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PI/PD Name: Daniel E Frye

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)

☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☒ White

Disability Status:
(Select one or more)

☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☒ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

Check here if you do not wish to provide any or all of the above information (excluding PI/PD name): ☐

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PI/PD Name: Mark A Grosenbaugh

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☒ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☒ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Walter Paul

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☐ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
☐ Visual Impairment
☐ Mobility/Orthopedic Impairment
☐ Other
☐ None

Citizenship: (Choose one) ☒ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Mark R Chaffey

Gender: ☐ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

Citizenship: (Choose one) ☐ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: J. Andrew Hamilton

Gender: ☐ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)
- ☐ American Indian or Alaska Native
- ☐ Asian
- ☐ Black or African American
- ☐ Native Hawaiian or Other Pacific Islander
- ☐ White

Disability Status:
(Select one or more)
- ☐ Hearing Impairment
- ☐ Visual Impairment
- ☐ Mobility/Orthopedic Impairment
- ☐ Other
- ☐ None

Citizenship: (Choose one) ☐ U.S. Citizen ☐ Permanent Resident ☐ Other non-U.S. Citizen

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PI/PD Name: Keith Raybould

Gender: ☒ Male ☐ Female

Ethnicity: (Choose one response) ☐ Hispanic or Latino ☐ Not Hispanic or Latino

Race:
(Select one or more)
☐ American Indian or Alaska Native
☐ Asian
☐ Black or African American
☐ Native Hawaiian or Other Pacific Islander
☐ White

Disability Status:
(Select one or more)
☐ Hearing Impairment
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☐ Other
☐ None

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List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Dr. Chris Meinig
NOAA R/PMEL
7600 Sand Point Way NE
Seattle, WA 98115-6349
Telephone: (206) 526-6149
Email: Christian.Meinig@noaa.gov

Dr. Tommy Dickey
Ocean Physics Laboratory
University of California, Santa Barbara
6487 Calle Real, Suite A
Goleta, CA 93117
Telephone: (805) 893-7354
Email: tommy.dickey@opl.ucsb.edu

Dr. Peter Worcester
Scripps Institute of Oceanography,
UCSD Mail Code: 0225
9500 Gilman Drive
La Jolla CA, 92093-0225
Telephone: (858) 534-4688
Email: pworcester@ucsd.edu

Dr. H. Thomas Rossby
Oceanography, Bay Campus
South Ferry Road
Narragansett, RI 02882
Telephone: (401) 874-6521
Email: trossby@gso.uri.edu

Dr. Rick Cole
University of South Florida - MSL 138
140 Seventh Avenue South
St. Petersburg, FL 33701
Telephone: (727) 553-1522
Email: rcole@marine.usf.edu

Dr. Tim Stanton
Naval Postgraduate School
1 University Circle
Monterey, CA 93943
Telephone: (831) 656-3144
Email: stanton@nps.navy.mil

Dr. George Wilkins
73-1410A Kaloko Drive
Kailua-Kona, HI 96740

Suggested Reviewers contd...

Telephone: (808) 325-6116
Email: g-mwilkins@juno.com

REVIEWERS NOT TO INCLUDE:

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 03-2

NSF 03-2

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

OCE - OCEAN TECH & INTERDISC COORDIN

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				001766682	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)

042105850

SHOW PREVIOUS AWARD NO. IF THIS IS
☐ A RENEWAL
☐ AN ACCOMPLISHMENT-BASED RENEWAL

IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

Woods Hole Oceanographic Institution

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

Woods Hole Oceanographic Institution
Woods Hole, MA. 02543

AWARDEE ORGANIZATION CODE (IF KNOWN)

0022301000

NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE

ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE

PERFORMING ORGANIZATION CODE (IF KNOWN)

IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS

☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Collaborative Research: Design, Modeling and Testing of Electro-Optic Mechanical [EOM] Mooring Cables for Moored-Buoy Observations**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 699,618	24 months	10/01/03	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
☐ HISTORIC PLACES (GPG II.C.9)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date ________
☐ HUMAN SUBJECTS (GPG II.C.11)
Exemption Subsection ________ or IRB App. Date ________
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.9)
☒ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT

Applied Ocean Physics & Engineering

PI/PD POSTAL ADDRESS

AOPE, Smith Building, MS #18

Woods Hole, MA 02543
United States

PI/PD FAX NUMBER

508-457-2195

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Electronic Mail Address
PI/PD NAME Daniel E Frye	MS	1971	508-289-2759	dfrye@whoi.edu
CO-PI/PD Mark A Grosenbaugh	Ph.D.	1987	508-289-2607	mgrosenbaugh@whoi.edu
CO-PI/PD Walter Paul	Ph.D	1967	508-289-3506	wpaul@whoi.edu
CO-PI/PD				
CO-PI/PD				

TPI 6252886

CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 03-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

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(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **Monterey Bay Aquarium Research Institute**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **Monterey Bay Aquarium Research Institute** **7700 Sandholdt Road** **Moss Landing, CA. 950399644**
AWARDEE ORGANIZATION CODE (IF KNOWN) **4000069000**	
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IS AWARDEE ORGANIZATION (Check All That Apply) (See GPG II.C For Definitions)
☐ SMALL BUSINESS ☐ MINORITY BUSINESS
☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS
☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Collaborative Research: Design, Modeling, and Testing of Electro-Optic Mechanical \(EOM\) Mooring Cables for Moored-Buoy Observatories**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **648,549**	**24** months	**10/01/03**	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
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PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS **Moss Landing, CA 950399644** **United States**
PI/PD FAX NUMBER **831-775-1620**	

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CERTIFICATION PAGE

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PROJECT SUMMARY

The NSF Ocean Observatories Initiative includes of three components: a **plate-scale observatory** consisting of interconnected sites on the seafloor that are linked to shore by a fiber-optic communications cable, a global network of **moored buoy observatories** that each consist of an array of instruments connected to a surface buoy that is capable of transmitting data ashore by satellite, and a network of **coastal observatories**. This proposal is for the development and testing of an electro-optical-mechanical (EOM) mooring system for use with the global network of moored buoy observatories. This EOM mooring cable and its related mechanical and electro-optical components is a crucial technological element of moored buoy observatories that at present is not well defined and is not available from commercial manufacturers. The goal of the proposed work is to develop a reliable and cost effective design for this key mooring component and the related termination and connection hardware. It will be applicable to most of the global network sites and reliable for periods of three to five years before replacement or repair. Existing EOM mooring/cable designs are expensive, unreliable and not designed for the full range of environmental conditions. In addition, reliable and tested methods for terminating the cables, connecting them to buoys and anchors and adjusting their buoyancy to meet the mooring configuration requirements are not available. We propose to develop and test a complete and integrated mooring system for long term observatory applications that will provide the capability for real-time data and power transfer between surface buoys and submerged instruments arrays.

The technical effort will include tasks to: 1) design and perform numerical modeling of candidate mooring configurations for moored buoy observatories, 2) develop laboratory test procedures that reliably predict cable and termination performance in the field, 3) design EOM cables, terminations, and strain-relief connection devices, 4) conduct laboratory strength, bending and fatigue testing of cable specimens, 5) develop techniques for predicting fatigue failure in synthetic EOM cables, 6) fabricate and field test a prototype EOM cable and mooring system, 7) instrument the mooring to collect engineering data on cable strain and bending to assess mooring and cable performance, and 8) perform post-deployment testing of mooring components to determine residual strength and compare these results to predictions of the fatigue models.

Intellectual Merit: Completion of the proposed work will result in cable designs and testing protocols that have been validated by field trials. These designs will be suitable for use with surface moorings that are part of the global observatory network.

Broader Impacts: The success of the moored buoy observatory program and the long-term science goals that are implicit in the observatory paradigm hinges on the development of a reliable EOM cable and mooring system. We will integrate research and education through active participation of undergraduate students through the WHOI and MBARI summer intern programs. The technical results of the effort, including mooring, cable and termination design will be published and otherwise made freely available to other institutions engaged in similar activity.

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Appendix Items:

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PROJECT DESCRIPTION

1. INTRODUCTION

Beginning in FY 2006, NSF plans to invest significant resources on the acquisition and construction of infrastructure for a network of ocean observatories, as part of its Ocean Observatories Initiative (OOI). The observatories will have different capabilities, but all will have the goal of providing scientists with the means to study oceanic and geological processes over a wide range of time scales and in real time. The OOI consists of three components: (1) a **regional scale cabled observatory** consisting of interconnected sites on the seafloor that are linked to shore by a fiber-optic communications cable (2) a global network of **moored buoy observatories** that each consist of arrays of instruments connected by acoustic link or EOM cable to a surface buoy that transmits data ashore by satellite, and (3) an expanded network of **coastal observatories**.

This proposal is directed specifically at the needs of the **moored buoy observatories**. One of the technical approaches planned for these moored systems is a single-point mooring that uses an electro-optical-mechanical (EOM) cable as its mooring line (Fig. 1). The cable provides power and communication from the surface buoy to a water column and benthic network of instruments. Power is generated on the surface buoy and communications between the buoy and a network of seafloor nodes is provided through optical fibers.

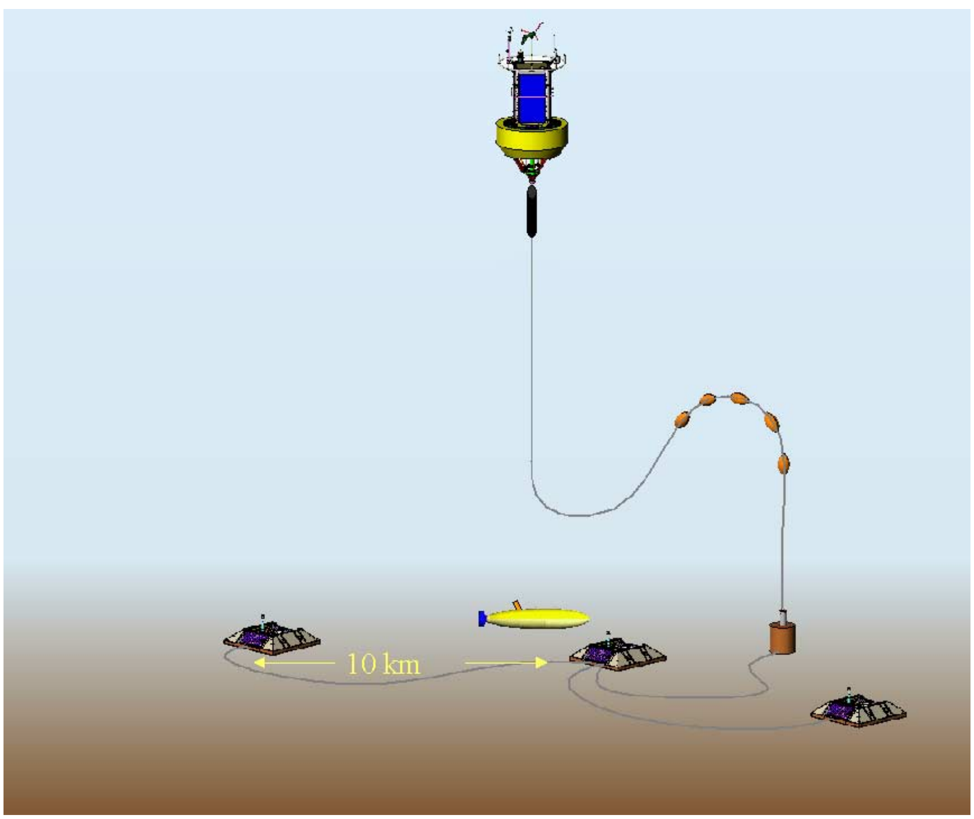

Fig. 1. The single point cable-linked mooring system proposed for use in the global network of ocean observatories. The mooring line is an EOM cable that carries power to the seafloor and data to the surface buoy, which sends data to shore by satellite.

A critical component of the cable-linked, single-point mooring is the EOM cable. Presently, there is no tested cable design that meets the requirements demanded of this application. Numerical modeling of oceanographic moorings has been very successful at predicting dynamic axial loads, however other important quantities such as the dynamic bending environment are less well defined. This was clearly demonstrated recently when MBARI selected an EOM cable for use with their prototype observatory mooring (described later in this proposal). The requirements for axial loading were well predicted by numerical models. Also, the cable's axial stiffness was predicted accurately and subsequently verified with laboratory tests. The specifications for bending performance, however, were less clearly understood and no established laboratory test protocol existed that accurately simulated mooring conditions. As a result, the EOM cable for the MBARI mooring was not tested in the laboratory for bending damage sensitivity, which subsequent experience showed to be a critically important parameter. We propose to design, develop, and test a new EOM cable and its related terminations and mooring components specifically for moored buoy observatory applications. The work will include numerical simulations of different mooring designs, the development of laboratory strength, bending and fatigue tests of candidate EOM cable specimens, and field testing of the best prototype EOM cable.

1.1 Background

The oceanographic community has extensive experience in the use of single-point surface moorings that are attached to the seafloor with elastically compliant nylon rope (Berteaux, 1976; Grosenbaugh, 1996). However, the use of EOM cables in deep-ocean surface moorings is relatively new and presents significant challenges. EOM cables used for moorings need to have synthetic strength members to provide compliance and scope to accommodate surface waves and strong currents and winds. Current synthetic fiber strengthened EOM cable designs (built with Kevlar or Vectran) have maximum strain limits of about 0.7% and therefore by themselves are unable to provide the compliance needed to follow surface waves. The solution is found in a mooring design that provides geometric compliance and incorporates a special snubber hose section that absorbs peak loading during extreme events. The design of the cable itself must combine the copper conductors, optical fibers, and a synthetic or steel jacket strength member such that the copper and optical elements stretch no more than 0.5%. (Paul et al, 2003).

Synthetic fiber strengthened EOM cables (with strength members made from Kevlar®, Vectran®, Zylon®, or polyester) are attractive for deep, single point moorings because their high axial strength-to-weight ratio lowers the self-weight that the buoy has to support, and reduces the static and dynamic loads on the cable. The optical elements in EOM cables cannot tolerate local contact pressure from surrounding spiraled cable elements under tension. Small point bends in the fiber cause catastrophic optical attenuation. One method of protecting the fibers is to enclose them in small gel filled stainless steel tubes (a proprietary design known as a K-Tube®). Alternate methods are to surround the fibers with a small diameter steel armor layer (available as Steel-Light® or ROC®), or to bed the optical fiber in a synthetic fiber bundle with an extruded plastic jacket. The copper conductors of EOM cables must be spiraled around a center core material, which reduces copper strain during cable stretch or bending under load. The core material may be a non-load bearing filler material, as in traditional steel armored cable designs, or it may be the strength member itself, with conductors and optical fibers spiraled around the core (i.e. the reverse of the traditional design).

These cable design issues involve complex trade-offs that have considerable impact on the mooring configuration. For example, increasing the helix angle of the strength member to provide less bend sensitivity in the cable requires more material to maintain the same overall strain characteristics. This increases the overall diameter of the cable and hence its current induced drag, producing higher storm loads and requiring more mooring buoyancy. An associated issue with the cable construction is the proper design of the cable terminations, which have to transfer cable tension and are used to breakout the conductors and optical fibers at the anchor and the buoy. The terminations are also an area where the cable is subject to repetitive bending forces and a carefully engineered transition is needed between the flexible cable and the rest of the mooring system. Most failures of moored EOM cables have occurred because of bending fatigue. In steel armored cables, this type of failure is due to the stress caused by the friction between the two layers of wire moving relative to each other. In synthetic cables, especially Kevlar®, failures are associated with a reduction in breaking strength due to abrasion and *kink-band* failure of the strength members. Identification of areas of potential excess bending of the EOM cable, the development of quantitative specifications for allowable EOM cable bending and the proper design of the bending relief will be key to the long-term survival of EOM cables. While we have proven tools for predicting bending fatigue of steel armored cables (Raoof, 1992), comparable techniques for synthetic cables do not presently exist.

1.2 Research Goals and Intellectual Merit

The goal of this proposal is the development of a reliable and cost effective synthetic EOM cable and mooring design (and the associated mooring termination and connection hardware) that can be used for cable-linked single-point moorings as part of a global network of moored ocean observatories. This development effort includes defining the specifications and developing the acceptance tests for an EOM cable, working with cable manufacturers to modify existing designs or create a new design, laboratory testing of samples to determine strength, bending and fatigue characteristics, and a full-scale field deployment to demonstrate the performance of the prototype cable system. Completion of the proposed work will lead to an EOM cable mooring that can be used for three to five years in applications that require a high bandwidth data link between the buoy and the seafloor. This development is critical to operating a global network of moored buoy observatories.

1.3 Broader Impact, Education, and Outreach

The success of science programs planned as an integral part of the global observatory network hinges on the development of a reliable EOM cable and a mooring design that can be used for single-point mooring applications. Twenty years ago, NSF funded the development of a steel-armored electro-optical-mechanical (EOM) cable for oceanographic research (Wilkens, 2001). This cable has been used extensively by the UNOLS fleet and has led to a revolution in the capabilities of towed survey vehicles through its tremendous increase in bandwidth. The proposed development of a new EOM mooring cable could lead to a similar revolution in how we conduct oceanographic research with moorings.

We will integrate research and education through active participation of undergraduate students through the WHOI and MBARI summer intern programs. The students will receive training in one or more aspects of the research including numerical modeling, engineering design, material testing, and assisting with the at-sea deployment. Our outreach activity will enable students at all levels (including K-12) and the general public to participate in the development of the technology and the laboratory and field-testing of this system through the WHOI *Dive and Discover* web-based education program and the MBARI educational web pages.

1.4 Relation to Other Programs

As we have previously stated, a reliable EOM mooring system will be an integral component of the global network of moored ocean observatories. The other two programs of the Ocean Observatories Initiative, the plate-scale observatory and the coastal observatories program (including the coastal mooring network maintained by the National Data Buoy Center) will benefit from this technology through the ability to deploy real-time telemetry moorings that can deliver power to and receive data from instruments on the seafloor and in the water column.

MBARI's Ocean Observatory System (MOOS), mentioned previously in this section, is an ongoing project that involves the deployment of a moored buoy observatory prototype system off the northern coast of California in 1800 m of water (Chaffey et al., 2001). It was initially deployed in December 2002 and produced important information validating the WHOI Cable design models during a range of conditions including a severe storm event. It also successfully tested a number of observatory subsystems such as a solar power generation system and a real-time satellite communication link. However, it also demonstrated the need for a reliable synthetic EOM cable and a mooring design that can be used for long term deployments. MBARI plans to continue working on this prototype observatory system. In the fall of 2003 they plan to test the operational ability of an ROV to make cable connections to seafloor instruments at the base of a mooring. MBARI's commitment to this effort through internal funding is an important in-kind contribution to the work outlined in the proposal and ultimately advances our ability to deploy and maintain mooring based ocean observatories. In the effort being proposed we will use the existing MBARI surface buoy system to test the new EOM mooring/cable design developed under this proposal.

2. EXISTING EOM CABLE DESIGNS

The development of synthetic electro-mechanical cables began shortly after the introduction of Kevlar® fibers in the early 1970's (Swenson, 1975; Ferer & Swenson, 1976; Ferer & Swenson, 1978). Kevlar® was the first high performance fiber with strength similar to steel wire with only slightly more stretch and less than 10% of the weight in water. The low density of Kevlar® cables makes them attractive for marine applications because the flotation needed to compensate for the weight of steel armor cables is dramatically reduced.

In the mid-nineteen eighties, new high-performance fibers were introduced under the trade names Vectran®, Spectra®, and Dynema®. These fibers have similar strength and stretch characteristics as Kevlar, but have higher abrasion resistance and higher resistance to cyclic loading. Spectra® and Dynema® fibers have proved to be unsuitable for many marine cable designs due to excessive creep, which occurs under sustained loads. More recently, a commercially available PBO fiber was introduced under the trade name Zylon®. This fiber is almost twice as strong as Kevlar and Vectran and has similar stretch characteristics, however, its behavior in marine cables has yet to be investigated.

Existing synthetic reinforced EOM cable designs have followed the traditional designs of steel-armor EOM cables. A center core of electrical conductors and optical fibers is covered by counter helical layers of high-performance synthetic fibers. A plastic jacket is then extruded over the synthetic fibers. Optical fibers in the center core use special metal or plastic tubes or matrices to protect the fibers during cable manufacturing and operational use.

Almost all commercially available synthetic marine cables use Kevlar strength members with a center conductor core (CCC). When MBARI sought an EOM cable for their MOOS mooring, they considered six designs from domestic and foreign cable manufacturers that met their specifications. Five of the designs used a CCC design with an external strength member made of Kevlar®. The sixth design had a center strength member (CSM) made from Vectran®. In this design the electrical conductors and the optical fibers were spiraled around the central strength member to reduce conductor and fiber strain. All six of these cable designs included a fish-bite protected top section, which incorporated a stainless steel braid as part of the outer plastic jacket. MBARI chose a CCC design from a company with significant experience in building Kevlar® reinforced cables (South Bay Cable). Also, the CCC design offered a straightforward means for making terminations based on technology developed for steel-armored cables. The CSM design was not chosen because it was unproven in mooring applications and its cost was significantly higher.

The EOM cable that MBARI selected for their prototype test mooring experienced two separate failures during its initial at sea deployment. Two of the four optical fibers failed during the deployment operation, which subsequent examination showed were K-tube failures probably initiated by handling during deployment or staging. A subsequent break in the Kevlar strength member occurred during a severe storm and was apparently caused by localized bending fatigue near a series of clamp-on syntactic floats that had bunched together on the cable- probably during the anchor drop. This failure occurred because cable bends and cyclical loading at low tensions caused local *kink-band* formations in the Kevlar® layers on the inside of the bend. These kink-bands led to rapid deterioration of the fiber strength.

Kink-bands are fine crease-like permanent deformations at right angles to the fiber axis, which become early fatigue failure points (Riewald, 1986; Riewald et al, 1986). The effects of cable bends is most pronounced in CCC designs, but can also be a problem in CSM designs. Formation of kink-bands in a Kevlar® cable (or rope) reduces breaking strength by as much as 80%.

One of the major conclusions based on previous experience with synthetic EOM cables is that there is a stretch compatibility problem versus bend sensitivity with CCC designs. The electrical conductors and optical fibers must be kept at a stretch below 0.5% in order to prevent conductor damage and failure. Current CCC cables have achieved this by maintaining low helix angles for the strength members, which increases the sensitivity to kink-band formation. The other conclusion is that strength fibers other than Kevlar® need to be considered in order to reduce the formation and effects of kink-bands.

3. TECHNICAL APPROACH

The objectives of this proposal are to:

1) Develop and model mooring configurations that are compatible with the properties of the EOM mooring cables and can be deployed at global network locations.
2) Develop a new synthetic EOM cable specifically for use with single-point surface moorings.
3) Develop termination and connecting hardware that protects the cables, electrical conductor and optical fibers from excessive tension, fatigue and bending strains.
4) Develop integrated fiber optic strain sensors, based on Bragg gratings, to provide a real-time record of cable strain and bending during the cable's deployment life.
5) Develop specifications and test protocols for EOM cable performance verification.
6) Develop models for predicting bending loads and bending fatigue of synthetic EOM cables.
7) Conduct sea trials of the prototype EOM mooring system and cables.
8) Disseminate the design information and test results to the oceanographic and ocean engineering community.

3.1 Mooring Configuration and EOM Cable Design

The mooring system design process will use numerical simulations to estimate loads under various environmental conditions and then use the results as specifications for designing the mooring components, including the EOM cable. The simulations will be used to calculate axial tension and bending loads. The response under storm conditions will be used to define the maximum operating conditions. Much of the numerical simulation work will involve parametric analysis aimed at minimizing the loads. Cyclic loading will also be estimated from the numerical simulations and used as input for a fatigue prediction model that will be developed as part of this proposal.

As a starting point in the mooring design process, we will investigate an inverse catenary single-point mooring configuration as shown in Fig. 2. In this proven design excess mooring line is held off the bottom by a series of floats and prevented from tangling with itself in slack conditions through the formation an “S” in a portion of the mooring. In this case the “S” is constructed in the lower portion of the mooring so that the upper portion of the mooring is free for using a profiling instrument that can crawl up and down the mooring line. A snubber hose at the top of the mooring provides elastic compliance. Designs that use a combination of steel armor EOM cable and synthetic EOM cable will be studied as well as designs that are all synthetic.

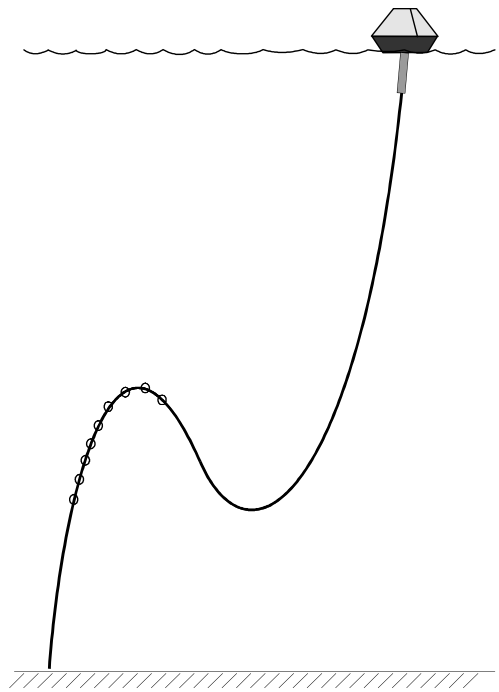

Fig. 2. Schematic of a conventional inverse catenary surface mooring.

Mooring Configuration Analysis

The dynamic response of the mooring configurations that are studied will be obtained using WHOI Cable, a general-purpose numerical code that was developed at WHOI for calculating the static and dynamic response of moored and towed oceanographic systems (Gobat and Grosenbaugh, 2000). The finite difference time domain simulation is built around a mathematical model of cable dynamics. The cable model is fully three-dimensional and includes the effects of torsion, bending, and geometric and material nonlinearities. For this application, the code will be used to analyze the dynamics during the deployment of the anchor as well as the on-station response in ocean waves. For the wave calculations, the program assumes that the vertical displacement of the surface buoy follows the wave elevation, which is described by the Modified Pierson-Moskowitz spectrum.

Tension measurements from the first deployment of the MOOS mooring gave us the opportunity to verify the numerical code with a mooring system that is similar to the proposed design. That mooring had tension recorders at the buoy and the anchor. Comparisons between the numerical simulations and measured tensions showed that the values were within 10% of each other in an 8.5-meter significant wave height storm (Fig. 3).

EOM Cable Design

For the cable design task we will design and build several candidate cables and test short lengths of them in the laboratory for overall fatigue properties and “conductor comfort” (i.e. avoiding overstretching of electrical conductors and optical fibers when the cable is tensioned and flexed). Synthetic fiber strengthened cable designs will use either a center strength member (CSM), with the electrical conductors and optical fibers wrapped around the outside, or a center conductor core (CCC) with the strength members applied around the conductors. An outer plastic jacket of sufficient thickness (with an encapsulated steel braid for fish-bite protection if this cable is used in the upper portion of the mooring) will complete the cable designs. Cable designs with strength members from Vectran®, Zylon®, Kevlar® and polyester fibers will be investigated. Specific information that will be used in the design process includes the following:

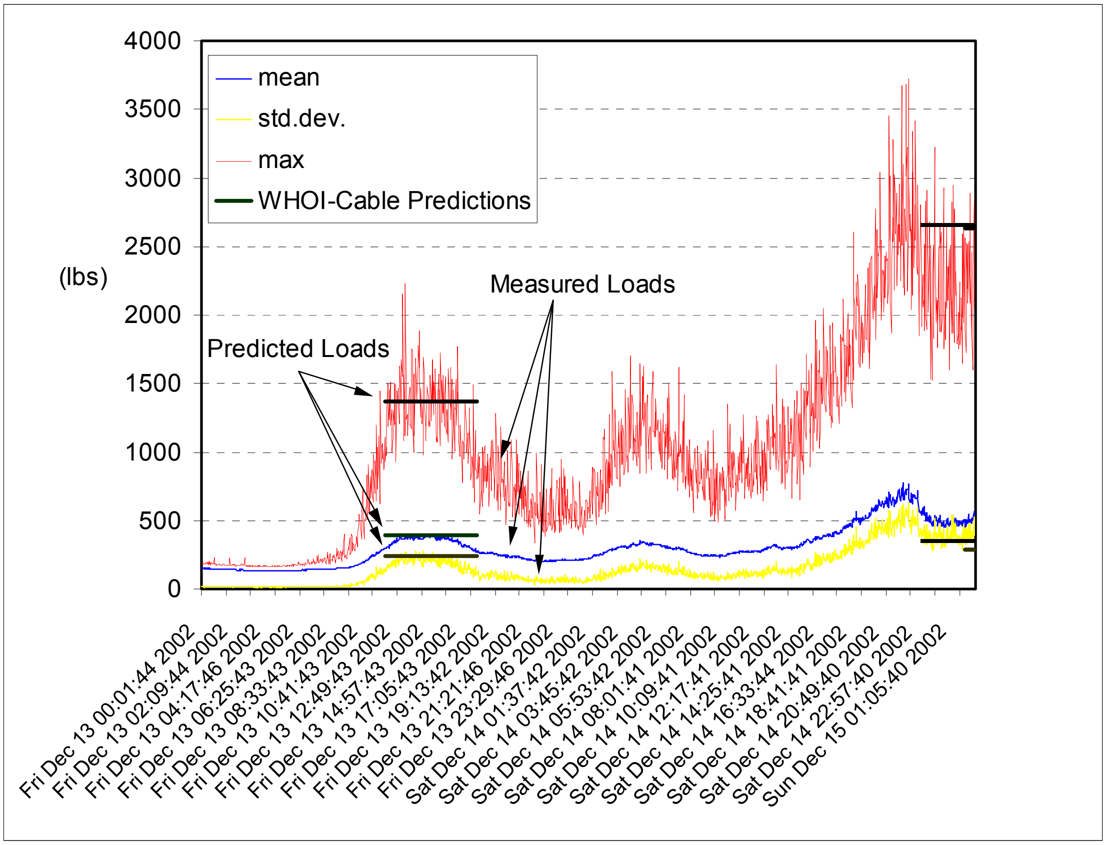

Fig. 3. MOOS test mooring measured anchor loads compared to modeled values at two different sea states.

1. Numerical models of cable mechanics (Paul, 1995) show that a center strength member (CSM) design with conductors spiraled around it provides long-term conductor durability by keeping the conductor stretch near zero and thereby providing 'conductor comfort" for long service life. CSM EOM cable designs can safely support survival loads with a safety factor of 5 to 10, depending on the frequency of such loads.

2. Synthetic EOM cables with a center conductor core (CCC) can function satisfactory. They require designs that result in safety factors of 12 or higher, and special conductor arrangements in order to keep the cable stretch under load within the 0.5 percent conductor strain limit. Such cables have more than sufficient strength to support system loads.

3. Kevlar®, Vectran®, and Zylon® fibers are suitable strength members for low stretching cables. Each fiber candidate has distinct characteristics which effect strength and durability of the cable at sea. The Kevlar strength members are of interest due to their relatively low cost and good strength. The more expensive Vectran® strength members provide superior fatigue endurance and much higher resistance to the formation of destructive kink-bands. Higher-strength and very expensive Zylon® fibers, so far little explored, need to be investigated for their suitability as cable strength members.

4. The weaker and less expensive polyester (and nylon) fibers offer excellent fatigue resistance and can provide significant stretch compliance in an EOM cable, but require more highly helixed conductors to avoid tension induced strains.
5. The flexural rigidity of synthetic cables is controlled primarily by the outer plastic jacket. Jackets require embedded textile reinforcement to provide coherence and additional steel armor in the upper mooring section for fish bite protection. Conductors and strength members also contribute some flex resistance, which varies with cable design choice. Supporting tests have to determine the optimum jacket thickness and jacket material to provide sufficient resistance against sharp bends. Since the bending stiffness grows with the fourth power of the jacket thickness, effective adjustments can be made with small dimensional changes.
6. The incorporation of optical fibers in CSM designs may require large cable core diameters since the fibers require a minimum radius of curvature above 1 inch. The radius of curvature minimum and structural stretch maximum has to be maintained at local flex points.
7. Copper conductors are less sensitive to sharp bends than optical fibers and only require structural arrangements to limit their stretch to 0.5 % maximum.
8. Cable termination issues are critical and require attention to detail. They have to gradually transfer the cable tension to the termination housing and allow a safe conductor path to connectors at instruments, buoys, or anchors. A bending strain relief boot is normally used to help transition form the stiff termination to the flexible cable. A properly designed bending strain relief keeps the cable bend radius large enough to prevent fatigue damage during tension and position changes. CCC designs with external strength members allow an undisturbed conductor path through the coupling area, but require careful cone designs and potting techniques to obtain smooth load transition and high strength efficiency. All steel armored cables are CCC designs. CCC cable designs typically terminate their external strength member inside a conical housing with epoxy used for strength transfer. The electrical and optical conductors maintain their core configuration in the termination area. CSM cable designs can be constructed using an easy to splice braided fiber rope core that is torque and rotation free. Eye splices transfer the cable tension with high strength efficiency and gradual transfer of the tension and stretch. Eye splices can be made quickly and reliably, even on board ship.

The construction of the test samples will follow the cable design task and these test samples will be exercised in extensive laboratory tests. Based on the results of laboratory testing, we will choose one design that will be manufactured into a full-length cable. The full-length cable will then be tested at sea as part of the complete EOM mooring system.

Proper choice of other mooring components is important for reducing cyclic loading in the EOM cable and at cable terminations. The main mooring components, besides the EOM cable, are the snubber hose, the cable floats, cable terminations, and the connecting hardware. A snubber hose (see Fig. 4 and 5) that is 15-30 m long is used between the surface buoy and the top of the EOM cable to reduce dynamic tensions and bending caused by wave induced motions of the surface buoy. The hose combines the properties of rubber and nylon tire-cord reinforcement together with coupling techniques developed for oil transfer hoses. The hoses are hand laid-up over steel mandrels and terminate with molded-in flange couplings. Their elongation, up to 140% at maximum working load, is controlled by the arrangement of two or more counter-helical layers of nylon tire cord and the rubber hose wall thickness. The nylon cord layers are sandwiched between an inner rubber liner, a layer of Kevlar tire cords used for fish bite protection, and an outer jacket of neoprene rubber. These rubber layers provide the hose with ruggedness and flexural rigidity through the vulcanization process. Numerical modeling of the mechanical properties of the snubber hose allows prediction of its tension response to applied strain as a function of the selected reinforcement geometry (Paul et al, 1994). The snubber hose also serves as a protective housing for the electrical conductors and optical fibers between the EOM cable and the surface buoy.

Figure 4. Snubber hose ready for deployment in the Labrador Sea.

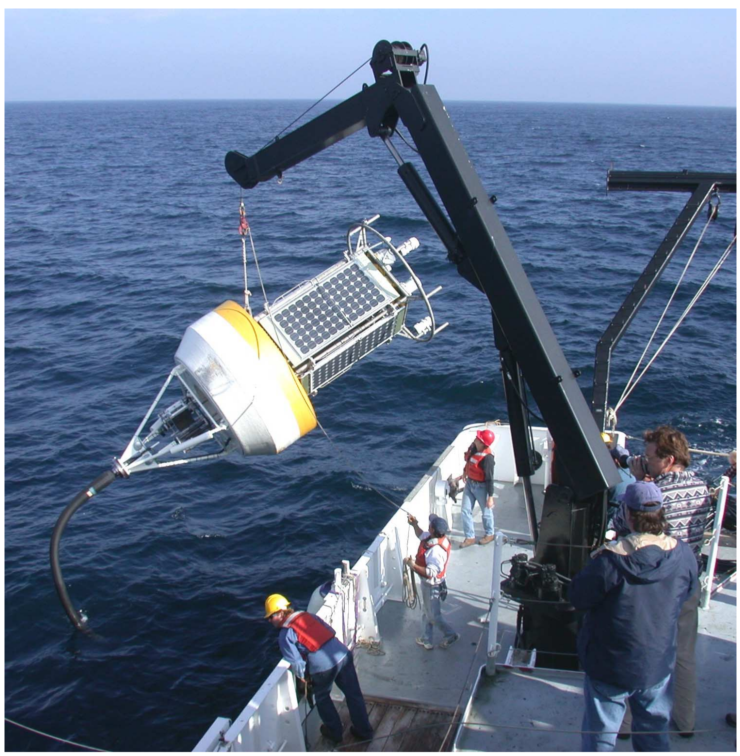

Figure 5. MBAR MOOS buoy deployment with snubber hose connected to the bottom of the buoy.

A sturdy EOM coil cord may be arranged inside the hose cavity or conductors and fibers may be spiraled inside the hose wall. Special optical fibers with low radius of curvature limits are required to provide a low attenuation path in a coil cord. Recently, specially designed electrical conductors were spiraled inside a snubber hose wall and these have worked well since being deployed five months ago. WHOI has deployed snubber hoses in a number of moorings since 1994 without failure.

The design approach for the EOM cable terminations builds on previous experience. In CCC designs the strength members typically terminate inside a conical housing filled with a suitable epoxy matrix. The electrical and optical elements feed through multiple seals to a splice chamber. At the base of the mooring snubber hose, a bending strain relief engineered to match the cable bending stiffness helps to manage the transition from the relatively stiff snubber hose to the flexible cable. This bending strain relief keeps the cable radius large enough to prevent fatigue damage during tension and angle changes. A similar termination and bending strain relief at the base of the mooring transitions the cable to the anchor system.

Cable floats are important for constructing “S-tethers” that increase the scope of the mooring while preventing the mooring line from chafing on the seafloor. Present methods for clamping floats on to cables were developed for steel-armor cable. MBARI’s experience with using these floats on synthetic EOM cables showed that the floats could slip and bunch along the cable creating a location that was susceptible to high bending loads. The use of these floats contributed to the cable failure described earlier. Our approach for this proposal is to design a new cable flotation system that is compatible with the mechanical properties of the synthetic EOM cable.

3.2 Test Program for Candidate Cable Systems and Mooring Components

Strength and Fatigue Analysis of Cables and Terminations

Over the past several decades much experience has been gained on the use of steel-armor and synthetic EOM cables for tow-sled and ROV umbilicals. A series of qualification tests and test protocols have been devised that do a good job of predicting the field performance of candidate tow-cable design - primarily by measuring the cable’s tensile characteristics and fatigue properties through thousands of cycles of tension and "bend-over-sheave" excursions. The prediction of the performance of EOM cables in mooring applications is not as well understood and the standard cable performance tests do not accurately simulate the conditions mooring cables experience in the field.

To solve this problem, a laboratory test protocol will be developed based on our previous mooring field experience, laboratory test experiments, and the results of model runs of the mooring configuration. What is important is that the local buckling and bending effects due to slack-snap conditions should be duplicated as accurately as possible. Cable dissections at the local flex points will be performed with microscopic magnification of the flex point area to see if kink-bands are forming in the load supporting fiber reinforcement, with a subsequent pull test to determine the cable’s breaking strength. The candidate cable designs, bending strain relief’s and cable terminations will be exercised though a large number of cycles that combine tension and bending cycles that simulate the predicted field bend angles and loads. Tests will also measure the cable's resistance to forming hockle bends during rotation under slack cable conditions. After fatigue cycling, the residual strength of each assembly will be measured and evaluated. This process will allow a quantitative evaluation of candidate cable and bending strain relief designs.

The measurements of cable tensile properties will be contracted to Tension Member Technology Laboratories, a recognized expert in cable testing. The testing that requires the generation of large numbers of bending and tension cycles for fatigue testing of cable performance at bending strain relief and buoyancy or instrument attachment points will be undertaken at MBARI on an apparatus specifically designed for this purpose.

Prediction of Fatigue in Synthetic EOM Cables

In contrast to steel-armored cables, very little is known about the fatigue properties and associated failure mechanisms of rope made from synthetic fibers such as Kevlar®, Vectran®, Zylon®, and even polyester. In this section, we propose to analyze the laboratory test results of the synthetic EOM cable test samples to determine failure mechanisms due to cyclic loading. Based on this analysis, we will then develop a model for predicting fatigue failure in synthetic EOM cables as a function of loading history.

In order to characterize the fatigue failure of the synthetic fiber reinforcement, we first will identify parameters that affect the fatigue failures under axial, bending, and combined axial and bending loads. Some of the parameters are the mean and peak-to-peak range of the axial tension, the mean and the peak-to-peak range of the curvature, and construction methods (wire rope construction, braided, plaited, etc.)

Laboratory tests must be performed in order to determine the effects of these parameters on the fatigue of synthetic cables. For example, the bending fatigue tests are usually done by running the cable over sheaves with various wrap angles and at constant axial tension. The available experimental data (e.g. Hobbs, 1991; Whitehill and Whitehill, 1995; Whitehill and Huntley, 1997) are by no means sufficient. Once laboratory tests are done, the next step is to extrapolate the laboratory tests performed under deterministic loads to the case under random loads, where the axial load and the curvature may vary randomly in time. The probability that the system will perform satisfactorily during its design life and the expected life are then computed.

Using the experimental fatigue data, appropriate generalizations should be made in order to understand the underlying physics that determines the fatigue failure of synthetic cables. For example, for the case of a steel wire strand, it was shown experimentally and theoretically (Raoof, 1992; Alani and Raoof, 1997; US Navy Wire Rope Handbook, 1976) that the mean axial load does not significantly affect the axial fatigue, and the bending stress in individual wires does not play a significant role in bending fatigue. Instead, it was found that interlayer and interwire friction is most important in fatigue of wire strands.

In the case of a synthetic fiber different fatigue mechanisms are observed. Inter-fiber and inter-strand abrasion was found to be dominant in nylon and polyester rope under cycling loads after a large number of tension cycles. Kevlar suffers from rapid failure if kink-bands can form under flex and slack-snap tension oscillations, and significant differences were found depending on the fiber rope or strength member construction (Seo et al., 1990; Wu, 1990; Riewald, 1986; and Riewald et al., 1986). The underlying physics that determines the fatigue failure is complex. In summary, the goal of this study is to perform laboratory tests of specific synthetic fibers to develop a model that accurately predicts the reliability and expected life of the cable under random environmental loading.

3.3 Field Tests of Cable and Mooring Designs

Deployment of the prototype mooring system is not only important to demonstrate success of the EOM design, but also to validate and calibrate the numerical techniques used to predict the loads on the system and to evaluate the fatigue damage that occurs in the system after lengthy service. The test deployment will be conducted in 3700 meters of water, 150 km offshore of Moss Landing, California and will utilize the MOOS buoy platform previously developed by MBARI (Chaffey *et al*., 2001). This infrastructure is well suited for the data acquisition, storage, and transmission that is required for monitoring the EOM cable system.

Data Acquisition and Distribution

A variety of sensors will be installed to monitor the mooring performance and to provide the data required to validate the load predictions. The data will be logged on the mooring and transmitted back to shore in real time. Load cells previously integrated with the MOOS test mooring will measure the cable tension at the base of the buoy and at the anchor. The MOOS system is capable of sampling the instruments at a rate sufficient to capture all expected behavior (> 4 Hz). We also propose to implement instrumentation that can provide information about the static and dynamic behavior along the length of the EOM cable. Based on fiber-optic Bragg grating (FBG) technology, the method provides a noninvasive method of measuring strain in an optical fiber imbedded in the cable. Depending on how the FBG's are incorporated into the cable, the measurements can provide an excellent verification of the overall cable design and the numerical prediction of cable bending.

Critical to the numerical model verification are measurements of local environmental conditions. These will be measured with wave height, wind speed, and wind direction sensors. An ADCP current profiler measuring down to 500 meters will provide the current conditions near the surface. The data from the mooring instrumentation will be automatically archived as it is received on shore and made available over the World Wide Web via the MBARI Shore-Side Data System.

Fiber Sensor Design and Operation

We propose to use fiber-optic Bragg gratings (FBG) to measure strain (Kersey and Morey, 1993) and bending in the EOM cable. A Bragg grating is comprised of a series of perturbations in the index of refraction along a small section of the fiber. These variations in index form a grating that reflects a spectral portion of the light within the fiber that is centered at a frequency that depends on the spacing of the grating. As the grating is stressed, it elongates and changes the center wavelength of the reflected light. Thus, the grating's center wavelength becomes proportional to elongation of the fiber at that location. By incorporating three or four sensors radially at a point of interest, cable bending can be measured. This type of sensor is very compact and can be employed serially along a single fiber allowing the use of many sensors with different grating center frequencies along the length of the EOM cable. This type of sensor has been successfully employed to monitor underwater structures for the offshore oil industry such as composite riser pipes, the latest revision of which uses 37 sensors. We anticipate using sensors at five points along the cable to monitor tension and bending strain at specific points of interest such as: at the cable to buoy connection point, at the cable to anchor attachment, and at several inflection points along the cable.

Optical sensors will be lab tested on small samples to assure suitability for this application prior to a full-scale implementation. A challenge will be determining where on the length of the EOM cable to apply strain sensors to acquire the most meaningful data. We will use numerical simulations to locate regions of high bending and tension. If these sensors yield valuable design information during this phase of the project, it is ultimately our goal to embed sensors of this type into cables for normal use as a means of determining the actual mechanical life cycle of the cable. This could allow longer use of mooring cables based on measured physical properties as opposed to periodic replacement based on statistical end of life analysis.

Connection to Benthic Networks

In a complimentary effort to test a complete observatory systems design, the ROV Tiburon will be used after mooring deployment to connect the base of the mooring EOM cable to a seafloor mounted instrument node network developed and deployed by MBARI. This will test the EOM cable to seafloor cable transition design as well as the operational procedures for making the necessary seafloor connections with an ROV. All costs and labor associated with the development and deployment of the seafloor instrument node network and the ROV connection to the mooring will be funded by MBARI as a cost share.

Mooring System Maintenance

Six months after the initial deployment, the upper part of the mooring will be exchanged with a spare surface buoy and snubber hose assembly. This will test the maintenance procedures necessary for servicing observatory moorings without releasing them from their anchors and give us the opportunity to examine the portions of the mooring line and snubber hose that operate in the high-energy, near surface zone.

4. RESEARCH AND MANAGEMENT PLAN

4.1 Research and Engineering Tasks

Task 1- Mooring Design and Analysis: During the initial several months of the project, single point surface mooring designs will be developed and modeled for global network sites at low, mid and high latitudes. These studies will use environmental data compiled during the DEOS Design Study (Detrick *et al*., 2000) to compute the expected cable loads for various mooring configurations and environmental conditions.

Task 2- Cable and Hose Design and Fabrication: EOM cable designs using low stretch and high stretch synthetic fibers will be developed based on the predicted loads from the model studies. Termination designs including those for hoses used at the top and bottom of the mooring will also be developed. All of these configurations will incorporate compatible electrical conductors and optical fibers so that they can be used on the same mooring without special interface fittings. Fiber optic strain sensors (i.e. Bragg gratings) will be designed as part of this effort, along with the electronics needed to monitor the sensors. The prototype cables will be built by commercial cable companies, the hoses will be built by HBD Industries Inc. Thermoid Division Salisbury, NC, and the terminations will be built at WHOI and MBARI.

Task 3- Laboratory Testing: Prototype cables, hoses and terminations will be tested at commercial testing facilities and at WHOI and MBARI to measure and characterize their strength, failure modes and response to loading. The results of these tests will be used to model each of the cable's long-term response to open ocean forcing. Fiber optic strain sensors will be calibrated as part of this process. Additional laboratory testing will be conducted following the sea trials to measure residual strength.

Task 4- Fatigue Modeling of Synthetic EOM Cables: The results of laboratory testing will be used to develop a model for predicting synthetic EOM cable life under anticipated environmental loading.

Task 5- Sea Trials of Prototype EOM Cable: A sea trial will be performed with the MOOS platform to test the prototype EOM mooring system under realistic conditions. A long-term (10- 12 month) deployment will be performed. Environmental, buoy motion and cable strain and flexure measurements will be part of the sea trials.

Task 6- Analysis and Documentation: Results from the sea trials, the cable modeling and laboratory testing will be analyzed and used to document the reliability of the EOM cables developed and the models used to estimate their long-term reliability. Presentations and articles presenting the results in reference to ocean observatory applications will be prepared.

4.2 Schedule

Months 1 to 4: Compute environmental loading and model different surface mooring configurations (Task 1).

Months 1 to 6: Design, build, and test EOM cables, hoses and terminations. Design and build fiber optic strain sensors (Task 2).

Months 6 to 8: Conduct laboratory tests of EOM cables, hoses and terminations (Task 3).

Months 6 to 12: Develop and test cable model for predicting cable life (Task 4).

Months 12 to 23: Conduct sea trials of prototype EOM cables, hoses and terminations (Task 5).

Months 22 to 24**:** Complete the analysis of the test and modeling results and document the designs and onclusions (Task 6).

4.3 Project Responsibilities

Dan Frye (WHOI) will provide overall project management. He will also participate on sea trials and oversee the documentation tasks. Mark Grosenbaugh (WHOI) will develop and analyze different mooring configurations (Task 1), lead the cable fatigue modeling effort (Task 4), and participate on analysis and documentation tasks. Walter Paul (WHOI) and Mark Chaffey (MBARI) will lead the EOM cable, hose and termination design tasks (Task 2) and specify the laboratory testing protocols (Task 3). Keith Raybould (MBARI) will provide project management for MBARI, lead the sea trials tasks (Task 5), and participate on the documentation task. Andrew Hamilton (MBARI) will work with Grosenbaugh (WHOI) in modeling the dynamic response of the different mooring configurations and participate on the sea trials and documentation tasks.

5. RESULTS FROM PRIOR NSF SUPPORT

OCE-9810641; Ultramoor, An Ultra Long-Life, Low-Cost Mooring System for Current Measurements; Daniel Frye, Nelson Hogg and Carl Wunsch, $1,122,871, 10/1/98-9/30/02

This project, which was recently extended via a Special Creativity Extension Grant, is designing and testing a new mooring system that can be deployed for periods of five years or more while delivering comprehensive data periodically throughout the deployment period. It consists of a lightweight subsurface mooring with a number of discrete current sensors, current profilers and CTDs that transfer their data to a central controller via low cost acoustic modems. Every few months (typically six, though the spacing is not necessarily even) an expendable data capsule releases itself, floats to the surface and transfers the data that has accumulated via Argos or Iridium links in the capsules. Key technologies developed for Ultramoor include the subsurface acoustic links, the low cost, expendable data capsules with their low power control, memory and RF link, the Data Capsule Magazine, which uses an inductive loop to transfer all of the data collected into all ten of the data capsules simultaneously without requiring any electrical connections, and the mooring system, which has been designed to be lightweight and to have low potential for corrosion. A prototype Ultramoor has been deployed in deep water offshore Bermuda since November 2001 and has operated successfully to date. A second prototype is planned for deployment in the Irminger Sea in Summer 2004.

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Ware, J., D. Frye, N. Hogg, P. Koski, B. Butman and M. Martini, "Acoustically linked ocean observatories- initial results from three installations," Presented at the 2002 Ocean Sciences Meeting, Honolulu, Feb. 2001.

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OCE-0215670; Development and Testing of a Deep-Water, Acoustically-Linked, Moored-Buoy Seafloor Observatory; Robert Detrick, John Collins, Lee Freitag, Daniel Frye and Will Wilcock, $812,094, 9/1/02-8/31/06.

We are developing a moderate bandwidth (a few Mbytes/day), acoustically linked moored buoy system that uses high-speed (~5 kbps) acoustic modems for two-way communication between instruments on the seafloor, or in the water column, and a surface buoy. An Iridium satellite system on the buoy will telemeter data to shore several times a day. This system is designed for a wide variety of applications where data telemetry requirements are relatively modest, but real-time or near real-time data are required. It is also ideally suited for applications where the observatory may need to be relocated after a period of time, or deployed quickly for rapid response studies. Preliminary tests of the system will be conducted in October 2003 and a 15-month demonstration project is planned for a deep-water site in the northeast Pacific in 2004-05. For this demonstration project several different types of sensors including an ocean bottom seismograph, an ADCP, CTD, and several chemical and hydrothermal flow sensors will be interfaced to acoustic modems at two separate seafloor nodes. In addition, meteorological sensors will be mounted on the surface buoy, and current meters and temperature recorders will be placed on the mooring line in the upper ocean. Through this project we will demonstrate the technical capabilities and scientific potential of acoustically-linked moored buoy systems for ocean observatory studies.

Publications:

Frye, D., "An acoustically linked seafloor observatory," presented at the ONR/MTS Buoy Workshop, Seattle, April 9-11, 2002.

Detrick, R, D. Frye, L. Freitag, J. Collins, W. Wilcock and R. Light, "Development and testing of a deep-water, acoustically-linked, moored buoy seafloor observatory system," abstract submitted to The Oceanographic Society Mtng., New Orleans, June 4-6, 2003.

IBN-01141480; Analysis of the Boundary Layer and Near-Field Flow Around Swimming Fish; Mark A. Grosenbaugh and Wade R. McGillis, $293,367, 7/01/01-6/30/04.

We are using digital particle image velocimetry to measure the flow velocity in the boundary layer and near-field of swimming fish. The data are used to calculate pressures and shear stresses over the body surface, which are combined to estimate total viscous and pressure drag. The data are also used to analyze the unsteady nature of the flow and determine if the boundary layer is laminar or turbulent and if the boundary layer has separated over any part of the fish body. Five local species of fish are used in a comparative study: scup (*Stenotomus chrysops)*, Atlantic mackerel (*Scomber scombrus*), American eel (*Anguilla rostrata*), and two local dogfish species (*Mustelus canis; Squalus acanthias*). These experiments are crucial to furthering our understanding of how fish swim and how fish power swimming with their muscles. Our results will improve understanding of energetic behavior as it applies, for example, to migration, schooling behavior, and flow sensing by the fish lateral line. In terms of engineering practice, the results of this study will provide insight into new ways of propelling unmanned underwater vehicles.

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EDUCATION:

American University, Physics, B.S., 1968
Oregon State University, Physical Oceanography, M.S., 1971

EXPERIENCE:

1996-present	Senior Research Specialist, WHOI, Dept. of Applied Ocean Physics and Engineering/Manager, Advanced Engineering Department
1987-96	Research Specialist, WHOI, Dept. of Applied Ocean Physics and Engineering
1983-86	Division Manager, Ferranti ORE, Ocean Services Division, Falmouth, MA
1974-82	Senior Physical Oceanographer/Group Leader, EG&G Environmental Consultants, Waltham, MA
1971-74	Associate Scientist, Argonne National Laboratory, Center for Environmental Studies
1969-71	Research Associate, Oregon State University (Air Sea Interaction Group)

RELATED PUBLICATIONS:

Frye, D., N. Hogg and C. Wunsch, "Design and operation of a long-duration mooring for ocean observations," Oceans '02 MTS/IEEE, Biloxi, Mississippi, October 29-31, 2002.

Frye, D., N. Hogg, C. Wunsch, "Ultramoor: A new-generation telemetering subsurface mooring system," *EOS, Transactions, American Geophysical Union*, Vol. 83, No.34, pp. 365-371, 2002.

Frye, D., J. Kemp, W. Paul and D. Peters, "Mooring developments for autonomous oceanographic sampling networks," *IEEE J. Oceanic Engineering—Special Issue on Autonomous Oceanographic Sampling Network*, Vol. 26, No. 4, pp. 477-486, October 2001.

Frye, D., B. Butman, M. Johnson, K. von der Heydt and S. Lerner, "Portable coastal observatories," *Oceanography*, Vol. 13, No. 2, pp. 24-31, 2000.

Doherty, K.W., D. E. Frye, S. P. Liberatore, and J. M. Toole, "A moored profiling instrument." *Journal of Atmospheric and Oceanic Technology*, Vol. 16, No. 11, Pt.2, pp. 1816-1829, November 1999.

Dickey, T., D. Frye, et. al., "Initial results from the Bermuda testbed mooring program" *Deep Sea Research*, I, 45, p. 771-794, 1998.

OTHER SIGNIFICANT PUBLICATIONS:

Detrick, R., J. Collins and D. Frye, “Seafloor to surface to satellite to shore,” *Oceanus*, Vol. 42, No. 1, pp. 12-13, 2000.

Detrick, R. and D. Frye, “DEOS moored buoy observatory design study,” Final Report, 2000.

Frye, D., K. von der Heydt, M. Johnson, A. Maffei, S. Lerner, B. Butman, “New technologies for coastal observatories,” *Sea Technology*, Vol. 40, No. 10, p. 29-35, October 1999.

Toole, J. M., K. W. Doherty, D. E. Frye, and R.C. Millard, "A wire-guided, free-fall system to facilitate shipborn hydrographic profiling." *Journal of Atmospheric and Oceanic Technology*, Vol. 14, No. 3, Pt. 2, June 1997.

Frye, D. E. and W. Brechner Owens, "Recent developments in ocean data telemetry at Woods Hole Oceanographic Institution." *IEEE Journal of Oceanic Engineering*, Vol. 16, No. 4, pp. 350-359, 1991.

ASSOCIATES AND COLLABORATORS:

Bradford Butman, U. S. Geological Survey
Robert Detrick, Woods Hole Oceanographic Institution
Tommy Dickey, University of California at Santa Barbara
David Fratantoni, Woods Hole Oceanographic Institution
Nelson Hogg, Woods Hole Oceanographic Institution
John Toole, Woods Hole Oceanographic Institution
Carl Wunsch, Massachusetts Institute of Technology

MARK ALAN GROSENBAUGH
Associate Scientist
Dept. of Applied Ocean Physics & Engineering
Woods Hole Oceangraphic Institution

Woods Hole, MA 02543
Phone: (508) 289-2607
FAX: (508) 289-2191
Email: mgrosenbaugh@whoi.edu

RESEARCH INTERESTS:

Dynamics of oceanographic moorings and towed cable systems, flow-induced vibrations of marine cables, hydrodynamic modeling of underwater vehicles, and fish propulsion.

I. EDUCATION:

1987-1988	Postdoc, Woods Hole Oceanographic Institution (Applied Ocean Physics & Engineering)
1987	Ph.D., U. of California, Berkeley (Naval Architecture & Offshore Engineering)
1983	M.S., Stanford University (Mechanical Engineering).
1976	B.S. & M.S., Stanford University (Geophysics).

II. APPOINTMENTS:

1992-pres	Associate Scientist, Dept. of Applied Ocean Physics & Engineering, WHOI
1996-2002	Education Coordinator, Dept. of Applied Ocean Physics & Engineering, WHOI
1988-2002	Lecturer, Dept. of Ocean Engineering, Massachusetts Institute of Technology.
1988-1992	Assistant Scientist, Dept. of Applied Ocean Physics & Engineering, WHOI
1987-1988	Postdoctoral Investigator, Dept. of Applied Ocean Physics & Engineering, WHOI
1983-1987	Research Assistant, Dept. of Naval Architecture & Offshore Engineering, U. of California, Berkeley
1981-1982	Research Engineer, McDonnell Douglas Corporation.

AWARDS, HONORS, NATIONAL COMMITTEES:

2002-pres	Chair, MIT/WHOI Joint Committee on Applied Ocean Science & Engineering
1999-pres	Member, Int. Soc. of Offshore & Polar Engineering Technical Program Committee
1996-2002	J. Seward Johnson Chair, Dept. of Applied Ocean Physics & Engineering
1997	DOD Augmentation Award for Science and Engineering Research Training
1996	Linnard Prize for Best Paper, Society of Naval Architecture & Marine Engineering
1993	DOD Augmentation Award for Science and Engineering Research Training

AFFILIATIONS:

American Physical Society
International Society of Offshore and Polar Engineers
Marine Technology Society

III. RELEVENT PUBLICATIONS

2003 Han, S. and Grosenbaugh, M.A. "Nonlinear Free Vibration of a Cable Against a Straight Obstacle", *Journal Sound and Vibration*, accepted.

2003 Han, S. and Grosenbaugh, M.A. "Bending Fatigue Analysis of Seafloor Observatory Moorings ", *ASME Proc. Offshore Mechanics and Arctic Engineering Conference*, Cancun, Mexico.

2002 Grosenbaugh, M.A., Anderson, S.P, Trask, R., Gobat, J.I., Paul, W., Butman, B., and Weller, R.A. "Design And Performance Analysis of a Horizontal Mooring for Upper Ocean Research", *J. Atmos. Oceanic Tech.*, Vol. 19, pp. 1376-1389.

2002 Gobat, J.I., Grosenbaugh, M.A., and Triantafyllou, M.S., "Generalized-α Time Integration Solutions for Hanging Chain Dynamics", *J. of Engineering Mechanics*, Vol. 128, pp. 677-687.

2001 Gobat, J.I. and Grosenbaugh, M.A., "Application of the Generalized-α Method to the Time Integration of the Cable Dynamics Equations", *Computer Methods in Applied Mechanics and Engineering*, Vol. 190, pp. 4819-4827,

2001 Gobat, J.I. and Grosenbaugh, M.A., "Dynamics in the Touchdown Region of Catenary Moorings", *International Journal of Offshore and Polar Engineering*, Vol. 11, pp. 273-281.

2000 Grosenbaugh, M.A., Gobat, J.I., and Eck, C.F., "Modeling the Dynamics of a Shallow-Water Oceanographic Surface Mooring Using Full-Scale Data", *International Journal of Offshore and Polar Engineering*, Vol. 10, pp. 10-19.

1998 Gobat, J.I. and Grosenbaugh, M.A., " WHOI Cable: Time Domain Numerical Simulation of Moored and Towed Oceanographic Systems", *Proceedings of Oceans '98,* Nice, France.

1997 Gobat, J.I. and Grosenbaugh, M.A., " Modeling the Vertical Motions of the Surface Suspended Acoustic Receiver", *Proceedings of Oceans '97*, Halifax, Canada.

1996 Grosenbaugh, M.A., "On the Dynamics of Oceanographic Moorings," *Ocean Engineering*, Vol. 23, pp. 7-25.

1994 Hover, F.S., Triantafyllou, M.S., Grosenbaugh, M.A., "Calculation of Dynamic Motions and Tensions in Towed Underwater Cables," *IEEE Journal of Oceanic Engineering*, Vol. 19, pp. 449-457.

IV. SYNERGISTIC ACTIVITIES

Co-developer of WHOI Cable, a numerical model for simulating the dynamics of oceanographic cable systems. Over 70 government labs and academic institutions in 10 different countries use the program.

Research on fish propulsion featured in popular publications including Scientific American, New Scientist Magazine, Smithsonian Magazine, and Turnstone Publishing's Ocean Explorer book series for children.

Research on fish propulsion included in MIT course on "Maneuvering and Control of Marine Vehicles".

V. COLLOBORATORS, ADVISORS, AND STUDENTS

(A) Collaborators in last 48 months: S. Coombs (Loyola U., Chicago), W.R. McGillis (WHOI), L. Rome (U. of Penn), M.S. Triantafyllou (MIT), L. Whitcomb (Johns Hopkins U.), D.R. Yoerger (WHOI), D.K.P. Yue (MIT), Chung-Chu Teng (NOAA-NDBC), Walter Paul (WHOI), Mark Chaffey (MBARI)

(B) Advisors: R.W. Yeung (Ph.D., U. of California, Berkeley), D.R. Yoerger (Post-graduate, WHOI)

(C) Graduate Student Advisor or Co-advisor last 5 years: J. Gobat WHOI (Ph.D. 2000), E. Anderson WHOI (Ph.D. exp 2003)

(D) Postgraduate Scholar Sponsor last 5 years: J. Gobat (5/00-9/00), H. Jiang (10/00-12/02), S. Han (10/01-present)

Total number of graduate students advised: (8) Total number of postgraduate scholars sponsored: (3)

Walter Paul

Senior Engineer
Head, Ocean Systems and Moorings Laboratory
Department of Applied Ocean Physics and Engineering
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

phone: 508-289-3506
fax: 508-547-2194
email: wpaul@whoi.edu

Date of Birth: 09-27-1935
Place of Birth: Bremen, Germany
Citizenship: United States

Education:

1961 M.S., Mechanical Engineering and Economics, University of Darmstadt, Germany
1967 Ph.D., Mechanical Engineering, University of Hannover, Germany
(Thesis work performed in the area of fiber rope mechanics)

Professional Experience:

1974-1993 Martin Marietta, Aero & Naval Systems Division, Ocean Systems Operation, (Formerly Chesapeake Instrument Corporation and Gould Inc.)
1993-present Senior Engineer and Head of the Ocean Systems and Moorings Laboratory, Woods Hole Oceanographic Institution

Research Interests:

Specialization in the development of compliant strength members for the use as buoy tethers, mooring ropes and cables, ship moorings, and anchor moorings for offshore aquaculture structures. Also design and test of reinforced rubber hoses, and of compliant EM and EOM cables for buoy moorings, and work in other aspects of mooring and buoy engineering.

Professional Affiliations:

Member, Marine Technology Society, Buoy Technology Committee
Chair, ONR/MTS Buoy Workshops, 1996 to present
Member, The Cordage Institute
Member, The Fiber Society
Member, World Aquaculture Society

Ph.D. Advisor:

Professor Kurt Wendel, University of Hamburg, Germany

Long-term Associates and Collaborators (within last four years):

D. Frye (WHOI), M. Grosenbaugh (WHOI), Jim Irish (WHOI),

Synergistic Activities:

- Design responsibility for all acoustic towed array hoses, vibration isolation hoses, array strength members, ropes, and tow cables that are used in towed array and towed antenna systems for the US Navy
- Designed reinforced rubber hoses and EM and EOM cables for buoy moorings and towed systems
- Development of compliant strength members for buoy tethers

Synergistic Activities (cont'd):

- Design of synthetic fiber strengthened electro-mechanical and electro-optical buoy mooring cables
- Design of moorings and very high stretch feed buoy mooring hoses with embedded conductor linkage between offshore submerged aquaculture net cages and fish feed buoy with wireless shore linkage
- Speaker Chair for two MTS Underwater Cable & Connector Workshops, Organizer of four ONR/MTS Buoy Workshops 1996, 1998, 2000, 2002; and 2004 Buoy workshop is in preparation
- Presentations at US Coast Guard Academy's Scholars class, MIT, MBARI, Mass. Maritime Academy

Publications most Relevant to Proposal:

Paul, W., J. Walther, TMT; "A Contribution to the Fatigue Behavior of an Electro-Mechanical Tow Cable Under High Service Load" *MTS'92 Conf. Proc.*, p. 977, Washington DC, Oct. 1992

Paul, W.; "Design Considerations for Stretch Conductors in Oceanographic Moorings", WHOI Tech. Report 95-15, Woods Hole, Dec. 1995

Paul, W., D. Bentley; "Conductor Survival in Light Weight Upper Ocean Working Cables", *Proceedings of the Eleventh (2001) International Offshore and Polar Engineering Conference*, Vol. II, pp. 708-714, Stavanger, Norway, June 2001

Chaffey, M., E. Mellinger, W. Paul "Communications and Power to the Seafloor: MBARI's Ocean Observing System Mooring Concept", *Oceans 2001 Proc.*, Vol. 4, pp. 2473-2481, Honolulu, HI, 11-2001

Paul, W., D. Bentley, M. Chaffey, D. Frye; "Electrical and Electro-Optical Mooring Links for Buoy Based Observatories" SSC03 (Scientific Submarine Cable 2003) Workshop, Tokyo, June 2003, submitted.

Other Significant Publications:

Paul, W.; "Review of Synthetic Fiber Ropes", Manual written for the US Coast Guard Academy and National Data Buoy Development Project, New London, CT, 1970.

Paul, W., A. Bocconcelli, "Drifting Buoy Systems Using Rubber Stretch Hose" *SEA TECHNOLOGY Magazine,* Vol. 35, No. 11, Nov. 1994, p. 37-43

Paul, W., A. Bocconcelli, M. Grosenbaugh; "Drifting Buoy Systems Using Elastic Rubber Stretch Hoses" *Boss'94 Behavior of Offshore Structures*, Pergamon Press, Vol. 2, p.213 - 225, Cambridge, MA, 1994. (WHOI Publication #8665)

Irish, J.D., Paul, W., Ostrom, W.M., Chambers, M., Fredriksson, D., Stommel, M., "Deployment of the Northern Fish Cage and Mooring, University of New Hampshire – Open Ocean Aquaculture Program, Summer 2000". WHOI Technical Report 2001-01, Sept. 2000

Paul, W.; "Buoy Technology", part of "State of Technology Report, Ocean and Coastal Engineering Division", M. Atturio, editor, *MTS Journal*, Vol. 35, No. 2, pp 54-57, Summer 2001

M A R K R. C H A F F E Y.

EXPERIENCE

08/99 – present **Monterey Bay Aquarium Research Institute**

Electrical Engineering Group Lead

- Supervise a department of seven electrical engineers working on original oceanographic platform and instrument design, fabrication and deployment. Hire staff, set priorities, assign resources to projects based on appropriate technical skills, provide mentoring, guide training, and evaluate staff performance.
- Systems Engineer on the overall MOOS oceanographic observatory project, a multi-year development effort to field a state-of-the-art ocean observatory system. Responsible for the overall technical success of the project. Maintain vision of overall system architecture. Develop functional and technical requirements and specifications. Specify interface requirements for subsystems.
- PI on the MOOS Mooring oceanographic observatory subproject managing all engineering aspects of the design and build effort including budget, scheduling, task allocation and quality control.

12/96 – 8/99 **Monterey Bay Aquarium Research Institute**

Electrical Engineer III

- PI on the HDTV underwater camera development project.
- PI on the Tiburon project managing all engineering aspects of the project including budget, scheduling, task allocation and quality control.

12/87 – 12/96 **Monterey Bay Aquarium Research Institute**

Associate Engineer

- Coordinated the electrical design and development for MBARI's new ROV project Tiburon.
- Designed the Tiburon to Western Flyer data link hardware utilizing a novel approach to provide high-speed network and other digital data over a single 5000-meter optical fiber.
- Direct design responsibility for the Tiburon to ship video uplink, control room video plant, overall vehicle systems interconnect wiring, the camera/viewing systems specification.

1980 – 1987 **Stanford University, Hopkins Marine Station**

Science and Engineering Technician

- Designed high-speed data acquisition computer hardware for neurobiology research.

1984 **Monterey Peninsula Water Management District**

Consultant, designed fish counting equipment

1977 – 1979 **University of California, Los Angeles, Geography Department**

Science Technician, designed 10 meter flume for fluvial geomorphology teaching and research

1973 – 1974 **University of Georgia, Skidaway Institute of Oceanography**

College Intern, Marine Geology

EDUCATION

- Monterey Peninsula College (Electronics and Mathematics), 1982-1984
- Antioch College (Geology), 1973-1975

SELECTED PUBLICATIONS:

Walter Paul, Doug Bentley, **Mark Chaffey** and Dan Frye, Electrical and Electro-Optical Mooring Links for Buoy Based Ocean Observatories*, 3rd International Workshop on Scientific Use of Submarine Cables and Related Technologies,* Tokyo, Japan June 25-27, 2003.

Mark R. Chaffey, Jon Erickson, Mike Kelley, Gene Massion, Lance McBride, Ed Mellinger, Wayne Radichonski, John Ryan, Keith Raybould, MBARI Ocean Observing System update, MOOS Mooring System, *ONR/MTS Buoy Workshop 2002,* Seattle, Washington, April 9-12, 2002.

Mark R. Chaffey, Ed Mellinger and Walter Paul, Communications and Power to the Seafloor: MBARI's Ocean Observing System Mooring Concept, *IEEE/MTS OCEANS Conference,* Honolulu, Hawaii, 2001.

Karen A. Salamy, **Mark R. Chaffey**, Jon Erickson, Douglas Au, Thomas C. O'Reilly, and Debra Stakes, Rock Coring Technology on the Juan de Fuca Plate with the MBARI ROV *Tiburon*, *OI Americas (Oceanology) Conference*, Miami, FL, April 2001.

Mark R. Chaffey, Implementing an ROV Based HDTV Camera System, *IEEE/MTS OCEANS Conference,* Seattle, WA 1999 (poster).

Mark R. Chaffey, Ship to ROV Telemetry for Tiburon, IEEE Oceans '96, Fort Lauderdale, Florida, September 1996.

Edward Mellinger, Andrew Pearce, and **Mark Chaffey**, Distributed Multiplexers for an ROV Control and Data System. IEEE Oceans '94, Brest, France, September 1994.

Mark R. Chaffey, Andrew Pearce, and Robert Herlien, Distributed Data and Computing System on an ROV Designed for Ocean Science, IEEE Oceans '93, Victoria, Canada, October 18-22, 1993.

MBARI TECHNICAL REPORTS:

- #94-17 Test Report: Tiburon Umbilical Hydrostatic Test. Mark Chaffey, May 12, 1994.
- #93-13 Instrument Bus Computer for New ROV Data Concentrators. Chaffey, Coletti, Kirkwood, Matthews, Mellinger and Wright. Sept. 1993.

MEMBERSHIPS:

- MTS, The Marine Technology Society.
- SPIE, The Society of Instrumentation and Optical Engineers.
- Invited member of the Deep Submergence Science Committee (DESSC)

PERSONAL

Born March 2, 1954 - Carmel CA

J. Andrew Hamilton

Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039
Email: hamilton@mbari.org
Tel: (831) 775-1861

Education

University of Colorado at Boulder	Mechanical Engineering	B.S.	1991
University of California at Berkeley	Ocean Engineering	M.S.	1993
University of California at Berkeley	Mechanical Engineering	Ph.D.	2002

Professional Experience

2002 – Present	Mechanical Engineer, Monterey Bay Aquarium Research Institute
1999-2002	Research and Teaching Assistant, University of California at Berkeley
1993-1999	Senior Engineer, Parker-Hannifin Corporation, Compumotor Division
1991-1993	Research Assistant, University of California at Berkeley

Publications

- Hamilton, J.A. and Yeung, R.W., 2003, "Spectral Shell and Perfectly Transparent Open-Boundary Condition for Unsteady Wave-Body Interactions", *Journal of Offshore Mechanics and Arctic Engineering*, **125**, pp. 9-16.
- Hamilton, J.A. and Yeung, R.W., 1997, "Shell-Function Solution for 3-D Nonlinear Body-Motion Problems", Schiffstechnik, **44**, pp.62-70.
- Yeung, R.W. and Hamilton, J.A, 2002, "A Spectral-Shell Solution for Viscous Wave-Body Interactions", *Proceedings of the 24th ONR Symposium on Naval Hydrodynamics*, Fukuoka, Japan.
- Hamilton, J.A. and Yeung R.W., 2003, "Viscous-Inviscid Matching for Surface-Piercing Wave-Body Interaction Problems", *Proceedings of the 18th International Workshop on Water Waves and Floating Bodies*, Nantes, France.

Graduate Advisor

Professor R.W. Yeung, University of California at Berkeley

Keith Raybould B.Sc, MSc, I.Mech.E, C.Eng

Professional Experience

Oct 00 - Present: Monterey Bay Aquarium Research Institute (MBARI)
Chief Operations Officer, Project Coordinator, MBARI Ocean Observing System Project Manager,

Responsibilities include (a) managing the MBARI Ocean Observing System, an integrated deployable mooring system (b) overseeing and managing MBARI's Facilities and Information System groups (c) coordinating resources on Institute projects (d) project planning and training project managers

Aug 99 – Oct 00: Monterey Bay Aquarium Research Institute (MBARI)
Project Coordinator, MBARI Ocean Observing System Project Manager, MBARI

Responsibilities included (a) managing the MBARI Ocean Observing System (b) coordinating resources on Institute projects projects (c) project planning and training project managers

May 93 – Aug 99: Association of Universities for research in Astronomy, Tucson, AZ
Gemini Telescope, Building, Enclosure Manager, AURA

Responsible for the design, fabrication and site construction of the telescope structure and coating plant. Also responsible for the rotating enclosures, buildings, power, comms, road infrastructure, support facilities and labs, operations buildings, including developing concept designs, contract bidding, contract negotiation, permit applications, geotechnical testing, managing AE firm and consultant engineers, managing site construction, scheduling, budget control.

May 92 – May 93: Association of Universities for research in Astronomy, Tucson, AZ
Gemini Telescope Group Manager

Responsible for the design, fabrication and site construction of the telescope structure and coating plant. Managed many other high technology development contracts, including a programs to develop protected silver coatings, develop and test composites for telescope structure, vibration transmission and Excimer laser cleaning of large optics.

Feb 89 – May 92: Oxford University, UK
UK Engineering Manager for UK 8m Telescope Project, Oxford University, UK

Oct 88 – Feb 89: Science and Engineering Research Council, Rutherford Appleton Laboratory, UK

Team Leader in Structural and Thermal Engineering, for space satellite systems.

Manager of the team at Rutherford Appleton Laboratory, responsible for the thermal and structural design of space satellite instrumentation.

Apr 83 – Oct 88 Science and Engineering Research Council, Joint Astronomy Center, Hawaii
Senior Mechanical Engineer, Head of Mechanical Engineering group

Manager of the mechanical group at the JAC responsible for the mechanical aspects of operating and developing two National astronomical facilities, the 15m James Clark Maxwell Telescope, and the 3.8m United Kingdom Infared Telescope, located on M Kea in Hawaii.

Apr 81 – Apr 83: Royal Corp of Naval Constructors, Ministry of Defense, UK
Mechanical Engineer, specialist design section

Specialist engineer working in Underwater Acoustics and Hydraulic Divisions at the Ministry of Defense Headquarters.

8/79 – 8/81, Royal Corp of Naval Constructors Ministry of Defense, UK
Post Graduate Training

Submarine design course, marine engineering application course, electrical engineering course, 6 months at sea on warship.

8/78 – 8/79, Royal Corp of Naval Constructors Ministry of Defense, UK
M Sc Marine Engineering, University College, London

8/75 – 8/78, Royal Corp of Naval Constructors Ministry of Defense, UK
B Sc, Honours, Mechanical Engineering

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION **Woods Hole Oceanographic Institution**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Daniel E Frye**				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Daniel E Frye - Co-Principal Investigator	1.00	0.00	0.00	$ 8,237	$
2. Mark A Grosenbaugh - Co-Principal Investigator	1.00	0.00	0.00	7,098	
3. Walter Paul - Co-Principal Investigator	2.00	0.00	0.00	14,434	
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	4.00	0.00	0.00	29,769	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	4.00	4.00	0.00	14,252	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	13.00	0.00	0.00	63,791	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				710	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				108,522	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				45,308	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				153,830	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				6,146	
2. FOREIGN				3,363	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				23,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				36,040	
TOTAL OTHER DIRECT COSTS				59,040	
H. TOTAL DIRECT COSTS (A THROUGH G)				222,379	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **G&A Costs (Rate: 34.3800, Base: 153830) (Cont. on Comments Page)**					
TOTAL INDIRECT COSTS (F&A)				121,111	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				343,490	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 343,490	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				
PI/PD NAME **Daniel E Frye**				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. NAME*				Date Checked / Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

TPI 6252886

SUMMARY PROPOSAL BUDGET COMMENTS - Year 1

** I- Indirect Costs
Laboratory Costs (Rate: 44.3500, Base 153830)

SUMMARY PROPOSAL BUDGET
YEAR 2

FOR NSF USE ONLY				
ORGANIZATION Woods Hole Oceanographic Institution	PROPOSAL NO.	DURATION (months) Proposed	Granted	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Daniel E Frye	AWARD NO.			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Daniel E Frye - Co-Prinicapl Investigator	1.00	0.00	0.00	$ 8,649	$
2. Mark A Grosenbaugh - Co-Principal Investigator	1.00	0.00	0.00	7,454	
3. Walter Paul - Co-Principal Investigator	2.00	0.00	0.00	15,154	
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	4.00	0.00	0.00	31,257	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (1) POST DOCTORAL ASSOCIATES	4.00	0.00	0.00	14,963	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	10.00	0.00	0.00	46,370	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (1) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				746	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				93,336	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				38,968	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				132,304	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				7,981	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				7,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				104,680	
TOTAL OTHER DIRECT COSTS				111,680	
H. TOTAL DIRECT COSTS (A THROUGH G)				251,965	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) G&A Costs (Rate: 34.3800, Base: 132304) (Cont. on Comments Page)					
TOTAL INDIRECT COSTS (F&A)				104,163	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				356,128	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 356,128	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME Daniel E Frye	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

TPI 6252886

SUMMARY PROPOSAL BUDGET COMMENTS - Year 2

** I- Indirect Costs
Lab Costs (Rate: 44.3500, Base 132304)

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION Woods Hole Oceanographic Institution				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Daniel E Frye				AWARD NO.	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Daniel E Frye - Co-Principal Investigator	2.00	0.00	0.00	$ 16,886	$
2. Mark A Grosenbaugh - Co-Principal Investigator	2.00	0.00	0.00	14,552	
3. Walter Paul - Co-Principal Investigator	4.00	0.00	0.00	29,588	
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	8.00	0.00	0.00	61,026	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (2) POST DOCTORAL ASSOCIATES	8.00	4.00	0.00	29,215	
2. (6) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	23.00	0.00	0.00	110,161	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (2) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				1,456	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				201,858	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				84,276	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				286,134	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				14,127	
2. FOREIGN				3,363	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				30,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				140,720	
TOTAL OTHER DIRECT COSTS				170,720	
H. TOTAL DIRECT COSTS (A THROUGH G)				474,344	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				225,274	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				699,618	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 699,618	$
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				
PI/PD NAME Daniel E Frye				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION	
ORG. REP. NAME*				Date Checked / Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

TPI 6252886

BUDGET DISCUSSION

Salary is requested for the principal investigators to provide overall project management (D. Frye), supervise numerical modeling and cable fatigue analysis (M. Grosenbaugh), and design and direct testing of new synthetic EOM cable designs (W. Paul).

Additional salary is requested to carry-out detailed numerical analysis of different mooring configurations and develop models to predict fatigue in synthetic EOM cables (S. Han), design and implement the optical sensor hardware and software that will be used to measure strain in optical fibers and assist in the design of new EOM cables (Snr. Eng. TBD), assist in the preparation of test-jigs for laboratory cable bending tests and fabricate and test mooring hardware for full-scale experiments (J. Dunn), design connectors for new synthetic cable designs (D. Peters), and provide administrative assistance (D. Chausse).

Funds are requested for domestic travel to MBARI, in Year 1 to hold design meetings with our collaborators and in Year 2 to participate in the full-scale mooring and cable deployment. (MBARI has requested funds in their budget to travel to WHOI for additional design meetings). Funds are requested in Years 1 and 2 to travel to Los Angeles to oversee laboratory cable tests at Tension Member Technology, Inc. Funds are requested in Year 2 to travel to San Diego, CA to present results of this development effort to the ocean engineering community. Foreign travel in Year 1 is included to travel to Southampton for training on the use of the fiber optic sensing system and its associated software.

Costs for the prototype synthetic EOM cable sections and the costs for contracting Tension Member Technology, Inc. to perform strength and bending tests on the prototype sections are contained in our collaborator's (MBARI) budget. Costs for a full-length synthetic EOM cable, which will be used in the field experiments, are also contained in MBARI's budget.

Other direct costs include materials and supply funds to construct rubber snubber hoses for use in the full-scale experiment. Funds include mechanical, electrical, and stockroom supplies, which will be used in all facets of the project. Other costs are requested for machine shop time to be used in constructing mooring hardware and test fixtures. Funds to purchase equipment from Smart Fibres Ltd. to show the feasibility of an optical fiber strain sensing system (Year 1) and ultimately instrument the full-length EOM cable to measure strain non-invasively (Year 2). Costs for shipping, communications and postage and photocopying are self-explanatory.

The Woods Hole Oceanographic Institution calculates overhead rates (both Laboratory Costs and General & Administrative Costs) as a percent of total direct salaries and benefits, as allowed by OMB Circular A-122. Direct salaries exclude overtime-premium pay. A proposed labor month is equal to 152 hours or 1824 hours annually versus 2080 hours (40 hours/week for 52 weeks). The difference is for vacations, holidays, sick time, and other paid absences, which are included in Employee Benefits.

The rates included in the proposal are negotiated with ONR or they are estimates. When estimated rates are finalized, costs will be in accordance with the rate agreement.

With the assistance of Pricewaterhouse Coopers, WHOI undertook a study to determine what our 1997 combined F&A overhead rate would be if we used the MTDC method used by most Universities that are subject to OMB Circular A-21. We repeated the study and determined that our rate for 2000 would be 49.88%, lower than most research institutions and research-intensive universities.

Collaborative Research: Design, Modeling and Testing of Electro-Optic Mechanical (EOM) Mooring Cables for Moored-Buoy Observatories

Daniel Frye, Mark Grosenbaugh and Walter Paul
10/01/03 - 09/30/05
BUDGET

	10/1/2003-9/30/2004	10/1/2004-9/30/2005	10/1/2003-9/30/2005
	Approximate Labor Months		Totals
A. SENIOR PERSONNEL			
1. D. Frye, Co-Principal Investigator	1.0	1.0	2.0
2. M. Grosenbaugh, Co-Principal Investigator	1.0	1.0	2.0
3. W. Paul, Co-Principal Investigator	2.0	2.0	4.0
B. OTHER PERSONNEL			
1. Seon Han, Postdoctoral Investigator	4.0	4.0	8.0
2. TBA, Senior Engineer	6.0	4.0	10.0
J. Dunn, Mooring Technician	6.0	6.0	12.0
D. Peters, Senior Engineer	1.0	0.0	1.0
5. D. Chausse, Sr. Administrative Assistant	0.25	0.25	0.5
C. TOTAL SALARIES, WAGES AND FRINGE BENEFITS	$ 153,830	$ 132,304	$286,134
E. TRAVEL--(see detail)			
Domestic:			
1. 6RT/3 people/1 trip ea. Yr./ to Monterey Bay, CA	4,530	4,530	
2. 2RT/ 1 person/ 1 trip ea. Yr./ Los Angeles, CA	1,616	1,616	
3. 1RT San Diego, CA (Attend Conference)	-	1,835	
Total Domestic Travel	6,146	7,981	14,127
Foreign:			
1. 1RT Southampton, England	3,363	-	3,363
Total Domestic and Foreign Travel	9,509	7,981	17,490
G. OTHER DIRECT COSTS			
1. Materials and Supplies			
a. Hoses	15,000	-	
b. Electrical supplies	3,000	2,000	
c. Mechanical supplies	4,000	4,000	
d. Stockroom supplies	1,000	1,000	
Total Materials and Supplies	23,000	7,000	30,000
6. Other			
a. Machine shop 80Hrs./yr1 & yr2 @ $37-$39 Hr.	2,960	3,120	
b. Outside services--	31,680	100,160	
c. Shipping	1,000	1,000	
d. Communications and postage	300	300	
e. Photocopying	100	100	
Total Other	36,040	104,680	140,720
TOTAL OTHER DIRECT COSTS	59,040	111,680	170,720
H. TOTAL DIRECT COSTS	$222,379	$251,965	$474,344
I. INDIRECT COSTS			
a. Laboratory Costs	68,223	58,677	
b. General and Administrative Costs	52,887	45,486	
TOTAL INDIRECT COSTS	121,110	104,163	225,273
J. TOTAL DIRECT AND INDIRECT COSTS	$ 343,489	$ 356,128	$ 699,617

Woods Hole Oceanographic Institution will cost share in accordance with current National Science Foundation policies.

31-May-03 WHOI Proposal OE11107.0

Budget Detail

	Year 1	Year 2
E. TRAVEL--		
Domestic		
1. 6RT/3 people/1 trip ea. Yr./ to Monterey Bay, CA $ 600 ea.	1,800	1,800
Per diem/3 people/1 trip ea. yr/5 days @ $140/day	2,100	2,100
Ground transportation to airport (2cars/trip) @ $280/trip	280	280
Ground transportation at Monterey, CA	350	350
(1 car/1 trip ea. Yr./5 days ea.trip) @ $70/day		
Total trip 1	4,530	4,530
2. 2RT Los Angeles, CA @ $600/trip	600	600
Per diem/1 person/1 trip/4 days @ $149/day (each year)	596	596
Ground transportation to airport @ $140/trip	140	140
Ground transportation Los Angeles, CA 4 days @ $70/day	280	280
Total trip 2	1,616	1,616
3. 1RT San Diego, CA @ $600/trip	-	600
Per diem/1 person/1 trip/5 days @ $149/day	-	745
Ground transportation to airport @ $140/trip	-	140
Ground transportation San Diego, CA 5 days @ $70/day	-	350
(Attend Conference)		
Total trip 3		1,835
Foreign		
1. 1RT Southampton, England @ $850/trip	850	-
Per diem/1 person/1 trip/7 days @ $269/day	1,883	-
Ground transportation to airport @ $140/trip	140	-
Ground transportation Southampton/ 7 days @ $70/day	490	-
Total trip 1	3,363	-

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION **Monterey Bay Aquarium Research Institute**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Mark R Chaffey**				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Mark R Chaffey - PI	2.50	0.00	0.00	$ 24,167	$	
2. J. Andrew Hamilton - Co-PI	2.25	0.00	0.00	17,438		
3. Keith Raybould - Co-PI	0.00	0.00	0.00	0		
4.						
5.						
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	4.75	0.00	0.00	41,605		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (4) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.75	0.00	0.00	10,438		
3. (0) GRADUATE STUDENTS				0		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				52,043		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				26,906		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				78,949		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) EOM Cable Test Samples $ 30,000 Laboratory bending test hydraulic power unit 6,000						
TOTAL EQUIPMENT				36,000		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				4,800		
2. FOREIGN				0		
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				61,000		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0		
3. CONSULTANT SERVICES				50,000		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				600		
TOTAL OTHER DIRECT COSTS				111,600		
H. TOTAL DIRECT COSTS (A THROUGH G)				231,349		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) H-D-F (Rate: 47.0000, Base: 195349)						
TOTAL INDIRECT COSTS (F&A)				91,814		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				323,163		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 323,163	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD NAME Mark R Chaffey				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*				Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET — YEAR 2

ORGANIZATION: Monterey Bay Aquarium Research Institute				FOR NSF USE ONLY — PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR: Mark R Chaffey				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Mark R Chaffey - PI	1.50	0.00	0.00	$ 15,080	$	
2. J. Andrew Hamilton - Co-PI	0.50	0.00	0.00	4,030		
3. Keith Raybould - Co-PI	0.00	0.00	0.00	0		
4.						
5.						
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	2.00	0.00	0.00	19,110		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0		
2. (4) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.50	0.00	0.00	9,295		
3. (0) GRADUATE STUDENTS				0		
4. (0) UNDERGRADUATE STUDENTS				0		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				28,405		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				14,685		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				43,090		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Riser Test Cable Manufacture (4500 meters) $ 225,000						
TOTAL EQUIPMENT				225,000		
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				4,800		
2. FOREIGN				0		
F. PARTICIPANT SUPPORT COSTS						
1. STIPENDS $ 0						
2. TRAVEL 0						
3. SUBSISTENCE 0						
4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				0		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0		
3. CONSULTANT SERVICES				20,000		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				400		
TOTAL OTHER DIRECT COSTS				20,400		
H. TOTAL DIRECT COSTS (A THROUGH G)				293,290		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) H-D-F (Rate: 47.0000, Base: 68290)						
TOTAL INDIRECT COSTS (F&A)				32,096		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				325,386		
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 325,386	$	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD NAME: Mark R Chaffey				FOR NSF USE ONLY — INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*				Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

TPI 6254964

SUMMARY **Cumulative**
PROPOSAL BUDGET

ORGANIZATION Monterey Bay Aquarium Research Institute	**FOR NSF USE ONLY** PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Mark R Chaffey	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Mark R Chaffey - PI	4.00	0.00	0.00	$ 39,247	$
2. J. Andrew Hamilton - Co-PI	2.75	0.00	0.00	21,468	
3. Keith Raybould - Co-PI	0.00	0.00	0.00	0	
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (3) TOTAL SENIOR PERSONNEL (1 - 6)	6.75	0.00	0.00	60,715	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (8) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	3.25	0.00	0.00	19,733	
3. (0) GRADUATE STUDENTS				0	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				80,448	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				41,591	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				122,039	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 261,000					
TOTAL EQUIPMENT				261,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				9,600	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				61,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				70,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				1,000	
TOTAL OTHER DIRECT COSTS				132,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				524,639	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				123,910	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				648,549	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 648,549	$

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME Mark R Chaffey	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME*	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

TPI 6254964

Budget Discussion (MBARI)

Salary is requested for the PI to perform systems engineering tasks for the overall proposed effort, manage the field test program and in conjunction with collaborators, manage the laboratory test program (M. Chaffey). Salary is also requested for CO-PI to perform design and analysis for the test mooring deployment, and, in conjunction with collaborators perform dynamic modeling of candidate mooring configurations and design the bending test protocols (A. Hamilton).

Salary is also requested for the MBARI Observatory Support Group and a mechanical technician to perform field test program final assembly, pre-deployment staging and deployment tasks for the test mooring deployment and subsequent mooring turn-around expeditions (M. Kelly, P. Cohen and J. Ferreira). Salary is also requested for a software applications developer to support a portion of the effort required to maintain the shoreside data archive and web based data retrieval services needed for the test mooring (K. Gomes).

Funds are requested for two PI's to travel to WHOI for design meetings once per year in each of the two years (WHOI has requested funds in their budget for additional design meetings at MBARI). Funds are also requested to make two trips per year to Tension Member Technologies to oversea cable testing efforts. Funds are requested in Year 2 for the PI's to travel to San Diego, CA to present results of this development effort to the ocean engineering community.

Funds are requested for contracting a portion of the cable tests proposed for the test program to Tension Member Technology Laboratories in Huntington Beach California. Funds are requested for the purchase of short test segments of candidate cable designs and in Year 2, the purchase of the full length mooring EOM cable selected for field testing. Additional funds are also requested for the required cable floatation devices.

To implement the proposed cable test program funds are requested for the long endurance bending fatigue tests which will be performed at MBARI's facility, requiring a hydraulic auxiliary power unit, two hydraulic rams, electro-hydraulic valves and associated hardware.

Two UNOLS regional class ship days are requested in year one for initial test mooring deployment and three ship days in year 2 for the proposed six-month turn around through the NSF/UNOLS ship request system.

Through internal funding MBARI is providing cost-share contributions of two completely designed and built up surface moorings with power, data logging and data telemetry-to-shore, including all associated engineering, machine shop and technician labor. The second mooring is to allow short-turn-around replacement of the surface float. MBARI is also providing two sets of load measuring instrumentation, ocean current measurement and two complete meteorological measurement sets. In addition MBARI is fabricating and installing a networked series of benthic instrument nodes on internal funds and providing ship and ROV days for installation and connection to the test mooring after deployment to fully test the seafloor ocean observatory concept. MBARI is also providing the majority of the costs of developing the shoreside data archival and retrieval services.

Daniel E. Frye--Current and Pending								
Principal Investigator(s) and Project Title	**Supporting Agency**	**1**	**2**	**3**	**4**	**Period Covered**	**Award Amount**	**WHOI Proposal#**
		Person mo./yr. committed						
Current Support								
Completion and Field Demonstration of a Portable Coastal Observatory (D.Frye)	NOPP: N00014-02-10062	1.0				9/20/01-07/31/03	$147,426	OE10735.0
SALP: A Submerged Autonomous Launch Platform for Drifitng Instrumentation (D.Fratantoni, D.Frye & J.Valdes)	NSF: OCE-0136255	0.5	0.25	0.25		2/1/02-01/31/05	$626,493	PO10849.0
Development and Testing of a Deep Water, Acoustically-Linked, Moored-Buoy Seafloor Observatory (R.S. Detrick, J.A. Collins, D.E. Frye, L.E. Freitag & K.R. Peal)	NSF: OCE-0215670	2.0	2.0	0.5	1.0	9/1/02-08/31/06	$1,161,094	GG11122.0
Continuation of The Bermuda Testbed Mooring Activities for 2003 and 20004 (Grant#N00014-96-1-0028)	ONR: N00014-96-1-0028	NC	NC			1/1/03-12/31/04	$107,944	OE10948.0
High Bandwidth Data and Power Linkage Between Seafloor Instrumentation and Surface Buoy Platforms (Cont. of Grant N00014-94-1-0346) (D.Frye & W.Paul)	ONR: N00014-03-1-008	3.0	3.0			1/1/03-12/31/04	$513,583	OE10952.0
ULTRAMOOR Special Creativity Extension	NSF: OCE-9810641	1.0	1.0			1/1/03-09/30/05	$472,787	OE11024.0
Design and Fabrication of Mooring Facility Surface Buoy	UCSB: PO#SB28709-0	NC				1/15/03-1/14/04	$75,843	OE11038.0
Principal Investigator(s) and Project Title	**Supporting Agency**	**Per 1**	**Per 2**	**Per 3**	**Per 4**	**Period Covered**	**Award Amount**	**WHOI Proposal#**
		Person mo./yr. committed						
Pending Support								
Collaborative Proposal: A Real-Time Nearshore Seafloor Seismic Station (D.Frye & R.Sohn)	NSF	1.0	1.0	1.0		3/1/03-02/28/06	$487,727	PO10924.0
Commercialization of the Autonomous Estuarine Profiler - FY 2003 (CICEET) Technology Transfer Proposal Application (D. Frye, W. Rockwell Geyer, K. Doherty)	CICEET	1.0				09/01/03-08/31/04	$246,209	OE11050.0
*Collaborative Research: Design, Modeling and Testing of Electro-Optic Mechanical (EOM) Mooring Cables for Moored-Buoy Observatories (D.Frye, M.Grosenbaugh, W. Paul)	NSF	1.0	1.0			10/01/03-09/30/05	$699,617	OE11107.0

*This proposal

Mark A. Grosenbaugh - Current and Pending Support

Principal Investigator(s) and Project Title	Supporting Agency	1	2	3	4	5	Period Covered	Award Amount	WHOI Research Project #
Current Support		Period Salary Months							
M.A. Grosenbaugh -- Understanding the Dynamics of Geometrically Compliant Oceanographic Moorings	ONR N00014-92-J-1269	3	3	3			1/1/01- 12/31//03	$219,757	OE10617.00
S.M. Gallagher, M. Grosenbaugh - A Computational Fluid Dynamics Study of Propulsion and Swimming Energetics of Cod Larvae	Ocean Life Institute	0.5					7/23/01 - 7/22/03	$59,755	OE10757.00
M.A. Grosenbaugh -- Verification of SAHRV Transponder Mooring Deployment Tables	ONR N00014-92-J-1269	1					1/1/02 - 12/31/03	$40,035	OE10842.00
M.A. Grosenbaugh & W. R. McGillis -- Analysis of the Boundary Layer and Near-Field Flow Around Swimming Fish	NSF IBN-0114148	1	1	1	1		7/01/01- 6/30/04	$293,368	OE10702.00
M.A. Grosenbaugh and H. Jiang - Development of a New Capability for Analyzing Bending Stresses in Sea Floor Moorings	WHOI Internal Deep Ocean Exploration Institute	2					7/1/02 - 6/30/04	$52,629	OE10921.00

Principal Investigator(s) and Project Title	Supporting Agency	1	2	3	4	5	Period Covered	Funds Requested	Research will be performed
Pending Support		Period Salary Months							
NOTE: THESE ARE SUBMITTED PROPOSALS. IN THE UNLIKELY EVENT THAT THEY WERE ALL TO BE FUNDED AT THE REQUESTED LEVEL, THE WORK SCHEDULE AND TIME ALLOCATIONS WOULD BE RE-NEGOTIATED WITH THE VARIOUS AGENCIES. UNDER NO CIRCUMSTANCES WILL WHOI COMMIT MORE THAN 100% OF AN INVESTIGATORS TIME TO RESEARCH.									
M.A. Grosenbaugh and H. Jiang - Dynamic Acquisition of Multisensory Information: Sensory Integration of the Lateral Line	NIH / Loyola University	1	1	1	1	1	4/1/03 - 3/31/07	$365,000	OE10920.00
M. Grosenbaugh, A. Bowen, D. Yoerger, L. Whitcomb, H. Singh - Exploring the Deepest Depths: A Novel, Light-Tethered, Hybrid ROV for Global Science in Extreme Environments	NSF	2	1	1			10/1/03 - 9/30/06	$5,555,657	OE11056.00
*D. Frye, M. Grosenbaugh and W. Paul - Collaborative Research: Design, Modeling and Testing of Electro-Optic Mechanical (EOM) Mooring Cables for Moored-Buoy Observatories	NSF	1	1				10/1/03 - 9/30/05	$699,617	OE11107.00

*This Proposal

Walter Paul -- Current and Pending Support

May-03

Principal Investigator(s) and Project Title	Supporting Agency	Proposal Period 1	2	3	4	Period Covered	Award Amount	WHOI Proposal #
CURRENT SUPPORT								
W. Paul and J. Irish - Monitoring of Offshore Aquaculture System--Phase II	UNH Agreement #02-595 (NOAA Prime)	2.3	1.0			9/1/01-8/31/03	$263,383	WHOI OE10731.00 & OE10731.01
D. Frye and W. Paul - Moored Array Technology: Telemetry Gateway Mooring Designs for Shallow Water Environments (Continuation of Grant N00014-94-1-0346)	ONR N00014-94-1-0346	2.0	3.0			1/1/01-12/31/03	$508,300	WHOI OE10621.00
W. Paul and D. Frye - High Bandwidth Data and Power Linkage Between Seafloor Instrumentation and Surface Buoy Platforms	ONR N00014-03-1-0008	3.0	3.0			1/1/03-12/31/04	$513,583	WHOI OE10952.00
W. Paul - Investigation of AN/SQR-19 VIM Behavior Phase 2: White Paper & Visit to Hose Manufacturing Facility	Lockheed Martin	0.3				3/1/03-5/31/03	$7,454	WHOI OE11066.00

PENDING SUPPORT

Principal Investigator(s) and Project Title	Supporting Agency	Proposal Period 1	2	3	4	Period Covered	Award Amount	Where research is performed
NOTE: THESE ARE SUBMITTED PROPOSALS. IN THE UNLIKELY EVENT THAT THEY WERE ALL TO BE FUNDED AT THE REQUESTED LEVEL, THE WORK SCHEDULE AND TIME ALLOCATIONS WOULD BE RENEGOTIATED WITH THE VARIOUS AGENCIES. UNDER NO CIRCUMSTANCES WILL WHOI COMMIT MORE THAN 100% OF AN INVESTIGATOR'S TIME TO RESEARCH.								
*J. Irish and W. Paul - Instrumentation of Salmon Cages	UNH (NOAA Prime)	0.3				5/1/03-10/31/04	$75,994	WHOI OE10965.00
J.D. Irish, and W.G. Paul - Monitoring and Control of Offshore Aquaculture Systems.	UNH (NOAA Prime)	1	1			-09/1/03-08/31/05	$268,964	WHOI OE11111.00
D. Frye, M. Grosenbaugh, and W. Paul - Collaborative Research: Design, Modeling, and Testing jof Electro-Optic Mechanical (EOM) Mooring Cables for Moored-Buoy Observatories.	NSF	2	2			10/1/03-09/30/05	$699,617	WHOI OE11107.00

* preliminary indication of funding has been communicated by sponsor.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: MARK CHAFFEY

Other agencies (including NSF) to which this proposal has been/will be

Support: ☐ Current XPending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Collaborative Research: Design, Modeling, and Testing of Electro-Optic Mechanical (EOM) Mooring Cables For Moored-Buoy Observatories

Source of Support: NSF
Total Award Amount: $648,550 Total Award Period Covered: 10/0/03 – 9/30/05
Location of Project: MBARI
Person-Months Per Year Committed to the Project. Cal: 11 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: J. ANDREW HAMILTON

Other agencies (including NSF) to which this proposal has been/will be

Support: ☐ Current XPending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Research: Design, Modeling, and Testing of Electro-Optic Mechanical (EOM) Mooring Cables For Moored-Buoy Observatories

Source of Support: NSF

Total Award Amount: $648,550 Total Award Period Covered: 10/0/03 – 9/30/05

Location of Project: MBARI

Person-Months Per Year Committed to the Project. Cal: 11 Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

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Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Other agencies (including NSF) to which this proposal has been/will be

Investigator: KEITH RAYBOULD

Support: ☐ Current X Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Collaborative Research: Design, Modeling, and Testing of Electro-Optic Mechanical (EOM) Mooring Cables For Moored-Buoy Observatories

Source of Support: NSF
Total Award Amount: $ 648,550 Total Award Period Covered: 10/0/03 – 9/30/05
Location of Project: MBARI
Person-Months Per Year Committed to the Project. Cal: 11 Acad: Sumr:

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: Monterey Accelerated Research System

Source of Support: NSF
Total Award Amount: $6,990,000 Total Award Period Covered: 10/01/2002 – 09/30/2005
Location of Project: MBARI
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: X Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory: **1.Electronic and mechanical design laboratories, fully equipped with test instrumentation and personal computers, will be available as needed.**
2.A large mooring fabrication shop equipped with cable winders, swaging machines, tension testers, etc., will be available.

Clinical: **NA**

Animal: **NA**

Computer: **Computers and software are available to all PIs and Engineers**

Office: **Each of the PIs and Engineers has office space at their disposal that will be available to this project.**

Other: **The WHOI dock, which is very useful for instrument and component testing, is available to this project.**

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

Facilities at the Woods Hole Oceanographic Institution which are available to all investigators include shop services, computer services, travel office and stockroom. The WHOI/MBL Library is also available. We plan to work with Smart Fibres, Ltd. of Southampton, England on the development of fiber optic strain sensors for mooring cables under a subcontract arrangment. We plan to collaborate with investigators at MBARI on all phases of the project.

Continuation Page:

LABORATORY FACILITIES (continued):

MBARI Facilities
02JUN03 mrc

Laboratory:
200 sq. meters of clean laboratory space is available for the proposed work fully equipped with electronic test equipment and optical test, measurement, and assembly instrumentation.
Several large assembly areas at MBARI are available for the proposed work, a large work bay with 10 ton overhead gantry crane and a separate assembly building for expedition staging and final testing is available with 500 sq. meters of floor space.

Computer:
Full computer facilities are available for the project, including disk space for data archival. All computer facilities are fully supported by permanent staff.

Office:
Office space including full communications and duplication facilities are available to all personnel working on the proposed project. Workstation computers are available fully equipped with office automation software as well as electronics simulation and design tools, MATLAB, mechanical modeling and design software and the WHOI cable dynamics modeling package.

Major Equipment:
Dock space is available for shipboard loading of buoy systems immediately adjacent to the final staging and test area. Dock and harbor entrance can accommodate regional class UNOLS vessels. Fork lifts, traveling cranes and similar facilities needed for staging and loading oceanographic equipment are available. Cable handling spoolers and a large oceanographic winch for shipboard buoy deployment are both available.

Other Resources:
Electronics shop with equipment and supplies for cable, wire and device fabrications including full surface mount fabrication and rework capability.
Full machine shop with CNC lathe and mill, multiple conventional machine machining and finishing tools, water jet cutting, and welding facilities. Facilities to work in all materials including composites and Titanium. Pressure test facility able to test deep submergence hardware as large as 25cm in diameter to 10,000 PSI. All MBARI shop facilities are fully supported by permanent staff.
A portion of the cable testing effort proposed will be contracted to Tension Member Technology Laboratories Inc. (TMT), of Huntington Beach California. TMT has extensive experience and equipment for cable testing including pull-to-failure and bend-over-sheave testing to hundreds of kilo Newtons cable load.

Smart Fibres Ltd

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Website: www.smartfibres.com · Email: info@smartfibres.com

For the development and supply of a

Underwater Mooring Tendon Optical Fibre Strain Sensing System

(part of broader proposal to Woods Hole Oceanographic Institute)

Document Ref:	6-306-3000-Draft 2
Document Date:	28th April 2003

1. BACKGROUND

Structural Health Monitoring (SHM) is a mechanism for reducing the cost of ownership of a structure. This is achieved in several ways:

- SHM allows for the design and development of more cost effective structures by providing input into the design function
- SHM significantly reduces the requirement for routine maintenance of a structure by providing the structure owner sufficient confidence in the structure's condition that regular routine maintenance is not required
- SHM extends the serviceable life of a structure by alerting the structure owner of impending damage occurrence such that preventative maintenance can be carried out

Smart Fibres have been involved in Structural Health Monitoring using Optical Fibre Strain Sensing Systems (OFSSS) for 10 years. In that time, the Company has developed OFSSS technology to provide SHM solutions to many structures including but not limited to yacht masts, military aircraft and wind turbines. Trials have also been carried out to verify the application of OFSSS to composite and concrete bridges, underground rail tunnels and road pavements.

Of direct relevance to the current proposed application is Smart Fibres R&D activities on the monitoring of underwater structures in the Offshore oil Industry. Attached is a copy of a paper presented by Mamdouh M Salama of Conoco Inc. to the 13th International Deep Offshore Technology Conference (DOT 2001) indicating the way in which Smart Fibres have played a leading role in offering optical fibre SHM technology to composite riser pipes (attention is drawn to pages 5 and 6 of the paper). This R&D work is ongoing and the latest iteration of composite pipe has been instrumented with no fewer than 37 FBG sensors.

Turning to the current requirement, initial discussions have indicated that a proposal is sought to instrument a length of mooring tendon constructed of several sections of differing materials in order to monitor the strains in tension and bend induced within the tendon sections.

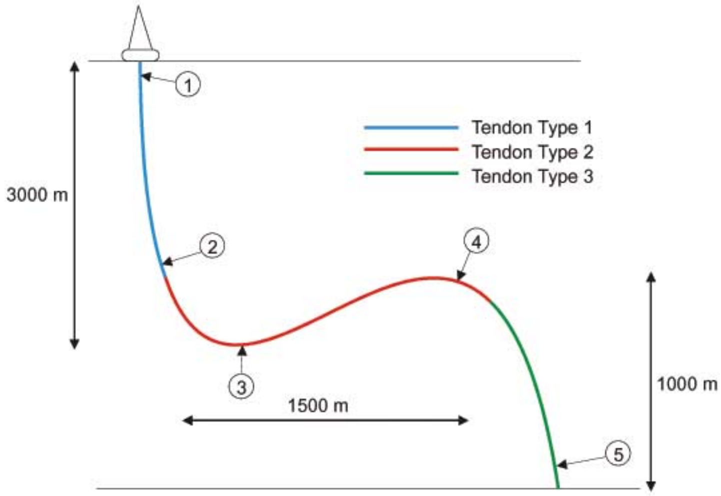
SMART FIBRES

2. Technical Proposal

2.1 Proposed Tendon Installation

It is understood that four materials are being considered as candidate materials for the tendon sections, namely steel, vectran, polyester and nylon.

The sketch below indicates the scheme and scale of the proposed tendon installation, assumed to be constructed of three selected materials, and initial thoughts as to the likely number and locations of the required strain sensors.



2.2 Proposed Sensor Construction

There are two candidate sensor technologies that can be considered as mature enough to be applied to the task of strain monitoring the tendon – Fibre Bragg Gratings and Electrical Strain Gauges. The former is consider to be far better suited to the application due to the following specific advantages over the latter:

- Miniature, unobtrusive sensors
- No need to amplify the sensor signal over long (multiple Km) distances
- Multiple sensors on single fibre achievable through multiplexing
- No recalibration required over time allowing long term SHM
- No EMC/RFI susceptibility or emission at sensors
- Compatible with underwater installation

TPI 6252886

Based upon initial discussions, it is considered that a three of four direction strain system is required in order to determine not only tension / compression but the direction of the bending strain on the tendon.

An area of concern raised from initial discussions is the maximum tension strain to be monitored by the sensors (by way of example, a nylon tendon is expected to elongate by 10% when 30% of its rated breaking strain is applied). Fibre-optic cables on the other hand can withstand 6 or 7 % but are typically only tested to 1 or 2%.

The lengths of fibre optic cable between the monitoring locations can be isolated from the larger strains by increasing their length with respect to the mooring tendon (by coiling around the tendon for instance). This of course does not apply to the monitoring locations themselves.

The proposed solution is to embed the FBG sensors within a structure which locally stiffens the tendon. By careful design of the sensor structure, the tension, compression or bending strain recorded at the sensors will be directly proportional to that which the tendon is subject to, whilst being of a magnitude that the fibre optic cable can accommodate.

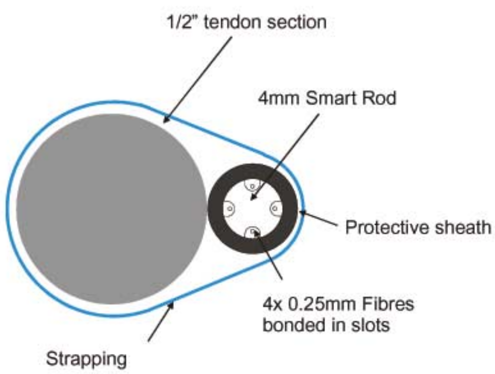
There are two principal mechanisms currently considered feasible to carry out this strain reducing function as briefly highlighted below:

2.2.1 Smart Rod Strapped alongside Tendon

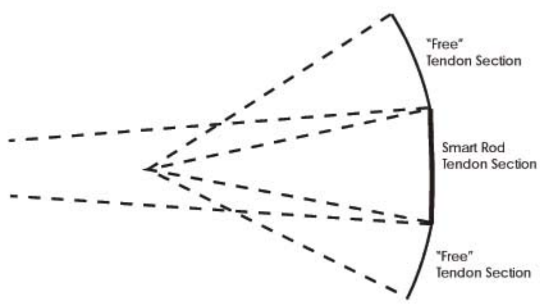
Smart Fibres have developed a product known as Smart Rod which can be embedded within structures or attached to them for the purpose of 4 direction bend sensing. The company has produced Smart Rods with a 6mm diameter from relatively short lengths to as long as 50m (pictured below).

Smart Rod has a circular cross section in which grooves are extruded, pultruded or machined on each quadrant in order to accommodate the fibres. It is currently envisaged that four of the 250 micron FBG sensors can be embedded within short sections of smaller (4mm diameter) Smart Rod which are enclosed within a thin protective sheath and then strapped to the tendon at the monitoring locations.

Below is a schematic of the proposed Smart Rod attached to the tendon.

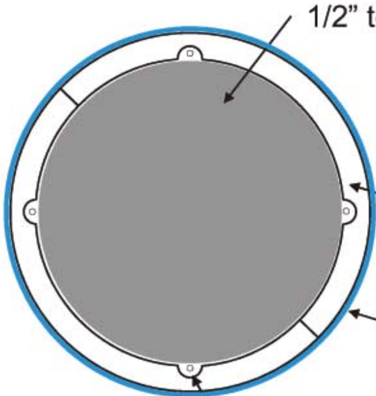


As the tendon bends, stretches or compresses, proportional bend, stretch or compression will be induced in the Smart Rod (as shown below) and recorded in 4 directions by the embedded FBG sensors.



2.2.2 Smart Sleeve Strapped around Tendon

It is proposed that an alternative mechanism to Smart Rod for carrying out the strain reducing and monitoring function is also investigated. The method, named in this document as Smart Sleeve involves constructing a sleeve in two halves with the fibres bonded within slots at the four quadrant positions on the internal radius of the sleeve. The sleeve can then be securely strapped to the tendon to hold the assembly together. The sketch below introduces this new concept.



2.2 Proposed Interrogation unit

Smart Fibres' are developing a number of wavelength division multiplex WDM and time division multiplex TDM based FBG interrogation units. The current OFSSS II WDM unit per the specification attached is proposed for the proof of concept Phase I of the project. For the Phase II development, a modified and cost reduced unit will be offered to a specification tailored to the application.

3. COMMERCIAL PROPOSAL

Smart Fibres Ltd offer the following service provision to the mooring tendon project:

- Assistance in determining the optimum configuration of monitoring locations ar sensor configurations at each monitoring location
- Design, manufacture and supply of special to purpose Smart sensors based upc experience gained on other applications and on customer performan requirements
- Development, manufacture and supply of FBG interrogation unit hardware, suitab amended as required to suit the specific requirements of the application
- Assistance in specification and procurement of optical fibre cables for connectir the FBG interrogation unit to the Smart sensor locations
- Development and supply of software, user interface and data storage means to su the specific requirements of the application
- Engineering support during system installation and commissioning

Based upon the opening outline discussions, and the initial proposals above, the following work programme and ROM costings are given:

		Person Weeks	Price
	Phase I: Proof of concept and test sampling		
1.1	**Design Requirements Specification** Liaison with WHOI personnel to determine the overall DRS of the monitoring system and specifications for the smart sensors and interrogation unit	2	£2,400
1.2	**Sensor Design** detailed design of the common smart sensor to be located at the various monitoring locations	4	£4,800
1.3	**Test Smart Sensor Manufacture** Manufacture of prototype smart sensor for proof of concept trials		
	Labour	1	£1,200
	Subcontract / Materials	-	£7,500
1.4	**Instrumentation of test section of tendon (UK)** Application of prototype smart sensor to trial length of mooring cable as supplied by WHOI	0.5	£600
1.5	**Evaluation of test system (UK)** Monitoring of artificially applied loads to trial length of mooring cable using prototype smart sensor and standard Smart Fibres OFSSS unit. Nominally for 1 week to include attendance and training of WHOI personnel as required, and preparation of test report		
	Labour	1.5	£1,800
	OFSSS Rental - 1 week	-	£1,500
	Total Phase I:	**9**	**£19,800**

		Person Weeks	Price
	Phase II: Development and supply of full monitoring system		
2.1	**Smart Sensor redesign *** as required and as determined by the results of Phase I	2	£2,400
2.2	**F/O Cabling** Assistance to WHOI personnel with F/O cabling system specification and identification of a suitable supplier	0.5	£600
2.3	**Smart Sensor Manufacture Labour *** Tooling and manufacture of nominally five smart sensors		
	Labour	2	£2,400
	Subcontract / Materials	-	£17,000
2.4	**FBG Interrogation Unit *** Development and supply of modified FBG Interrogation system, amended to suit project requirements:		
	Standard Unit Cost	-	£25,000
	Design modifications to standard unit to suit power/environmental requirements		
	Labour	2	£2,400
	Components/Materials	-	£3,000
	Design modifications to standard unit to provide interface to wireless transmission unit		
	Labour	2	£2,400
	Components/Materials	-	£2,000
2.5	**Installation/Commissioning Support** On-site support to WHOI engineers during land Instrumentation of complete tendon and system deployment / commissioning (US)		
	Labour	2	£2,400
	Travel/Subsistence	-	£3,000
	Total Phase II:	**10.5**	**£62,600**

* the requirement for and/or scope of the items marked * will likely be subject to change dependant upon the outcome of Phase I

Monterey Bay Aquarium Research Institute
INSTITUTIONAL ENDORSEMENT

Proposal Submitted To: **NSF**

Project Title: **Collaborative Research: Design, Modeling, and Testing of Electro-Optic Mechanical (EOM) Mooring Cables for Moored-Buoy Observatories**

Support Requested: **Total: $648,550** Year 1 - $323,163
Year 2 - $325,387

Duration of Project: **October 1, 2003 – September 30, 2005**

Submitted By:
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039

Principal Investigator:

Mark Chaffey
T: (831) 775-1708 / F: (831) 775-1620 email: chma@mbari.org

INSTITUTIONAL ENDORSEMENT:

Marcia McNutt 05/30/03
Marcia McNutt Date
Executive Director and CEO

05/30/03
C. Mike Pinto Date
Comptroller and CFO

05/30/03
Keith Raybould Date
Chief Operations Officer

05/30/03
Ken Johnson Date
Science Chair

05/30/03
Jim Bellingham Date
Director of Engineering

Judith L Connor 05/30/03
Judith Connor Date
Director of Information and Technology Dissemination

05/30/03
Steve Etchemendy Date
Director of Marine Operations

Contact Information:
Grants Office:
Tayeko Yamada / Susan Lantis
Tel: (831) 775–1803 / 1788 Fax: (831) 775 – 1620 *Email:* grants@mbari.org

In the event that this proposal is accepted, the signatures on the proposal constitute acceptance of and compliance with statutes and regulations of the U.S. Government and U.S. Department of Commerce.

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UNOLS Ship Time Request Form - Section ONE
==
UNOLS Request ID #: 20030602135805RF
Version #: 001
Last Modified: 2003/06/02 13:58 EDT
Date Issued: 2003/06/02 14:00 EDT
==
P.I. Name Last: Chaffey First: Mark MI: R
==
Institution: MBARI Research vessel required for:
Address: 7700 Sandholdt Road _ Ancillary Only
Moss Landing, CA X Principal Use
_ No Ship Required
_ Long Range Planning Document
==
Phone: 831 775 1708 Fax: 831 775 1646 Email: chma@mbari.org
==
Co P.I. Name Institution Co P.I. Name Institution
------------ ----------- ------------ -----------
Keith Raybould MBARI Andrew Hamilton MBARI
==
Proposal Title:

Collaborative Research: Design, Modeling, and Testing of Electro-Optic
Mechanical (EOM) Mooring Cables for Moored-Buoy Observatories
==
Large Program Name: None Research Purpose: Instrumentation
If Other, specify: If Other, specify:
==
New Proposal? Y Agency Submitted to: Foreign EEZ? N
Funded Grant? N NSF/OCE/OTIC
Institutional Proposal #: Amount Requested: Area(s) of Operation:
648,550 NP9
Agency Proposal #:
6254964 Lat/Long:
Renewal? N Start Date: 10/01/2003 Begin: 36N 123W
Grant #: End Date: 09/30/2005 End: 36N 123W
==
Ship(s) Requested # Science
Year (Name or Size) Days Req. Optimum Dates Alternate Dates
---- ----------------- ---------- ------------- ---------------
2004 Point Sur 2 11/15/04 11/03/04
2005 Point Sur 3 5/15/05 5/03/05
==
Total Science & Ship Days Needed: --------------- PORTS ------------
5 Start: Intermediate: End:
Number in Science Party: Moss Landing NA Moss Landing
12
==
Equipment Required:
_ Vans _ P-Code GPS _ MCS _ Alvin _ DSL 120
_ Dynamic Positioning _ Multibeam _ SCS _ ROV _ 680 Cond.
_ Helicopter Operation
==
Other Special Equipment; Comments:

Large Oceanographic winch supplied by MBARI
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