection are clearly and fully stated.

2.0 CABLE SPECIFICATIONS

To the extent indicated, the following Figures and Tables are part of this specification document.

FORMAL SPECIFICATION DOCUMENTS

MODEL DESIGN #1	Figure (1):	Cross Section Sketch.
	Table (8):	Diameters And Geometries.
MODEL DESIGN #2	Figure (2):	Cross Section Sketch.
	Table (9):	Diameters And Geometries.
FOR BOTH	Table (6):	Material Specifications.
	Table (7):	Optical Fiber Specifications.
	Table (12):	Performance Specifications.
	Table (13):	Specified Measurements.

INCLUDED FOR GUIDANCE ONLY

MODEL DESIGN #1	Table (1):	Study of Conductor Structure.
	Table (3):	Model Geometry/Performance.
	Table (5):	KNAPPSAC Torque Analysis.
	Table (10):	Cross Sections And Weights.
MODEL DESIGN #2	Table (2):	Study of Conductor Structure.
	Table (4):	Model Geometry/Performance.
	Table (11):	Cross Sections And Weights.

2.1 Cable Length

Four 9.2+-km-long sections of opto-mechanical tube will be supplied to the cable manufacturer. Four sections of the specified E-O cable are to be completed by the cable manufacturer and delivered to the University of Hawaii. These sections will later be joined to form a 36-km-long deployment length. While the length of each delivered cable need not be precisely 9 km, it is essential that joining of the four delivered cables must result in a total cable length of at least 36 km. The following constraints are specified on cable length.

2.1.1 **CONDUCTOR CONTINUITY.** Each delivered E-O cable section must contain twelve continuous optical fibers and one continuous electrical conductor. These conductors and the cable insulation must pass all tests specified elsewhere in this document.

2.1.2 **CABLE SECTION LENGTHS.** Each cable section must be continuous for a length of not less than 8.5 km. In addition, the length of all four cable sections must total at least 36 km.

2.2 Cable Materials

The materials chosen for the model cable design are listed in Table (6). Any proposals of alternative materials must be accompanied by complete sets of manufacturer's supporting data sheets, as well as by substantial arguments to support the substitution.

2.2.1. **OPTO-MECHANICAL TUBE.** Four 9200-m lengths of this 12-fiber metal tube---the heart of the DUMAND E-O tether---are being built by Laser Armor Tech* under a separate contract, and will be shipped to the cable manufacturer by that company. The following table, extracted from the Appendix, describes the expected and specified attenuation of the fibers in that tube.

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 O-M tube, on shipping reel, ready to leave L.A.T.	< 0.38	< 0.29
In E-O cable, on shipping reel, ready for delivery.	< 0.39	< 0.31

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* **To determine status and performance of this O-M tube while preparing bids for this contract, all cable companies are invited to contact Laser Armor Tech, 10581 Roselle St., San Diego, CA 92121 (Chambos Theodossi, 619-453-0670).**

2.2.2. CONDUCTOR BEDDING LAYER. This Nylon-12 jacket will be extruded by the cable manufacturer over the bare O-M tube. Its purpose is to form an elastomeric bedding layer which acts to diffuse contact stresses of the copper wires on the stainless steel tube. This jacket should be added immediately after the as-received O-M tube has been tested for optical attenuation.

2.2.3. ELECTRICAL CONDUCTOR STRUCTURE. In both keystone- and wire configurations, this conductor will be copper, drawn to at least a half-hard temper. Even higher tempers are desirable in order to increase that metal's elastic strain limit. During serving into the cable structure, however, these wires must be yielded so that they fully conform to the surface of the conductor bedding layer.

The values shown for cable resistance in Tables (1---4) assume that work hardening of the copper units will have reduced their conductivity to 96% (re the IACS standard for electrical copper). Tables (2) and (4) also assume that the keystone-shaped conductor units have 96% coverage.

All voids within the conductor structure are to be completely filled. The model designs assume that the INSTAWELD (a thermosetting elastic glue) is used for this purpose. It is a requirement of this specification that all outer conductor channels must be thoroughly cleaned of void filler in order to ensure better bonding between the copper and the insulation.

2.2.4. DIELECTRIC INSULATION. The electrical insulation is to be pressure extruded to the diameter shown in Table (8) or 9). A conventional spark test is to be applied between the cooling trough and the takeup reel. All regions which fail the spark test are to be marked and repaired in an offline operation.

Before proceeding on to application of the armor bed and the steel armor, the E-O core must pass a standard soak/HIPOT test. The core will be immersed in a conductive water bath, with the ends of the core free of the water and dry. A detergent additive and ultrasonic agitation will be used if necessary to ensure complete wetting of the insulation surface. High voltage will be applied from both ends to determine if the cable passes the insulation resistance test. If it does not, then the point(s) of low resistance will be determined---if necessary, by increasing the test voltage until the regions of reduced insulation resistance are punched through. After repair of any weak points, the wet soak test is to be repeated.

2.2.5. ARMOR BEDDING LAYER. In the model designs, this layer is an uncured Butyl/Nylon or Neoprene/Nylon tape, wound around the E-O core with 50% overlap. It serves as a soft distortable layer into which the armor wires will bed as the cable passes through the (inner armor) closing die. Ideally, the distortion will be just sufficient to fill all cusps under these wires, and bedding will occur without axial cable strain.

After armoring, the bedding layer is to be cured into its normal hardened condition by heat-soaking the entire cable in an oven. The curing time/temperature profile must be chosen so that there is no danger of softening elastomeric cable components or of vaporizing any volatiles in the cable void fillers (including those in the opto-mechanical tube).

2.2.6. **LOADBEARING ARMOR.** Dimensions and helix geometry for the contrahelical steel armor are shown for the model design in Tables (8) and (9). The wire material is described in Table (6). The performance expected for the Model #1 armor package is shown in Tables (5) and (12). The model design armor is Run #16 in Table (5).

Both the inner and outer armor layers are to be applied with a preform factor of 70% to 75%, defined by:

$$\textbf{\% Preform} = 100 \left[\frac{Ho - 2d}{Do - 2d} \right]$$

where;

Do = The overall diameter of an armor layer, after it has been served onto the cable core.

Ho = The greatest height of a helix (above a flat surface) formed by an armor wire after it has been removed (without distortion) from the armor helix. This value must always be less than Do.

d = The diameter of the armor wire.

Conforming (bedding) of the first armor helix into the surface of the armor bedding layer is a "most critical" part of this specification. It is the intention of the specification that this is to be done with little or no permanent stretching of the opto-mechanical tube. Tables (8) and (8) show the effective diameter of the armor bed after serving of the first armor layer.

The wet soak test is to be repeated after completion of the armoring operation. If any region(s) of low insulation resistance are observed, then (only) non-destructive means are to be used to determine their approximate location. In this event, the HIG Technical Coordinator is to be **immediately** notified.

3.0 CABLE PERFORMANCE

This document is primarily a manufacturing specification. At the same time, certain minimum standards for cable performance must be set to ensure that "best manufacturing practices" are followed in fabrication of the E-O cables described here. These standards are shown in Table (12).

4.0 CABLE TESTING

Table (13) lists performance tests which are to be run during and after fabrication of each E-O cable section. Additional details are given below.

(a) 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 are to be maintained of each OTDR measurement run.

(b) The wet soak technique for measurement of cable insulation resistance was described in Section (2.2.4).

(c) Tensile properties (ultimate strength and stress/strain) need be measured only once for each discrete delivery of armor wires. Ten load/strain (during pull-to-break) tests will be performed for each wire size and delivery group.

(d) Two pull-to-break tests will be carried out for each section of E-O cable---one with both cable ends fixed and the other with one cable end free to rotate. At loads to 30% of rated breaking strength, each cable section must be instrumented for measurement of cable strain versus tensile load.

(e) Two strain-vs-load measurement will be made for each section of E-O cable---one with both cable ends fixed and the other with one cable end free to rotate. The cable need not be broken, as long as the applied tension load is at least 30% of the measured value for ultimate cable strength. For each test sample, ten load cycles are to be imposed, with strain-vs-load measured and documented for each cycle.

Note that tests (d) and (e) naturally fit together. It is recommended that test (e) be applied first, and that the test sample then be pulled to break.

5.0 TEST DATA

Each cable section is to be assigned a unique serial number, which is to follow it throughout production, and which is to be permanently attached to the cable (and marked on its shipping reel when it is delivered). Each cable will be provided with a test log which bears this serial number. As a minimum, this log is to include:

(a) Manufacturing data, using the general formats of Tables (6) for materials, and (8) and (9) for cable geometry.

(b) Cable performance, reporting the results of tests described in Table (13) and Section (4).

6.0 DELIVERABLES AND DELIVERY SCHEDULE

Four 9-km cable units are to be delivered to the University of Hawaii under this contract. Each delivered cable unit will consist of two items---the cable on its shipping reel and the cable test log described in Section (5).

Each cable section is to be precision wound on a substantial wood or steel shipping reel. The core of that reel will have a diameter of at least 76 cm (30 in).

At least 10 meters of the inside end of each cable must be accessible on the shipping reel. This can be done by ducking that inside end through the reel core and into the center of the reel. As an alternative, it can be done by providing the reel with a false end to contain the inner end of the cable.

The reel is to be mounted on a pallet so that its axis of symmetry (axis of rotation) is constrained to lie in a horizontal plane. An impact-resistant cover must be provided to protect each cable on its shipping reel.

Each cable reel is to be delivered by expedited truck and sea transport to the address shown below. Test reports are to be airmailed to the same address.

Hawaii Institute of Geophysics
2525 Correa Road,
University of Hawaii,
Honolulu, Hawaii 96822
ATTN: George Wilkins, Room 320
808-956-4596 (Office)
808-261-0549 (Home)
808-956-2538 (FAX)
or:
Bob Mitiguy, Room 153
808-956-8910

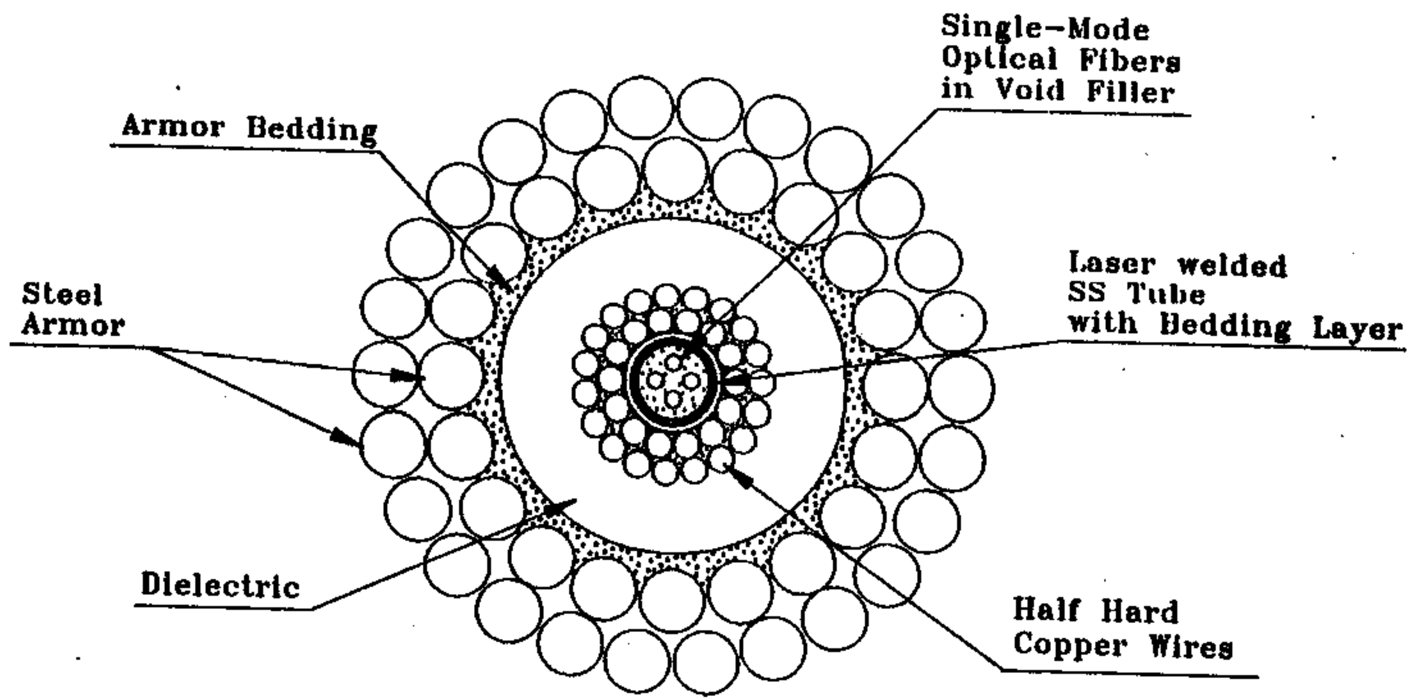
The first cable section is to be delivered within four months after the contract starting date, or within 4 months after receipt of its opto-mechanic core unit (whichever comes later). Succeeding deliveries will be made every two weeks afterward, with the same stipulation. Test Reports will be delivered within two weeks after their corresponding cable sections have been shipped.

7.0 TECHNICAL COORDINATION

Technical Coordination by the University of Hawaii will be provided by:

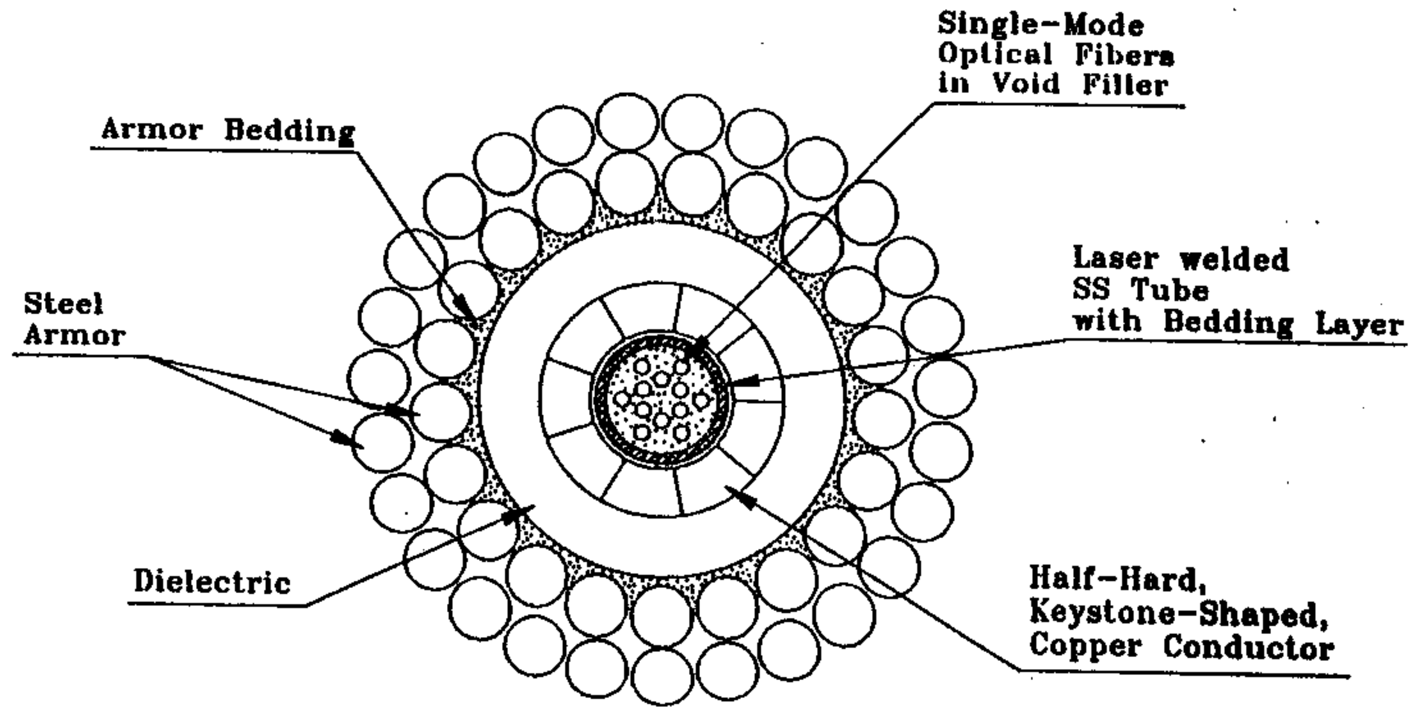
TECHNICAL COORDINATOR: George Wilkins
(See Section 6.0).

ASSOCIATE COORDINATOR: Bob Mitiguy
(See Section 6.0).



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)

System And Material Design Constraints		
Cable Length	35,000	meters
Operating Depth	4800	meters
Required Cable Safety Factor	> 3	
Delivered Power	5500	watts
Power Delivery Mode	DC	sea return
Voltage Drop At The Vehicle	350	VDC
Conductor Conductivity	96%	
Max. Ins. Voltage Stress Allowed	1970	VDC/mm
Assumed Conductor Helix Angle	15	deg
Assumed Armor Helix Angle(s)	18	deg
Armor Ultimate Stress	20,390	kg/squ-cm

Electrical Section:				
Cond. Wire O.D. (mm)	0.4049	0.4547	0.5105	0.5733
Armor I.D. (mm)	7.664	7.363	7.339	7.454
# Wires, 1st Conductor	22	20	18	17
Wire Coverage (%)	96.3	96.7	96.0	97.5
# Wires, 2nd Conductor	28	26	24	23
Wire Coverage (%)	96.8	97.2	96.7	97.9
Supply Voltage (VDC)	1902	1692	1519	1326
Line Current (amp)	15.71	15.71	15.71	15.71
Cable Resist. (ohm/km)	2.822	2.440	2.125	1.775
Ratio; Load-to-Line Res.	0.225	0.260	0.299	0.358
First Armor Layer				
Wire Diameter (mm)	1.024	1.024	1.024	1.024
Number of Wires	25	24	24	24
Wire Coverage (%)	98.6	98.0	98.3	97.0
Second Armor Layer				
Wire Diameter (mm)	1.291	1.291	1.291	1.291
Number of Wires	25	24	24	24
Wire Coverage (%)	98.1	96.8	97.1	96.0
Cable Weight (kg/km)				
In Air	560.3	547.3	556.3	571.9
In H2O (Sp.Gr. = 1.04)	448.2	441.5	450.8	464.9
Specific Gravity	5.19	5.37	5.48	5.55
Cable Strength (kg)	11,000	10,600	10,640	10,700
"Free" Length (km)	24.5	24.0	23.6	22.9
Cable Diameter (mm)	12.29	11.99	11.97	12.08

Table (1). DUMAND Model #1 Design: Responses To Four Values Of Conductor Wire Diameter.

System And Material Design Constraints					
Cable Length	35,000 meters				
Operating Depth	4800 meters				
Required Cable Safety Factor	> 3				
Delivered Power	5500 watts				
Power Delivery Mode	DC sea return				
Voltage Drop At The Vehicle	350 VDC				
Conductor Conductivity	96%				
Max. Ins. Voltage Stress Allowed	1970 VDC/mm				
Assumed Conductor Helix Angle	15 deg				
Assumed Armor Helix Angle(s)	18 deg				
Armor Ultimate Stress	20,390 kg/squ-cm				

Electrical Section:				
Cond. Thickness (mm)	0.70	0.75	0.80	0.85
Armor I.D. (mm)	6.780	6.597	6.841	6.941
Supply Voltage (VDC)	1754	1644	1547	1462
Line Current (amp)	15.71	15.71	15.71	15.71
Cable Resist. (ohm/km)	2.554	2.353	2.177	2.022
Ratio; Load-to-Line Res.	0.249	0.270	0.292	0.314
First Armor Layer				
Wire Diameter (mm)	1.024	1.024	1.024	1.024
Number of Wires	22	22	22	23
Wire Coverage (%)	96.6	98.9	95.8	98.9
Second Armor Layer				
Wire Diameter (mm)	1.291	1.291	1.291	1.291
Number of Wires	23	22	23	23
Wire Coverage (%)	98.2	95.6	97.6	96.6
Cable Weight (kg/km)				
In Air	510.4	502.5	521.1	534.3
In H2O (Sp.Gr. = 1.04)	415.3	410.9	425.3	436.3
Specific Gravity	5.58	5.70	5.65	5.67
Cable Strength (kg)	9,740	9,500	9,780	9,9600
"Free" Length (km)	23.3	22.9	22.8	22.6
Cable Diameter (mm)	11.41	11.23	11.47	11.57

Table (2). DUMAND Model #2 Design: Responses To Four Values Of Conductor Annulus Thickness.

SYSTEM PARAMETERS

CABLE OD (MM)	= 11.969	POWER (W)	= 5500
C. LENGTH (KM)	= 35	# FIBERS	= 12
TUBE CONDUCT.	= .1	WIRE CONDUCT.	= .96
MAX. V. STRESS	= 19700	TRUE DIEL. S.	= 18485

COMPONENT SPECIFIC GRAVITIES

FIBERS	= 2.2	FIBER BUFFER	= 1.12
VOID FILLERS	= .872	METAL TUBE	= 7.94
COND. BED	= .92	COND. WIRES	= 8.84
INSULATION	= .9	ARMOR BED	= 1.43
ARMOR	= 7.94	DEESEA WATER	= 1.04

COMPONENT ULTIMATE TENSILE STRESSES (KG/SQ-CM)

TUBE	= 5000	COND. WIRES	= 3000
ARMOR	= 20390		

DIAMETERS OF CABLE COMPONENTS (MM)

FIBER OD	= .254	TUBE ID	= 1.981
COND. WIRE OD	= .5105	TUBE OD	= 2.387
COND. STR. OD	= 4.683	COND. BED OD	= 2.641
DIELECTRIC OD	= 6.889	ARMOR BED OD	= 7.789
ARMOR ID	= 7.339	ARMOR OD	= 11.969

CABLE HELIX PROPERTIES (deg & mm)

WIRE # 1ST CDR	= 18	1ST CDR WIRE OD	= .5105
1ST CDR ANGLE	= 15	1ST CDR COVER.	= .96
WIRE # 2ND CDR	= 24	2ND CDR WIRE OD	= .5105
2ND CDR ANGLE	= 15	2ND CDR COVER.	= .967
WIRE # 1ST ARM	= 24	1ST ARM WIRE OD	= 1.024
1ST ARM ANGLE	= 18	1ST ARM COVER.	= .983
WIRE # 2ND ARM	= 24	2ND ARM WIRE OD	= 1.291
2ND ARM ANGLE	= 18	2ND ARM COVER.	= .971

CABLE WEIGHTS (KG/KM)

FIBERS	= 3.239	F. BUFFERS	= 5.16
METAL TUBE	= 11.07	V. FILLERS	= 3.4
COND. BED	= .92	CU. WIRES	= 78.67
INSULATION	= 19.33	ARMOR BED	= 14.83
ARMOR	= 427.2	IN-AIR WEIGHT	= 556.3
IN-H20 WEIGHT	= 450.8	SP. GRAV.	= 5.48

CABLE TENSILE PROPERTIES (KG, KM AND UNITLESS)

TUBE STRENGTH	= 72.4	COND STRENGTH	= 110.8
ARMOR STRENGTH	= 10309	CABLE STRENGTH	= 10640
OPER. DEPTH	= 4.8	FREE LENGTH	= 23.6

CABLE ELECTRICAL PROPERTIES (VOLTS/AMPS/OHMS)

VOLTAGE REGUL.	= .299	J-BOX VOLTAGE	= 350
SHIP VOLTAGE	= 1519	LINE CURRENT	= 15.71
CABLE RESIST.	= 74.39	LOAD RESIST.	= 22.27

TABLE (3): DUMAND MODEL #1 DESIGN DETAILS.

SYSTEM PARAMETERS

CABLE OD (MM)	= 11.227	POWER (W)	= 5500
C. LENGTH (KM)	= 35	# FIBERS	= 12
TUBE CONDUCT.	= .1	WIRE CONDUCT.	= .96
MAX. V. STRESS	= 19700	TRUE DIEL. S.	= 19700

COMPONENT SPECIFIC GRAVITIES

FIBERS	= 2.2	FIBER BUFFER	= 1.12
VOID FILLERS	= .872	METAL TUBE	= 7.94
COND. BED	= .92	CONDUCTOR	= 8.84
INSULATION	= .9	ARMOR BED	= 1.43
ARMOR	= 7.94	DEESEA WATER	= 1.04

COMPONENT ULTIMATE STRESSES (KG/SQ-CM)

TUBE	= 5000	CONDUCTOR	= 3000
ARMOR	= 20390		

DIAMETERS OF CABLE COMPONENTS (MM)

FIBER OD	= .254	TUBE ID	= 1.981
COND. THICKNESS	= .075	TUBE OD	= 2.387
COND. STR. OD	= 4.141	COND. BED OD	= 2.641
DIELECTRIC OD	= 6.197	ARMOR BED OD	= 6.997
ARMOR ID	= 6.597	ARMOR OD	= 11.227

CABLE HELIX PROPERTIES (deg & mm)

COND. ANGLE	= 15	COND. COVERAGE	= .97
WIRE # 1ST ARM	= 22	1ST ARM WIRE OD	= 1.024
1ST ARM ANGLE	= 18	1ST ARM COVER.	= .989
WIRE # 2ND ARM	= 22	2ND ARM WIRE OD	= 1.291
2ND ARM ANGLE	= 18	2ND ARM COVER.	= .956

CABLE WEIGHTS (KG/KM)

FIBERS	= 3.239	F. BUFFERS	= 5.16
METAL TUBE	= 11.07	V. FILLERS	= 2.36
COND. BED	= .92	CONDUCTOR	= 68.52
INSULATION	= 15.23	ARMOR BED	= 11.85
ARMOR	= 391.6	IN-AIR WEIGHT	= 502.5
IN-H20 WEIGHT	= 410.9	SP. GRAV.	= 5.7

CABLE TENSILE PROPERTIES (KG, KM AND UNITLESS)

TUBE STRENGTH	= 69.7	COND. STRENGTH	= 337.9
ARMOR STRENGTH	= 9098	CABLE STRENGTH	= 9505
OPER. DEPTH	= 4.8	FREE LENGTH	= 23.1

CABLE ELECTRICAL PROPERTIES (VOLTS/AMPS/OHMS)

VOLTAGE REGUL.	= .27	J-BOX VOLTAGE	= 350
SHIP VOLTAGE	= 1644	LINE CURRENT	= 15.71
CABLE RESIST.	= 82.35	LOAD RESIST.	= 22.27

TABLE (4). DUMAND MODEL #2 DESIGN DETAILS.

Parameter	Design 18	Design 16	Design 19
Inner Armor			
Number of Wires	24	24	24
Core Diameter (mm)	7.34	7.340	7.340
Wire Diameter (mm)	1.024	1.024	1.024
Helix Length (mm)	75	85	90
Helix Angle (deg)	19.31 L	17.18 L	16.28 L
No-Load Coverage (%)	99.3	98.1	97.6
Outer Armor			
# of Wires	24	24	24
Wire Diameter	1.291	1.291	1.024
Helix Length (mm)	100	100	100
Helix Angle (deg)	18.55 R	18.55 R	18.55 R
No-Load Coverage (%)	97.6	97.6	97.6
Ends Fixed; 2500-kg load			
Torque (kg-cm)	115.0	117.5	119.5
Cable Strain (%)	0.2895	0.2804	0.2769
Coverage; inner (%)	99.6	98.4	97.9
outer (%)	97.8	97.8	97.8
Safety Factor			
(inner)	4.37	4.26	4.22
(outer)	4.18	4.30	4.34
Ult. Strength (kg)	10,445	10,640	10,545
Breaks In ____ Armor	Inner	Inner	Outer
Ends Free; 2500-kg load			
Rotation (deg/m)	-26.8	-26.5	-31.15
Cable Strain (%)	0.3115	0.2999	0.3037
Coverage; inner (%)	99.6	98.4	98.0
outer (%)	97.8	97.7	97.7
Safety Factor			
(inner)	3.35	3.19	3.12
(outer)	4.96	5.21	5.32
Ult. Strength (kg)	7,582	7,966	7,804
Breaks In ____ Armor	Inner	Inner	Outer

Table (5). KNAPPSAC Analysis Of Torque, Rotation and Strain Vs. Load For DUMAND Design Model #1 And Three Different Armor Packages. (Armor I.D. is common at 7.34 mm for all three designs.)

Material	Use And Description
OPTICAL FIBERS	12 type "SL" single-mode fibers, buffered with UV-cured acrylate to 0.25-mm O.D.
VOID FILLERS	Used to fill all cable voids.
A.	SynchoFox 280---manufactured by Syncho Chemical Corporation, 24 DaVinci Drive, Bohemia, New York 11716, and used to fill all voids in the stainless steel tube.
B.	Instaweld 34-3120---used to fill all voids under the conductor wires.
METAL TUBE	Type 304 SS---formed from a tape, laser-welded into a hermetically sealed cylinder, then drawn down to final diameter. After drawing, it must be at least 1/2-hard. As formed, the tube will contain the optical fibers plus the SynchoFox void filler.
CONDUCTOR BED	Nylon 12---forms a protective bed between the tube and the conductor wires.
CONDUCTOR	Electrical grade copper wires, drawn to a temper of (at least) half-hard.
DIELECTRIC	Ethylene/Propylene copolymer (EPC); Hercules Pro-Fax SE-012 or equivalent.
ARMOR BED	Tape, applied as smooth (50%) overlap of the EPC, and serves as a distortable bed for the first steel armor layer. Can be an uncured Neoprene or uncured Butyl rubber---on either Nylon or cotton cloth backing. The bed must be fully cured after armoring.
ARMOR WIRES	XGIPS (Galvanized Extra-Improved Plow Steel) or Special XGIPS, with no butt welds in the wires. Galvanizing must be a hot-dip process, with a zinc coating of at least 105 gm/sq-m (0.35 oz/sq-ft). Other constraints are shown below (in units of kg/sq-cm). Tensile Modulus > 2,000,000 Ultimate Tensile Strength > 20,330 Yield Point (at 0.2% offset) > 19,000

Table (6). DUMAND Shore Cable: Specified Materials.

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
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	 < 0.40 (in cable) < 0.30 (in cable)
12. Dispersion	ps/km/nm	3
13. Index Difference	--------	0.37%
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 (7). DUMAND E-O Cable: Optical Fiber Specifications.

Component	Component Diameter (mm)	Assembly Diameter (mm)	Mean Pitch Diameter (mm)	Helix Angle (deg)	Helix Length (mm)
1. E-O Core					
A. 12 Opt. Fibers	0.125	-----	------	-----	------
B. Fiber Buffers	0.250	-----	------	------	------
C. Tube V.Filler	-----	1.98	------	-----	------
D. Metal Tube					
I.D.	1.98	1.98	------	-----	------
O.D.	2.39	2.39	------	-----	------
E. Conductor Bed	2.64	2.64	------	-----	------
F. 18 Cu. Wires	0.5105	3.66	3.15	15.0R	37.0
G. 24 Cu. Wires	0.5105	4.68	4.17	15.0L	48.9
H. Cond. V.F.	------	4.17	------	-----	------
I. Dielectric	6.89	6.89	------	-----	------
J. Armor Bed					
Initial	7.79	7.79	------	-----	------
Compressed	7.34	7.34	------	-----	------
2. Armor Package					
A. First Armor 24 Wires	1.024	9.39	8.36	17.2L	85.0
B. Second Armor 24 Wires	1.291	11.97	10.68	18.5R	100.0

Note: Compression of the inner armor layer into the armor bed is accomplished at the closing die with negligible axial cable strain.

Table (8). DUMAND Model #1 Cable: Dimensions And Geometry.

Component	Component Diameter (mm)	Assembly Diameter (mm)	Mean Pitch Diameter (mm)	Helix Angle (deg)	Helix Length (mm)
1. E-O Core					
A. 12 Opt. Fibers	0.125	-----	------	-----	------
B. Fiber Buffers	0.250	-----	------	------	------
C. Tube V.Filler	-----	1.98	------	-----	------
D. Metal Tube					
I.D.	1.98	1.98	------	-----	------
O.D.	2.39	2.39	------	-----	------
E. Conductor Bed	2.64	2.64	------	-----	------
F. "N" Keystone Copper Wires (96% Coverage)	-----	4.14	3.39	15.0R	39.8
G. Cond. V.F.	------	4.14	------	-----	------
I. Dielectric	6.20	6.20	------	-----	------
J. Armor Bed					
Initial	7.00	7.00	------	-----	------
Compressed	6.60	6.60	------	-----	------
2. Armor Package					
A. First Armor 22 Wires	1.024	7.62	8.65	17.2L	77.3
B. Second Armor 22 Wires	1.291	9.94	11.23	18.5R	93.3

Notes: (1) Compression of the inner armor layer into the armor bed takes place at the closing die with negligible axial cable strain.
(2) "N"---the number of keystone conductor units---must be an odd number in order to minimize the effects of conductor cleavage planes.

Table (9). DUMAND Model #2 Cable: Dimensions And Geometry.

Component	Material	Specific Gravity	Cross Section (sq-cm)	Air Weight (kg/km)
1. E-O Core				
A. 12 Opt. Fibers	Silica	2.20	0.0015	3.24
B. Fiber Buffers	Acrylate	1.12	0.0046	5.16
C. Tube V.Filler	Syncofox	0.872	0.0247	2.16
D. Metal Tube	SS-304	7.94	0.0139	11.07
E. Conductor Bed	Nylon	0.92	0.0100	0.92
F. 1st Cond. Wires	Copper	8.84	0.0381	33.72
G. 2nd Cond. Wires	Copper	8.84	0.0509	44.96
H. Cond. V. F.	Instaweld	0.872	0.0142	1.24
I. Dielectric	EPC	0.90	0.2148	19.33
J. Armor Bed	Butyl	1.43	0.1038	14.83
E-O CORE		2.867	0.4766	136.63
2. Armor Package				
A. Inner Armor	XGIPS	7.94	0.2078	165.01
B. Outer Armor	XGIPS	7.94	0.3303	262.28
ARMOR		7.94	0.5382	427.29
TOTAL		5.48	1.0148	556.3

Table (10). DUMAND Cable Model #1: Cross Sections And Weights.

Component	Material	Specific Gravity	Cross Section (sq-cm)	Air Weight (kg/km)
1. E-O Core				
A. 12 Opt. Fibers	Silica	2.20	0.0015	3.24
B. Fiber Buffers	Acrylate	1.12	0.0046	5.16
C. Tube V.Filler	Syncofox	0.872	0.0247	2.16
D. Metal Tube	SS-304	7.94	0.0139	11.07
E. Conductor Bed	Nylon	0.92	0.0100	0.92
F. Cond. Annulus	Copper	8.84	0.0775	68.52
H. Cond. V. F.	Instaweld	0.872	0.0024	0.21
I. Dielectric	EPC	0.90	0.1693	15.23
J. Armor Bed	Butyl	1.43	0.0829	11.85
E-O CORE		3.059	0.3869	118.36
2. Armor Package				
A. Inner Armor	XGIPS	7.94	0.1905	151.26
B. Outer Armor	XGIPS	7.94	0.3028	240.42
ARMOR		7.94	0.4933	391.69
TOTAL		5.71	0.8802	502.5

Table (11). DUMAND Cable Model #2: Cross Sections And Weights.

Performance Parameter	Analysis Of Model #1	Specified Value
1. Cable Physical Performance		
A. Length, Each Section (km)	9,000	≥ 9000
B. Diameter (mm)	11.97	11.9--12.1
C. Ultimate Strength (kg)		
Ends Fixed	10,640	> 9,500
One End Free	7,970	> 7,400
D. Torque (kg-cm at 2500 kg)	117.5	< 130.0
E. Rotation (deg/m at 2500 kg)	-26.5	|R| < 30.0
F. Air Weight (kg/km)	556.3	Nominal
2. Electrical Performance		
A. Cond. Resistance (ohm/km)	2.125	< 2.15
B. Ins. Resistance (ohm-km)	$6.14X10^{8}$	> $3X10^{8}$
3. Optical Performance		
A. Attenuation (dB/km)		
At 1.30 micrometers	-----	< 0.40
At 1.55 micrometers	-----	< 0.35

NOTES:

(1) Resistivity of primary insulation is 10^{15} ohm-cm.
(2) Resistivity of Butyl/Nylon armor bed is ignored.
(3) As alternative, length of 4 cable sections must be at least 36 kilometers.

Table (12). Calculated And Specified Performance For DUMAND Cable.

Measurement	Measure After Manufacturing Step Shown			
	Material Receipt	Tube Jacket	E-O Core Assembly	Armoring
1. Component Length	X	X	X	X
2. Optical Fiber Attenuation	X	X	X	X
3. Cutoff Wavelength	X	X	X	X
4. Cond. Resistance			X	X
5. Insul. Resistance A. Spark			During Extrusion	
B. Soak/HIPOT			X	X
6. Diameter/Weight	X	X	X	X
7. Armor Wire Tens. Properties	X			
8. Strength				
Ends Fixed				X
One End Free				X
9. Load/Strain				
Ends Fixed				X
One End Free				X
10. Load/Torque Ends Fixed				X
11. Load/Rotation One End Free				X

Table (13). In-Plant Tests Required For DUMAND Seafloor Cable.