Moorings for Ocean Observatories: Continuous and Adaptive Sampling

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Abstract **– Present autonomous moored profilers often undersample the ocean and alias "high" frequency processes such as tides and internal waves because they are slow and have short missions and/or intermittent sampling schedules. To improve this situation we are developing a moored profiler system to be connected to a cabled observatory node, thereby removing power as the major constraining factor. A profiler docking station with an inductive coupler will transfer power from the cabled node to a modified McLane moored profiler (MMP). This will permit near-continuous profiling (>90% duty cycle) at 0.25 m s^{-1}. Further, two-way inductive communications will be used to offload profiler data at modest rates in real time as well as transfer adaptive sampling commands. With sensors on the profiler and with dual sensors at fixed points top and bottom on the mooring, cross-calibration and overall robustness will be improved.**

Secondary junction boxes on the subsurface float and on the seafloor will provide several hundred watts, 100 Mb/s Ethernet, precise time, and be ROV-serviceable. Instrument packages can be added on the subsurface float, such as a winched profiling system to carry in-situ and point and remote sensors through the mixed layer to the surface.

This mooring will be tested in mid-2006 in Puget Sound and deployed on the MARS cabled observatory system in Monterey Bay, California, in 900 m of water in late summer 2007. These developments enable a wide range of new sensing modalities with moored profiler systems, one essential element (hybrid fixed-mobile sensor platform) of ocean observatory sensor network infrastructure. The current system design is presented.

I. INTRODUCTION

The ALOHA-MARS Mooring (AMM) project will demonstrate the scientific potential of combining adaptive sampling methods with a moored deep-ocean sensor network. It is desgined for use with seafloor observatories with power and communications provided by a connection to shore via an electro-optical cable [1]. This system will address the challenge of sampling the ocean with both high temporal and vertical resolution [2, 3, 4, 5, 6, 7, 8]. The mooring will consist of three main components (Fig. 1): a near-surface float at a depth of 165 m with a secondary node (J-Box) and suite of sensors, an instrumented motorized moored profiler moving between the seafloor and the float that will mate with a docking station on the float for battery charging; and a secondary node (J-Box) on the seafloor with a suite of sensors. Both secondary nodes will have ROV mateable connectors available for guest instrumentation. The profiler will have real-time communications with the network via an inductive modem that will provide some remote control functions to allow the sampling and measurement capabilities to be focused on the scientific features of greatest interest. The power and two-way real-time communications provided by cabled seafloor observatories will enable this sensor network, the adaptive sampling techniques, and the resulting enhanced science. The sampling and observational methods developed here will be transferable to ocean observatories elsewhere in the world.

After testing a short version of the mooring system in Puget Sound, the system will be deployed in Monterey on the MARS observatory [9] in summer 2007 and likely recovered in summer 2008. A successor mooring will be proposed for the ALOHA Observatory north of Oahu after a cabled node is installed [10, 11]. Additional moorings of this type are expected to play a significant role in the NSF funded ORION program and the Ocean Observatories Initiative (OOI) [2, 12, 13, 14, 15, 16, 17, 18].

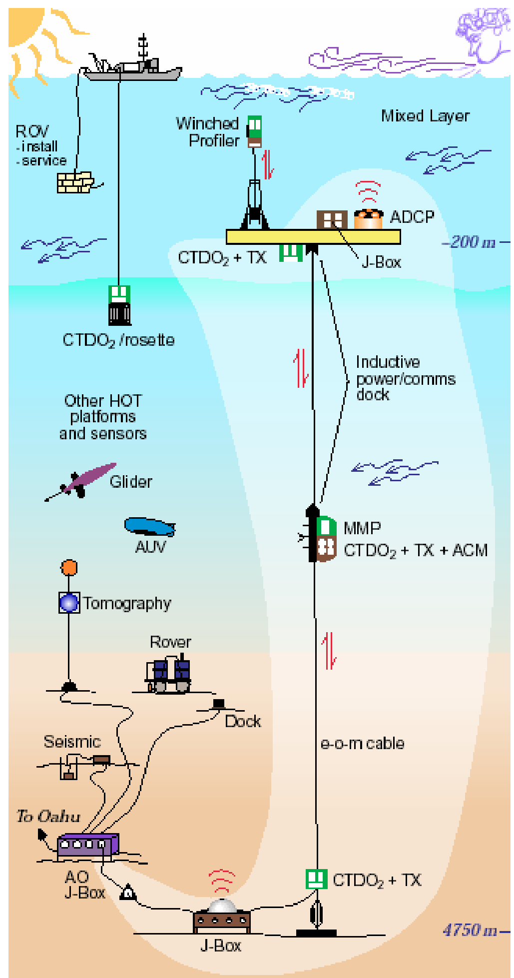

Fig. 1. Concept Observatory Mooring Sensor Network, originally planned for the ALOHA Observatory north of Oahu at the Hawaii Ocean Timeseries (HOT) site, now planned for the MARS Observatory in Monterey Bay in 900 m water depth [1].

II. GENERAL DESCRIPTION

The AMM is a deep ocean sensor network that extends from the seafloor at ~900 m water depth to a subsurface float at 165 m. The mooring contains three “nodes” that include power supply and network connections and suites of sensors located on the seafloor, on the subsurface float, and on a moored profiler that is capable of traversing from the seafloor to the float (Fig. 2). At all three locations are $CTDO_2$ and optical backscatter sensors. The float will also have an ADCP, camera, and attitude sensor and the profiler will have an acoustic current meter.

The AMM is electrically connected to the MARS Observatory Node (the “primary” node), which provides 400 and 48 Vdc power, 100BaseT Ethernet communication, and precision time distribution. Each secondary node in the AMM provides 48 Vdc, 100BaseT Ethernet, and precise time distribution to users via ROV-mateable connectors. The profiler communicates in real time with the float secondary node via an inductive modem.

Command and control of the mooring as well as data monitoring and archiving is accomplished from shore via the MARS network. Voltages, currents, and ground faults throughout the system are monitored and action taken as necessary to connect or disconnect secondary networks or instruments remotely.

The syntactic foam float and mechanical structure serves as a mounting platform for the float secondary node and sensors (Fig. 3). The framework around the float is designed for ease of serviceability by ROV and it has a modular design to simplify modifications and allow for future expansion.

AMM uses a combination of electrical, electrical/mechanical (EM) and electrical/optical/ mechanical (EOM) cables. The long cables (>100 m) are EOM type, which allows optical Ethernet communication and the short cables are EM type and use twisted pair wire Ethernet communication. The EOM and EM cables use synthetic fibers (Kevlar or Vectran) as strength members. The EOM cables contain a stainless steel tube with four optical fibers for communications.

The system uses a variety of underwater electrical connectors. The science connector ports (on the MARS primary node and the mooring system secondary nodes) utilize ROV-type wet mateable electrical connectors. The number of these ROV wet mateable connectors is limited because of high cost. Whenever possible, dry mate connectors are used and components that do need an ROV-type disconnect are grouped together with a Science Instrument Interface Module (SIIM) to allow the use of a single ROV connector to connect multiple instruments. The EOM cables are connected into the system with EO penetrators. An Ethernet optical-to-electrical “in-line” converter is inserted between the EO cables and electrical connections at the primary and secondary node science connectors. The sensors are attached by dry mate underwater electrical connectors to the SIIM, which has a single ROV wet mateable electrical connector.

Deployment and recovery requires a dynamically positioned (DP) ship and an ROV. Deployment is anchor first. A special rail frame system is used on the fantail to facilitate deployment operations. The seafloor cable will be laid and connected with a ROV equipped with cable sled/reel.

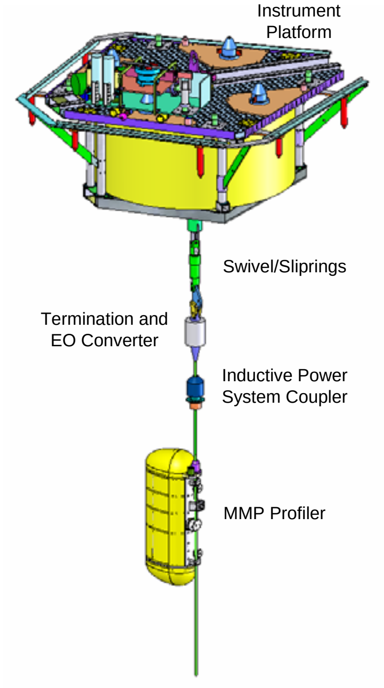

Fig. 2. Upper part of mooring, with profiler

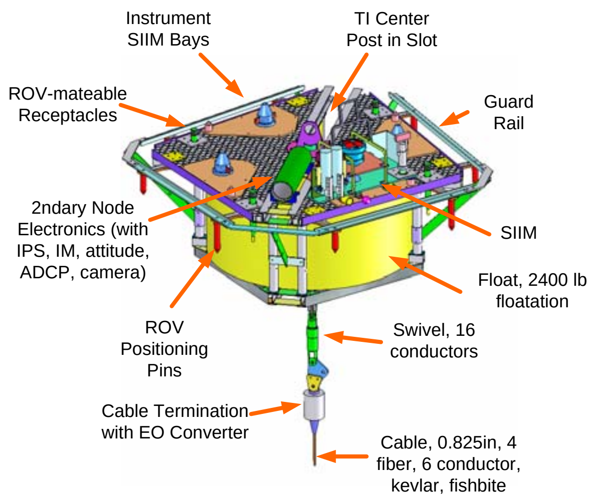

Fig. 3. Subsurface float detail

III. FUNCTIONAL REQUIREMENTS

The science user requirements are [11]:

- Provide full water column current profiling Near continuous in-situ profiling from near surface to seafloor with $CTDO_2$, acoustic current meter (ACM), bio-optics
- Profiler rate of advance will allow one sampling cycle per tidal half cycle (6 h)
- Profiler charging time (in dock) must be less than 6 h
- Profiler duty cycle must be greater than 90%
- Provide extra science user connectors with standard power and data interface on float and seafloor

- Provide near real-time, high-bandwidth communication for science user instruments
- Compatible with MARS power and data interfaces
- Provide 48 Vdc, 100BaseT communications, and PPS Timing at Science User Connectors
- Provide interface method for standard RS-232 sensors
- ROV serviceable with replaceable instrument packages
- Testable during deployment
- Operational life of >2 years
- Located far enough from the primary node to allow ROV access to observatory node and instruments

In the long-term we want to work towards the concept of the profiler as a “truck” responding to science commands. This will make the system more modular and easier to improve, e.g., to increase the speed and payload.

IV. SYSTEM DESCRIPTION

A schematic block diagram (Fig. 4) show that a seafloor extension cable connects the primary observatory node to the mooring system seafloor secondary node. Connected to the latter are the mooring, project instruments, and guest instruments. The mooring cable rises through the water column to the subsurface float. There, a float secondary node connects to project instruments, guest instruments, and transfers power and communicates with the profiler.

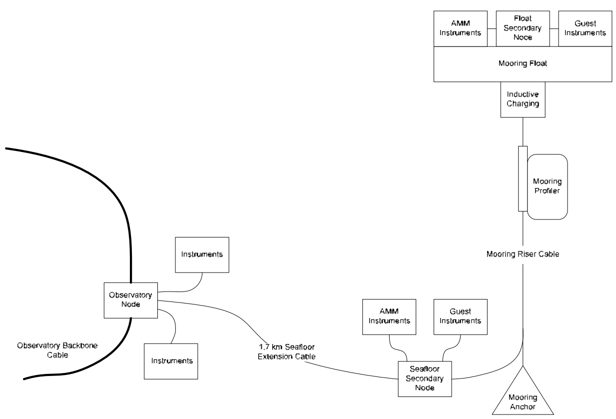

Fig. 4. System Block Diagram

A. *MARS Observatory Interface*

The voltages available at the MARS Observatory Node will be 400 Vdc and 48 Vdc. The overall power budget for the mooring system is approximately 500–1200 W, depending on whether the MMP is being charged and if any additional guest instruments are connected. The data communications provided by the MARS Observatory is 100BaseT Ethernet. This will be provided at each of the Secondary Node Science Connectors. RS-232 will be provided by a science instrument interface module (SIIM) located at each secondary node. The time distribution will include two different levels of resolution and access: on the order of 1-10 ms, a Network Time Protocol (NTP), and on the order of 1–10 µs, a GPS pulse-per-second (PPS) signal.

ROV underwater mateable connectors will be utilized on the underwater nodes to allow modularity and maintainability in the infrastructure and also to allow science instruments and SIIM to be connected and disconnected by ROV without bringing any of the equipment to the surface. There will be ROV mateable science connectors at both the seafloor and float nodes. The science connectors will be compatible with the science connectors on the MARS primary node, and also with the science connectors on the VENUS [19] and NEPTUNE Canada [20] nodes (albeit the latter do not provide 48 V). The science connectors are supplied by Ocean Design, Inc., and have 12 pins: 400 Vdc (2), 48 Vdc (2), 100BaseT Ethernet (4), PPS Timing (2), Spare (2).

In-line media converters are required to convert electrical communication and timing signals to optical form for transmission over any significant distance using optical fibers and back again. The seafloor and mooring riser cables both have four fibers. One optical fiber is used for the Ethernet communications, and one for the PPS/RS-422 time distribution and two are spares. Wave division multiplexers (WDMs) allow bi-directional data transmission using 1310 and 1550 nm wavelengths on the fibers. The Ethernet and time distribution converters (Omnitron models 8910/8790) plug into a common backplane that provides power to the converters and also provides SNMP management of the converters. Management features include event monitoring, trap notification, and temperature range violations. It will also send a “Dying Gasp” trap if it loses power. The EO converters will be housed in a beryllium-copper pressure case, 4.38-inch inside diameter, 12.8 inches long, weighing 32 lbs, and rated for 5000 m. (Beryllium-copper was chosen because it is now cheaper than titanium.)

The cable between the primary node and the seafloor secondary node junction box is a 12.7-mm diameter electrical/optical cable with six conductors and four single mode optical fibers in a 1.2-mm stainless steel tube. An electro-optical penetrator terminates each end of the cable into the EO converter. ROV mateable connectors will allow connection of the cable to the primary and secondary nodes. The Seafloor cable (with EO converters and connectors) will be installed by ROV with a reel that will be mounted in the cable laying tool sled on the ROV; the spool will be left on the seafloor at the end of the cable laying process.

B. *Secondary Nodes*

The AMM will have two secondary nodes that will provide the same connectivity functions that are available at the primary observatory nodes, though with reduced power and communications rate capability. Fig. 5 shows the basic block diagram for the secondary nodes; there are small differences between the seafloor and float secondary nodes that will be discussed in the following sections. Much of the design is based on that of the MARS power system [21].

ROV mateable connectors are the same as on the MARS primary node. An input of 400 V can come in on any connector; there is one 400 V output, either on one connector for the mooring cable (seafloor node) or internally to the inductive charging system (float node). All connectors output 48 V.

The precise timing signal is split into four and distributed to the user connectors.

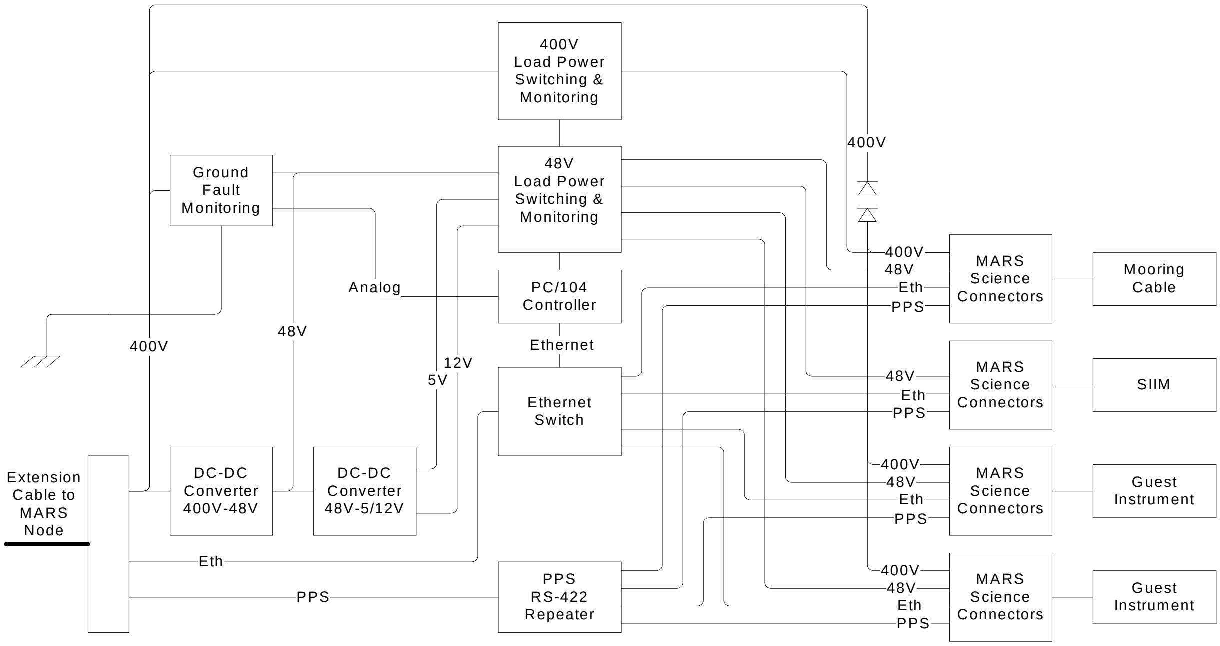

Fig. 5. Secondary node general block diagram

The secondary node controller (SNC) consists of a PC-104 stack with a Diamond Prometheus CPU board with analog I/O, a MOSFET power switching board and a mechanical relay board. The SNC acquires data from the current sensors, the ground fault isolation circuits, and controls the relays. It communicates with the shore server via the 100Mb/s Managed Ethernet switch (Sixnet EtherTRAK, 9 ports, SNMP management), through which all the communications to/from the instruments also pass.

Within the secondary nodes are six custom printed circuit boards: 400–48 V/300 W dc–dc converter, 48-12 V/150 W dc–dc converter, load control and monitoring, ground fault detection, timing converter (RS422 to 1 PPS), and timing repeater (four channels out).

Vicor dc–dc converters (with filtering) are used throughout. Each secondary junction box consumes about 40 W for the "hotel" load, and there is ~200–400 W available for other uses (instruments, inductive power system, etc). The load control and monitoring board has a current sensor, a deadface switch to provide galvanic isolation, and a semiconductor FET switch for each 48-V channel. Both switches are controlled by the power management and control system (PMACS). The maximum current/power through these switches at 48 V is 2 A/100 W. The ground fault protection board cycles through the output channels, making a measurement on a separate channel every 10 s; this circuit is based on a similar one used in the MARS system. The timing converter board converts the RS-422 signals to TTL 1 PPS signals, and then the repeater board splits the latter to the four science connectors. These components are packaged in a stainless steel (SS 17-4PH) pressure case, 7-inch inside diameter by 30.5 inches long, weighing 230 lbs, and rated for 6000 m.

The seafloor secondary node serves as the terminus for the 1.7-km seafloor EOM cable that runs from the MARS node to the base of the mooring. The node will include a frame, electronics housing, and ROV mateable electrical connector receptacles (Fig. 6). The mechanical design of the node was done in consultation with the ROV pilots at MBARI.

The seafloor secondary node has the following:

- Five ROV-mateable connectors
  - one for connection to the MARS node via the seafloor cable
  - one for connection to the mooring riser cable
  - one for connection to the seafloor SIIM
  - two available for guests
- Power capacity
  - AMM sensor load ~15W
  - 48 Vdc to guest ports, total power ~200 W
- Removable ballast (lead weights) and "fork" slots to facilitate moving the entire frame with ROV
- Flotation (glass or ceramic spheres) to keep the weight within the paylod limits of the ROV

The AMM seafloor sensor module is a small rack suspended on the mooring a few meters above the anchor. The rack is designed to hold at least four sensors connected electrically via a SIIM (on the rack, too) to the seafloor secondary node by a 12-m cable and ROV wet mateable connector.

The float secondary node has the following:

- Three ROV mateable science user connectors
  - one for connection to the float SIIM
  - two available for guests
- Power capacity
  - AMM sensor load ~45 W
  - 48 Vdc to guest ports, otal power ~100 W
- Inductive power coupler electronics (see below)
- Internal SIIM electronics modules (see below) connected to:
  - Sea-Bird inductive modem (for communication to profiler)
  - Attitude sensor
  - Acoustic Doppler current profiler (ADCP)
  - Video camer and light

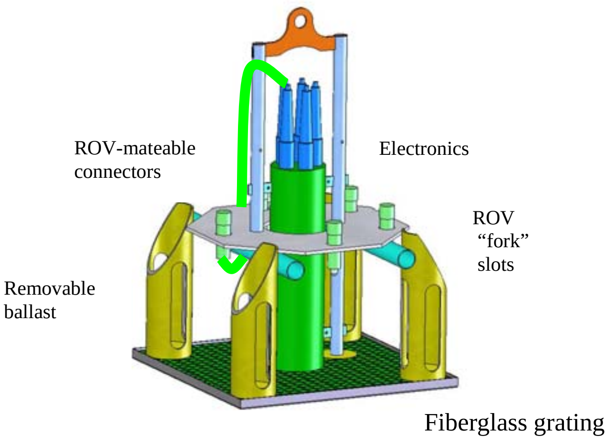

Fig. 6. Seafloor secondary node (buoyancy not shown)

C. Science Instrument Interface Module (SIIM)

Attached to the secondary nodes will be a number of science instruments:

- Dual SBE 52MP $CTDO_2$
- Wetlabs BB2F bio-optical sensors
- RDI 150kHz Workhorse ADCP (float node only)
- DSPL Video camera with lights (float node only)

To minimize the number of ROV wet mateable connectors used, an intermediate multiplexer/SIIM is required to first connect all the sensors together (using dry mate connectors); then the SIIM is connected to the secondary J-box housing using a single ROV-mateable connector. This SIIM will need to have a mix of the following features:

- Four–eight RS-232 ports (dry-mate connectors)
- One–two video inputs
- Provide required instrument voltages (48 Vdc and 12 Vdc)
- Provide RS-232 to Ethernet conversion (to communicate with higher level node)
- Node ROV mateable cable connector interface
- Individual software controlled load switching and deadface switching

This is accomplished with a custom, easily modified, four-channel printed circuit board, a "SIIM board." Each channel has a Digi Connect ME embedded module, a FET switch, and a deadface relay. The Digi Connect module provides a 10/100BaseT network interface, one high-speed RS-232 serial interface, 2 MB Flash memory, and 8 MB RAM. It is built on 32-bit ARM technology using the network-attached NetSilicon NS7520 microprocessor. It provides an extremely convenient way to convert instrument RS-232 to Ethernet. It is the only "smart" device in the SIIM.

On the float and at the base of the mooring, the SIIM board will be housed in a titanium pressure case 130 mm inside diameter by 345 mm length (5.13 inches by 13.6 inches), weighing 30 lbs in air, and rated for 5000 m.

A SIIM board will also reside in the float secondary node for the attitude sensor, ADCP, Sea-Bird inductive modem, and video camera.

D. Sensors and Instruments

The fixed sensors will be sampled once per second. The sensors on the profiler will be sampled as fast as possible: for the MMP sensors ($CTDO_2$, ACM) this is nominally at 1.8 Hz (every 0.14 m at 0.25 m s^{-1}) while for the BB2F, this is nominally at 1.15 Hz.

The Sea-Bird 52MP/43F $CTDO_2$ will be used, two each (for redundancy) on the subsurface float and at the base of the mooring, and one on the profiler. These have titanium pressure cases rated for 6000 m. They use a pump to control the flow past the thermistor and through the conductivity cell.

The WetLabs BBF2 sensor will measure optical backscatter at 470 nm and 700 nm, and chlorophyll fluorescence within the same volume. There will be 1 each on the float, on the seafloor and on the MMP.

The ADCP on the subsurface float is a RD Instruments Workhorse Sentinel 150 kHz. It is mounted permanently on the float with a dry mate connector to the float secondary node electronics case. The ADCP has an integral attitude sensor package.

The ACM on the profiler is a Falmouth Scientific 4-axis device measuring a 3D velocity vector.

To better understand the float/mooring dynamics, related stresses, and impact on the optical fibers, an orientation sensor package will be included inside the secondary node electronics case. A 3DM-GX1 Gyro Enhanced Orientation Sensor combines three angular rate gyros with three orthogonal DC accelerometers, three orthogonal magnetometers, multiplexer, 16-bit A/D converter, and embedded microcontroller to output its orientation in dynamic and static environments.

There will be a color video camera with lights on the subsurface float looking at the profiler dock to monitor the MMP docking and undocking. The primary purpose of this camera is to better understand the MMP docking dynamics and to ease any necessary trouble shooting. The camera is a Deep Sea Power and Light LED Multi SeaCam.

E. Moored profiler

This project will modify and use the McLane Moored Profiler (MMP, Fig. 7).

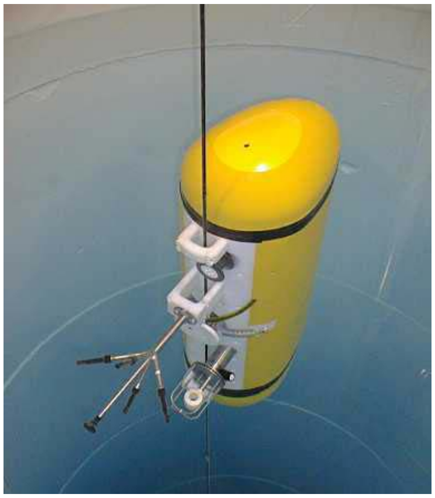

Fig. 7. The standard McLane Moored Profiler

This project will modify the standard design:

- New motor, gearbox, wheel redesign to fit larger EOM cable (0.85 inch, ~22 mm)
- Mount WetLabs BB2F optical sensor
- Use Sea-Bird 52MP/43F $CTDO_2$
- Interface APL MPC controller to the MMP controller to offload data after every profile
- Replace primary Li battery pack with rechargeable 860 Wh Li-ion battery bank mounted in glass sphere
- Mount inductive charging coupler and electronics
- Use extended length McLane housing with additional glass sphere for rechargeable battery bank and for increased buoyancy
- Ratio run time : charging time = 4 days : 4 h with reasonably sized battery bank

APL will be adding a Moored Profiler Controller (MPC) to the modified MMP. The MPC hardware will consist of a motherboard, CF-2 CPU board, and two OES U4S 4-port Serial Communications boards. The primary tasks of the MPC are:

- Collecting optical data (backscatter and fluorescence)
- Interfacing with and downloading data from the MMP ($CTDO_2$, ACM, engineering data)
- Interfacing with and transferring data/commands to/from the shore server (SS)
- Interfacing with and controlling the MMP Battery Controller (MBC)
- Supervising charging of the battery bank

All communication between the MMP and MPC is initiated usingASCII text messages. Some messages have the ASCII text string immediately followed by binary data (in particular, messages containing file content). Messages can be sent from the MMP to the MPC, including ready indicator, docking and obstruction status, the current pressure, and files and directories. Commands can also be sent from the MPC to the MMP, for instance, to instruct the MMP to go to the charging dock and to request files and directories.

F. *Inductive Power System (IPS)*

The inductive power transfer to the profiler is one of the key new technical development of the project.

The MMP will periodically connect or "dock" to the mooring float infrastructure to charge its battery bank. Due to the fact that the system components are submerged in conducting seawater, the connection must not utilize any contacts that allow an electrical connection to contact the seawater. Wet mateable connectors that have enclosed, oil-bathed contacts have some potential for this but they typically require a relatively high mating force and have a limited number of mate/de-mate cycles. The technique that has been selected is to use inductive coupling for the power. S&K Engineering has been contracted to make the inductive power coupler (the "dock") and the associated drive and charging electronics [22].

The solid works model of the inductive coupler is shown in Fig. 8. Specifications are given in Table 1.

At the end of a profile, the MMP with the coupler secondary core will ascend and make contact with the guide and coupler primary core. As soon as the primary and secondary cores are engaged, as indicated by a proximity/contact switch, current will start to flow. Keeping the mating gap small is crucial to the transfer of power. Similarly, the MPC will be continually polling the MMP controller and as soon as the MMP docks, the MMP will reply and the data transfer will begin.

Table 1. Inductive power system specifications

Supplier	S&K Engineering
Input voltage	400 Vdc
Input Power	up to 300 W
Output voltage	15 Vdc
Output Power	up to 225 W
Efficiency	70% with 2 mm gap
Operating Frequency	~100 kHz

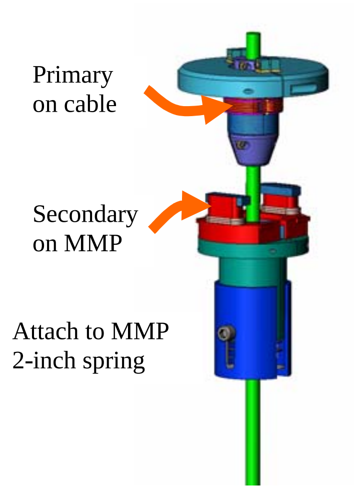

Fig. 8. Moored profiler inductive coupler

A block diagram of the inductive charging system is shown below, Fig. 9.

The DC–HFAC converter (DHC) converts the float 400 Vdc to a high-frequency alternating current (HFAC) that can be transmitted across the inductive coupler. This circuit board, inside the float secondary node housing, generates 40 W of waste heat that is conducted to the pressure case endcap through a long wedge section of copper.

The primary and secondary ferrite cores can survive long term submergence in seawater (cf. Sea-Bird inductive modem). The shapes and mechanical design of the cores will need to allow reliable coupling between the primary and secondary and be tolerant of biofouling. Both the primary and secondary cores will be bolted around the mooring cable (a future version might have them more easily removable for ROV servicing).

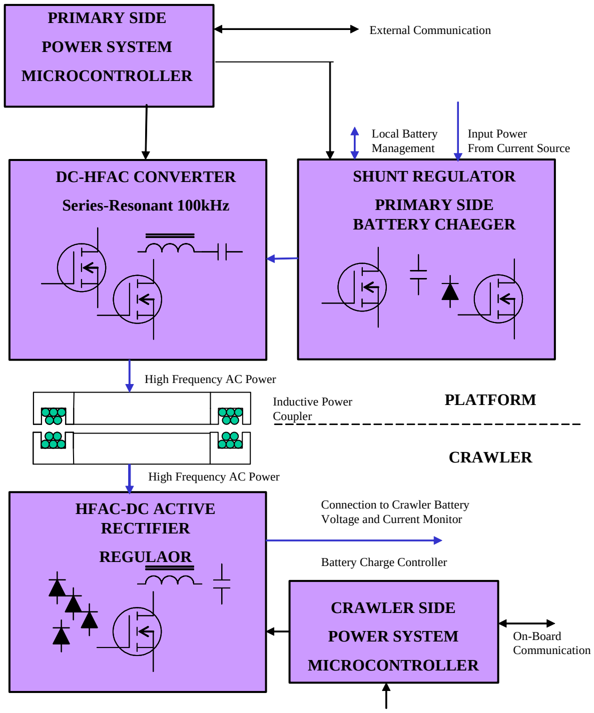

Fig. 9. Inductive power system block diagram

The HFAC-DC rectifier (HDR) converts the HFAC power to DC. The DC output can them be converted to the required voltages with DC-DC converters. Again, a copper plate attached to the backside of the circuit board conducts 20 W of waste heat to the endcap.

The efficiency of the inductive power coupler is important for many reasons. Low efficiency leads to long charge times and waste heat inside pressure cases. This IPS can be considered a part of the sensor network infrastructure. This project is clearly showing that the infrastructure of sensor networks is a major use of the observatory power. This complete mooring system is about 70% efficient overall; ~300 W is used for hotel electronics and resistive losses. Power within a cabled observatory, as well as an ORION “global buoy” observatory [23, 24], will very quickly become a limited resource. The efficiency as a function of the coupler gap varies from 72% at 0 mm to 68% at 5 mm; at 2 mm, the power transfer is 250 W.

The profiler battery bank must have sufficient capacity to allow the profiler to operate for the required survey duration. The profiler battery bank must utilize a chemistry that has high power density, is capable of a high number of charge/discharge cycles, and that can be charged as rapidly as possible. Lithium ion batteries have been selected for their good density, cycling and charging characteristics, and have been selected. The AMM MMP battery bank consists of five battery packs connected in parallel. Each of the packs consists of two parallel stacks of four 3.6V Li-ion cells in series. Charging every 4.6 days for 5 hours gives a 97% duty cycle.

There are two built in protection functions to reduce the risk of fire. When temperature increases past ~90°C, a switch opens; when the temperature decreases below this temperature, the switch re-closes and the battery can continue to be used. If the temperature exceeds 100°C a fuse opens and the battery is permanently disabled.

The battery charger function is contained on the IPS HDR board, located in the MMP pressure housing.

Li-ion batteries need to be charged with a constant current until the cell/pack voltage is 4.1 V/16.4 V and then with that constant voltage until the charging current drops below some desired fraction of the original charging current. The rate of change of pack capacity falls off after 4 h and reasonable efficiency would be obtained by terminating the charge with a pack/bank charging current of 1 A/5 A, which is reached in a little over 4 h. The last hour of charging (20% of the charge time) only increases the capacity from 11.5 to 12.2 Ah (6% increase). Li-ion batteries do not have any “memory effect” and, consequently, there is no negative impact from terminating the charge before 100%. Terminating the charge earlier may also reduce the chance of over charging the battery cells which would cause permanent damage.

The MMP Battery Controller (MBC) is a custom designed microcontroller board whose primary function is to tell the MPC the state of battery charge, so it can instruct the MMP to go to the docking station when the batteries need recharging. The MBC monitors the battery voltage and current, monitors battery temperature, and estimates battery charge level (coulomb counter). Based on these data, the following check/actions are performed:

- Temperature–charging permitted only between 0°C and 45°C
- Charge current must not be too high, typically below 0.7*C*, where *C* = 12 A/pack (for the bank of five packs, the maximum charging current is 42 A)
- Discharge current protection to prevent damage due to short circuits
- Charge voltage–permanent fuse opens if too much voltage is applied to the battery terminals
- Overcharge protection–stops charging when voltage per cell rises above 4.30 volts
- Over-discharge protection–stops discharge when battery voltage falls below 3.2/12.8 volts per cell/pack.

G. *Inductive Modem (IM) Communications*

The SeaBird Inductive Modem (IM) system will be used for communications between the float and the MMP. The float will contain the IM node that is connected to shore through the mooring network and the MMP will contain another IM node that will connect to the MPC, allowing bi-directional communications. Communications rate is nominally 150 bytes/s; with forward error correction and other overhead the effective rate is 90 bytes/s.

H. *Mooring Riser Cable*

The 22-mm (0.85-inch) diameter mooring cable has six 18 AWG conductors with polypropylene insulation, four loose fibers in a 1.3-mm diameter steel tube (in center), a Kevlar strength member, and a steel mesh for fishbite protection, all enclosed in a polyethylene jacket, Fig. 10. This cable, connecting the seafloor secondary node to the subsurface float and the float secondary node, has connector terminations identical to the seafloor cable connecting the

MARS primary node to the seafloor secondary node. Specifications for the mooring cable are given in Table 2.

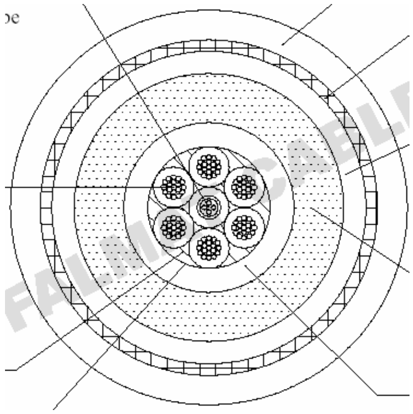

Fig. 10. Cross section of 22-mm mooring riser cable

Table 2. Mooring riser cable specifications

Cable Type	EOM, water blocked
Manufacturer	Falmat
Length	800 m (2620 ft.)
Diameter	22 mm (0.865 in)
Conductors	six #18 AWG (4-power, 1-IM, 1-spare), 21 Ω/km
Voltage Rating	1 kV, 2.5 A ac
Fiber optic	four fibers, Corning SMF-28™
Outer Jacket	Polyurethane, lime green
Fishbite Protection	Stainless steel braid, 70% coverage, 0.25 mm 304 SS wire
Breaking Strength	24,000 lbs
Working Load	4,000 lbs
Elongation	< 0.5% at working load (< 4 m for 4000 lbs and 800 m length)
Weight in air	864 lbs for 800 m (330 lbs/1000 ft)
Weight in water	241 lbs for 800 m (92 lbs/1000 ft)

I. Mooring Float

The subsurface float tensions the mooring riser cable and serves as an instrument platform. The float contains a secondary node with ROV-mateable connector manifold, the profiler dock (just below the float), four instrument/SIIM bays, and several sensors. The secondary node operates as the power and communication port for the instrument modules and the moored profiler and is described in detail above.

The instrument modules are designed to be installed, removed, and serviced by ROV. They will snap and lock into one of the module bays on the subsurface float. The modules allow for simple customization for individual instrumentation and provide space for future instrument expansion. The present instrument modules consist of a simple titanium frame, a pressure housing, and a cable storage tray. The pressure housing contains an Ethernet switch, a science instrument interface module (SIIM), and the appropriate voltage conditioning electronics for connection to a sensor. The instrument modules are connected electrically by a ~2-m cable and a wet mateable ROV electrical connector to the connector manifold.

The surface float and structure have the following characteristics:

- Designed for ROV servicing in collaboration with MBARI and ROPOS ROV pilots
- Non-corrosive materials (plastic, aluminum, easily made with water jet cutting)
- Secondary junction box, SIIM and float sensor package, inductive modem, inductive power system, two extra guest ports
- Instrument/SIIM with sensors (dual $CTDO_2$, one BBF2)
- Float structure slotted to engage titanium post at top of mooring cable
- Slip ring/swivel beneath float (16 electrical passes)

Figures 2 and 3 show the float and structure. The 300-m depth rated syntactic foam float is 1.829 mm diameter, 0.813 mm high, weighs 2052 lbs in air, and has a buoyancy of 2400 lbs. The float stucture is made from 6061-T6 painted aluminum.

Using a SIIM permits combining several instruments that are natural to have together (i.e., the $CTDO_2$ and the BBF2 bio-optical sensors) together in one package that can be installed/removed easily from the network using an ROV.

An electro-mechanical swivel/slip ring assembly is used at the top end of the mooring cable just beneath the subsurface float. The swivel has 16 slip rings in an oil-filled, pressure-compensated housing with an external pressure compensator. The stainless steel swivel is rated at three tonnes (6600 lbs) working load.

The mooring anchor has not yet been designed. It will likely consist of either a stack of steel railroad wheels mounted on a central hub, or a cast steel cylinder with an eye (to minimize overall height above bottom).

J. Software

The successful operation of the mooring sensor network depends crucially on software [25].

The mooring will use a scaled-down version of the MARS power management and control system (PMACS) with the secondary node controller (SNC) serving a similar role as the MARS node power controller. The shore server will run a scaled-down version of the MARS PMACS server program (this is a SOAP-based server). The PMACS "console" will be a SOAP client process most likely running in a web browser.

The secondary node controller (a PC-104 stack) will run a modified version of the software from the MARS node power controller. It will monitor load current and bus voltage, allow for the setting of per-load current limits, and provide circuit-breaker and ground-fault monitoring capabilities. The PMACS server will communicate with the SNC via an XML-RPC interface.

The shore server (SS) will run a dedicated process for each sensor (an instrument server process). Each process will interface to its respective sensor over the network and archive the sensor data on the local disk. All sensor configuration will be handled through the SS. The system will also run the PMACS server process. The system operator will be able to access the server remotely (physcially residing at MBARI) to make changes to the infrastructure and instrumentation, via the PMACS and instrument server processes.

The network description is given in [26]. In total, there are 36 IP addresses required. All of the switches (secondary nodes and Digi-Connects on each SIIM board) can be managed should MARS DCS have a need to do so. From the point of view of the MARS PMACS and DCS, the AMM is just another science user and must follow their procedures with regards to setting current limits and starting/shutting-down the mooring and managing the network.

There is currently no plan for an integrated observatory control system (OCS) for the mooring sensor network. Project personnel will perform this role, including arbitration between different users on the AMM for power and communications resources. This is likely to become a problem only when more instrumentation is added to the system (e.g., a near-surface winch system competing for power).

Regarding data management and archiving, the system is sufficiently flexible that the AMM data can be provided in a suitable format. We will interface with the HOT DMAS and live-action server at the University of Hawaii (R. Lukas, [27]), and the RoadNet system at UCSD (F. Vernon, [28]).

V. CONCLUDING REMARKS

The development of the ALOHA-MARS Mooring is on-going. The first full test will be in several months (spring 2006). Readers are encouraged to provide comments and suggestions to the authors, and to visit the web sites [1, 25] to keep abreast of the effort.

While there is some new development work (e.g., the inductive power system), much of the project work and effort is integration. Relative to what has been done before this is quite a complex system.

There are many other related technical developments that need to proceed for the vision of sensor networks to evolve. Some of these topics are: improve profilers with more power and payload, continue work on anti-biofouling, address re-usability of components, improve the inductive power system for general observatory use, drive the inductive communications modem to higher rates, make use of the precise timing in short range acoustic and seismic experiments, quantify and improve reliability, develop an observatory control system, interface a shallow winch system on the subsurface float, develop energy storage capability on mooring/seafloor to accommodate high peak loads (and/or autonomous operation), add an acoustic modem to the profiler and/or float and use for local communications, mooring and mobile platform navigation, and tomography with bottom transponders and remote sources [29, 30].

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