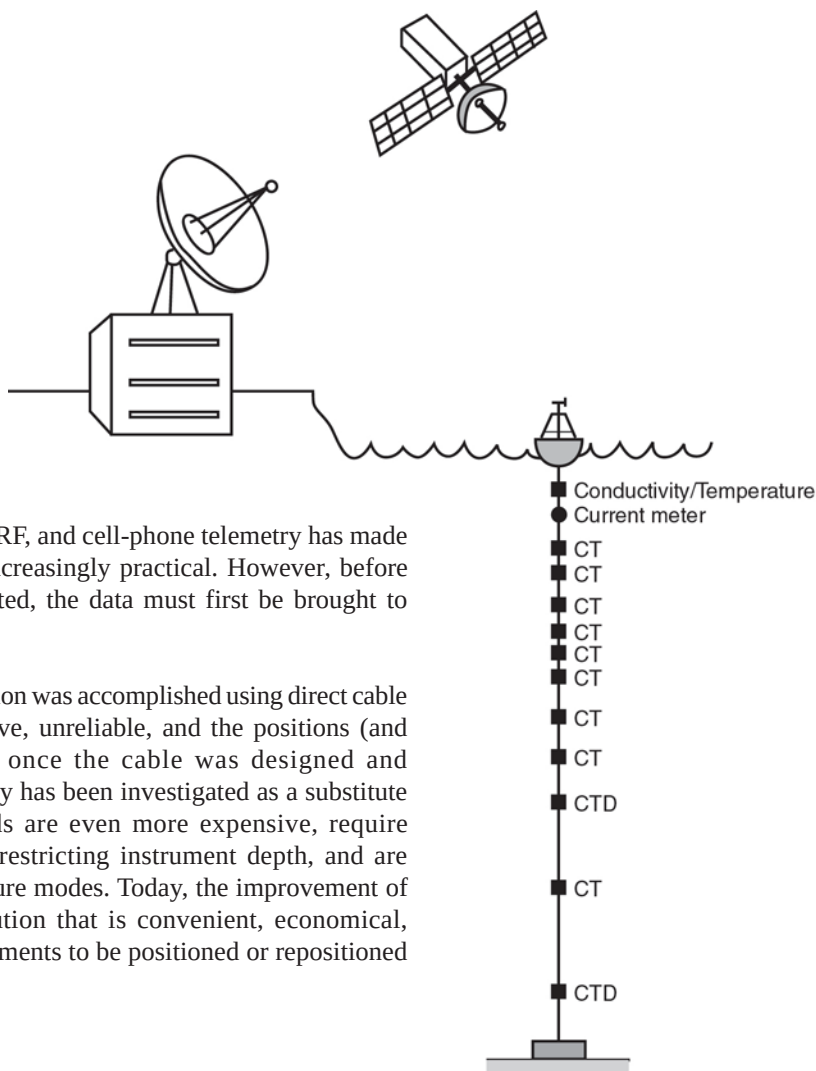


Real-Time Oceanography with Inductive Moorings

Sea-Bird Electronics, Inc.

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I. Introduction

Rapid progress in the development of satellite, RF, and cell-phone telemetry has made real-time, unattended, remote oceanography increasingly practical. However, before these new telemetry techniques can be exploited, the data must first be brought to the surface.

In the past, underwater-to-surface data transmission was accomplished using direct cable connections. Such cables were bulky, expensive, unreliable, and the positions (and number) of individual sensors were fixed once the cable was designed and manufactured. More recently, acoustic telemetry has been investigated as a substitute for direct cables. However, acoustic methods are even more expensive, require additional battery packs, have limited range restricting instrument depth, and are subject to a multitude of error sources and failure modes. Today, the improvement of inductive modem technology provides a solution that is convenient, economical, reliable, and flexible; allowing up to 100 instruments to be positioned or repositioned at any depth (Figure 1).

II. Description of Inductive Modem

These systems are termed *Inductive Modems* or *Inductively Coupled Modems* because they employ transformers to couple data to the mooring cable. In the Inductive Modem (IM) system, sensor data is applied to the primary winding of a toroidal transformer. The mooring cable passes through the toroid, forming a single-turn secondary that conveys the data to the surface. In practice, the toroids are split into halves so that they can be clamped around the cable without the need to *thread* the cable through.

Since transformers cannot operate at zero frequency (DC) and are inefficient at very low frequencies, and because serial data may be DC (all ones or all zeros) or very low frequency (occasional bit changes), reliable data transmission depends on the use of a high-frequency carrier onto which the data is impressed. Such devices are called MODEMS (from MODulator-DEModulator) because they modulate a carrier at the data source and demodulate the data back into the serial form usable by the target PC or CPU.

FSK (frequency-shift-keyed) MODEMS assign one frequency to data zeros and a second frequency to data ones. This approach has been popular because filters set to the two frequencies can be used to recover the data pattern, but the FSK approach is inefficient in terms of energy requirements and bandwidth, and exhibits relatively higher error rates for any given implementation.

Sea-Bird's Inductive Modem uses a DPSK (Differential Phase Shift Keyed) data transmission method that overcomes most of the disadvantages of FSK, resulting in superior transmission efficiency and much lower error rates. It is the same method employed with the widely proven SBE 911*plus* CTD system but operating at a lower baud rate (1200 vs 8640).

Figure 1: Inductive Mooring

In the SBE IM DPSK system, the carrier frequency is 4800 Hz, so there are four cycles of carrier frequency during the time allotted to each data bit. The encoding scheme is straightforward: if the next bit is to be a one, the phase of the carrier is inverted (shifted 180 degrees); if the next bit is a zero, the carrier phase does not change.

With DPSK, both the modulation and demodulation hardware are extremely simple. Modulation requires only an OR gate and flip-flop, and demodulation is inherently coherent (bit energy is averaged rather than spot-sampled) using minimal hard logic, a shift register implementing a one-bit delay being the principle component. Further advantages are that the transmission of all-zeros creates a single coherent frequency (4800 Hz) that is readily detected in IM instruments as the *wake up* signal, and that — unlike FSK — the connection polarity of the transformers used for coupling is immaterial.

III. Principles of Inductive Coupling

A transformer has two or more coils that share a magnetic field. Materials such as ferrite can be used to form a transformer *core* that ensures the necessary sharing of magnetic fields (Figure 2). An AC voltage applied to an 8-turn *primary* winding will induce a voltage half as large on a 4-turn *secondary* winding.

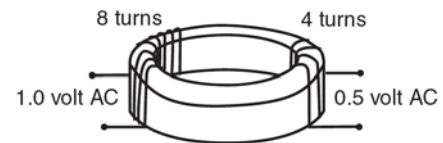


Figure 2: Basic Transformer Operation

A transformer is similarly employed in IM systems. Figure 3 illustrates the operation of the transformer defined in the *Alternative IM System* (section IVb), which is conceptually the simplest type. Note that the secondary *winding* (in this case, the mooring cable) does not have to be *wound* tightly on the transformer core. The *winding* must only *pass* through the hole in the core.

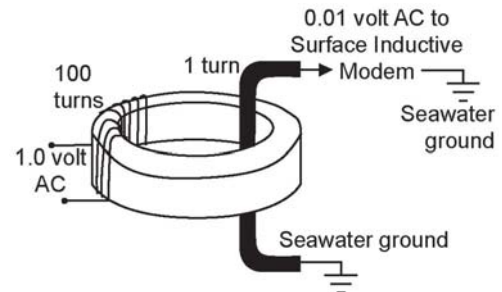


Figure 3: Sea-Bird Inductive Coupling

In the *Preferred IM Configuration* (Section IVa), the ends of the mooring cable are grounded to the seawater. This causes a current to flow through the mooring wire and seawater. The Inductive Cable Coupler (ICC) senses this current providing a voltage for presentation to the Surface Inductive Modem (SIM), shown pictorially in Figure 4 and schematically in Figure 5.

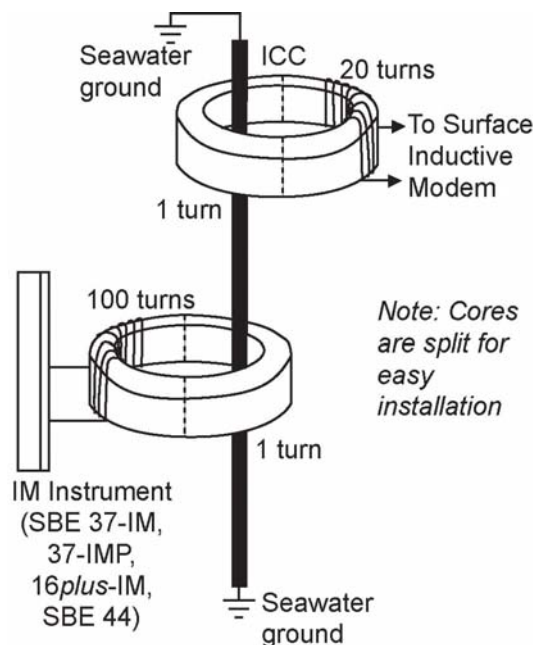


Figure 4: SBE Inductive Coupling

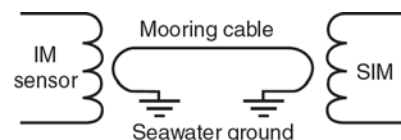


Figure 5: Inductive Coupling Schematic

IV. Inductive Mooring Configurations

a. Preferred Inductive Mooring

A typical ocean mooring is shown schematically in Figure 6. The mooring cable is a plastic-jacketed galvanized steel wire rope, a type frequently used for non-inductive oceanographic moorings because of the corrosion resistance provided by the plastic jacket. The ends of the wire rope are terminated with steel thimbles or swaged eye terminals. Deep moorings typically employ synthetic line below the lowest instrument.

Individual inductive modem instruments may be clamped along the mooring cable at any position. It is not necessary to break the cable at the instrument positions or to provide any electrical connection between instrument and cable. Each instrument can be freely moved up or down the cable.

The surface buoy contains a Sea-Bird Surface Inductive Modem (SIM, see page 6) that communicates with the underwater components via a through-hull bulkhead connector, polyurethane cable, and Sea-Bird Inductive Cable Coupler (ICC, see page 6). Like the IM instruments, the ICC simply clamps anywhere along the plastic jacketed portion of mooring cable below the seawater ground — no electrical connection to the mooring cable is required. The buoy controller / CPU (not supplied by Sea-Bird) links to the SIM using RS-232 to permit two-way half-duplex communication with the entire suite of IM instruments.

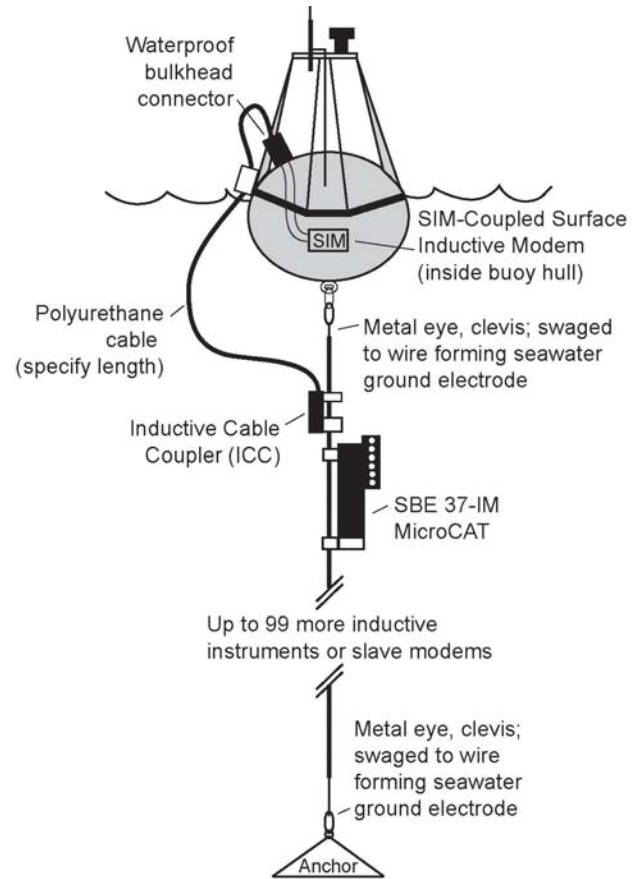


Figure 6: Preferred Inductive Mooring configuration

b. Alternative Inductive Mooring

An alternative system can make use of a direct electrical connection between the surface buoy and the top of the mooring cable as shown in Figure 7. In this configuration, the plastic-jacketed cable is brought inside the buoy. The buoy must be mechanically secured to the top of the cable without compromising the electrical insulation of the plastic jacket. The SIM connects to the galvanized steel wire and to the buoy hull (or other seawater return). This configuration eliminates the need for the ICC, but may complicate connecting the buoy to the mooring wire.

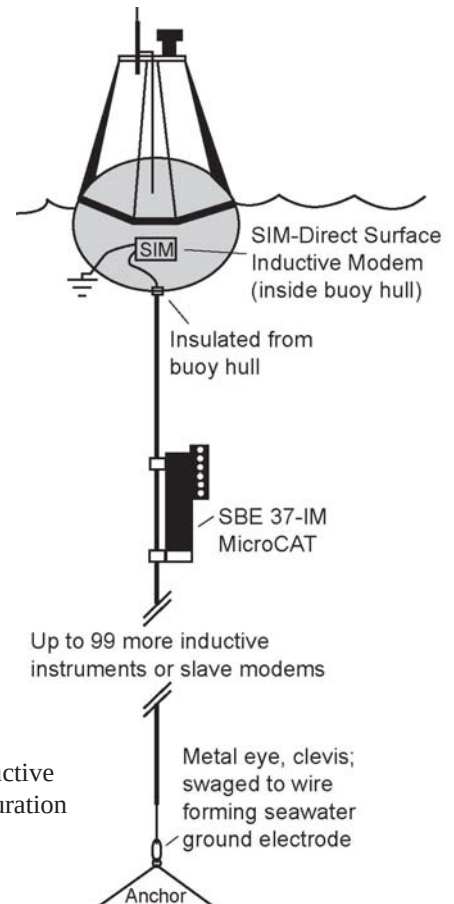


Figure 7: Alternative Inductive Mooring configuration

c. Cable-to-Shore Mooring

As shown in Figure 8, instruments may be placed at any position along a jacketed wire rope leading from shore. Here the problem of insulating the inner conductor at the shore end is easily solved, making the direct-connection approach the preferred method (Section IVb).

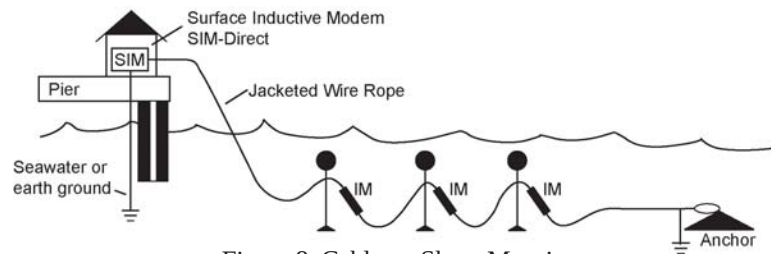


Figure 8: Cable-to-Shore Mooring

d. Through-Ice Mooring

Figure 9 shows the arrangement permitting IM moorings to be used for through-ice applications.

It is essential that both ends of the mooring cable are immersed in the seawater to complete the circuit.

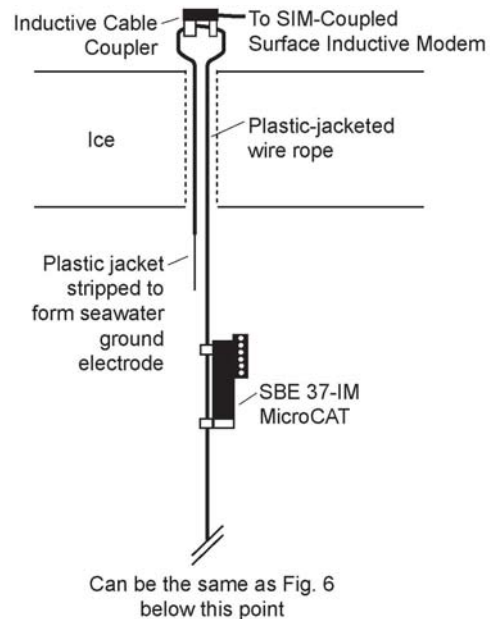


Figure 9: Through-Ice Mooring

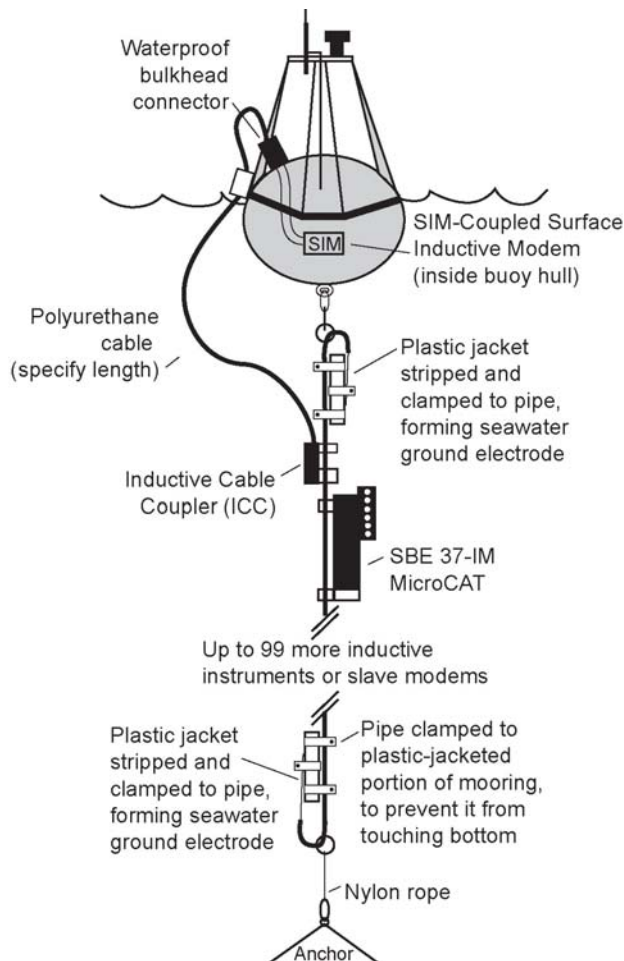


Figure 10: Fresh Water Mooring

e. Fresh Water Mooring

Figure 10 shows an arrangement permitting IM moorings to be used for fresh water applications, for a mooring with a SIM-Coupled Surface Inductive Modem and an Inductive Cable Coupler.

It is essential that you make a good contact to the bulk water to complete the circuit. For fresh water applications, this requires a large electrode in the water at the top and bottom of the mooring. Use at least a 0.7 m length of 2 inch (outer diameter) or larger conductive pipe (galvanized or stainless steel). Strip the end of the mooring line and clamp it to the pipe. Do not let the electrode pipe lie on the bottom; clamp the pipe to the mooring line at least 2 or 3 meters above the bottom. A mooring with this design should provide good communications over 1000 meters of mooring line in water with conductivity as low as 100 $\mu\text{S}/\text{cm}$.

For a mooring with a SIM-Direct Surface Inductive Modem, the bottom connection would be as shown in Figure 10. The connection to the buoy is as shown in Figure 7; several square feet of un-painted surface on the buoy is required to provide the large electrode at the top.

V. Inductive Modem System Components

a. Mooring cable

Mooring cables are usually polyethylene-jacketed galvanized steel wire rope. Provision for electrical contact with the water must always be made at the lower end of the cable. Typically a few centimeters of insulation are removed and a swaged eye terminal (Figure 11) is installed, providing both a means of mechanical attachment and a suitable seawater ground.

Sources of mooring cable and cable assemblies are given in Section VI.



Figure 11: Swaged Eye Terminal

b. Underwater Sensors

While the IM system can support sensors operating in command mode only (i.e., the sensor is asked to take a sample and it returns the data), it is desirable that IM sensors can also operate autonomously. This requires each sensor to sample and self-record data using its internal clock, while allowing the IM system to command for the most recent data. This approach has the advantage that data can ultimately be extracted from individual sensors despite a failure in the IM, buoy, or telemetry components. The sensor's ability to avoid conflict between its own clock-driven sampling and the separately clocked commands issued by the buoy controller is also useful.

1. Sea-Bird MicroCAT CT/CTD Recorder, SBE 37-IM and 37-IMP

The SBE 37-IM (Figure 12) is a self-contained CT (optional pressure) recorder for depths to 7000 meters. The SBE 37-IM can be commanded to sample via the IM link. However, it is usually desirable to make use of the MicroCat's Autonomous Mode based on its internal clock and memory. In this mode, samples are taken and recorded in non-volatile memory at fixed time intervals, while the buoy uses the IM link to request the most recent results.

The SBE 37-IMP combines the features of the 37-IM with an integral, internal pump.



Figure 12: SBE 37-IM

2. Sea-Bird Temperature (pressure optional) Recorder, SBE 39-IM

The SBE 39-IM (Figure 13) is a self-contained Temperature (optional pressure) recorder for depths to 10,500 meters. This operates in command or autonomous mode, just as the SBE 37-IM.



Figure 13:
SBE 39-IM

3. Sea-Bird SEACAT CT/CTD Recorder, SBE 16plus-IM (fitted with built-in IM adapter). This operates in command or autonomous mode, just as the SBE 37-IM. (Figure 14)

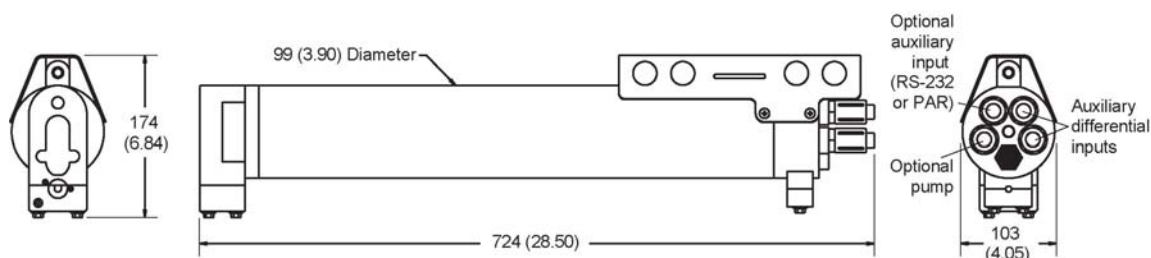


Figure 14: SBE 16plus-IM

4. Equipment manufactured by other companies, incorporating built-in Sea-Bird OEM IM components. (Figure 15)

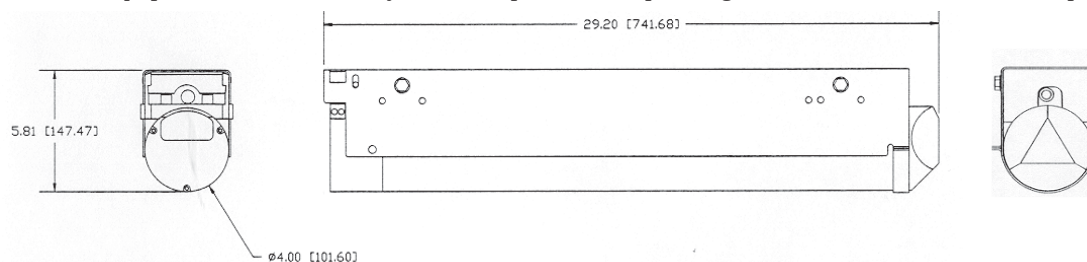


Figure 15: Sontek Argonaut ADCM with Inductive Modem End Cap

5. Equipment manufactured by other companies interfaced with a Sea-Bird Underwater Inductive Modem, SBE 44 (Figure 16). The SBE 44 contains a real-time clock, buffer memory, RS-232 interface, and internal batteries. It allows a variety of serial instruments to be coupled inductively and addressed (polled) as one of up to 100 units on the mooring cable.

Instruments in all of the categories above are battery powered. Additionally, they have serial-data interfaces that can respond to commands and provide data in digital formats. Voltage output (analog) or frequency output sensors cannot be directly interfaced to the IM system.



Figure 16: SBE 44 Underwater Inductive Modem

c. Surface Inductive Modem

A small printed circuit card mounted in the surface buoy, or on-shore in the case of cable-to-shore systems (Figure 17). The SIM is offered in two configurations:

1. Sea-Bird SIM-Coupled for use with a Sea-Bird Inductive Cable Coupler (*Preferred Inductive Mooring System*, Section IVa).
2. Sea-Bird SIM-Direct for direct connection to the mooring cable (*Alternative Mooring or Cable-to-Shore Systems*, Section IVb, c)



Figure 17: SIM Board

SIM Board Specifications	
Board Dimensions	4.25 x 5.83 inches (108 x 148 mm)
Power Required	7 to 25 volts at 10 microamps quiescent; 60 milliamps communicating

d. Inductive Cable Coupler (ICC)

Used with SIM-Coupled for moorings similar to Figure 6. The ICC (Figure 18) is available in a number of sizes for clamping to mooring cables with diameters from 1/4 inch to 16 mm. The ICC cable can be specified for the desired length, with a pigtail or a molded connector.

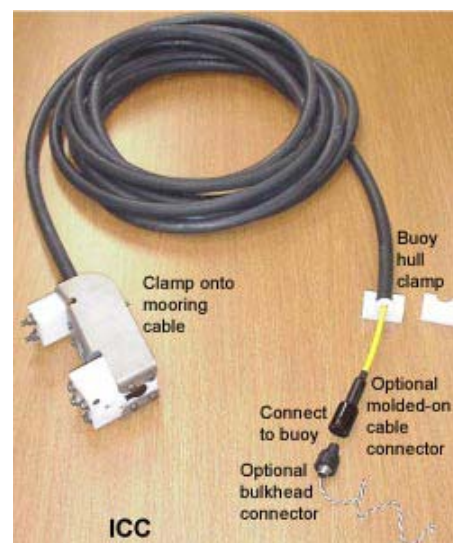


Figure 18: Inductive Cable Coupler

e. Buoy Controller

This is typically a microprocessor that schedules interrogation of the underwater instruments, interfaces to any desired atmospheric sensors, and controls the telemetry of data back to shore via RF, cell phone, satellite, or hard-wire link. This item is not presently supplied by Sea-Bird.

The surface buoy's CPU controller connects via RS-232 (9600 baud, 8 data bits, 1 stop bit, no parity) to the Sea-Bird Surface Inductive Modem (SIM). The SIM-Direct version of the SIM connects directly to the cable, while the SIM-Coupled connects via the Sea-Bird Inductive Cable Coupler. Although the CPU communicates with the SIM at 9600 baud full duplex, the SIM communicates with the underwater sensors using half-duplex 1200 baud telemetry link. Commands to and replies from IM instruments are sequential, not simultaneous. Commands may be global — all IM instruments respond — or individually addressed to a specific sensor (each instrument is programmed with an ID number in the sequence 00 to 99). Global commands may be used to set all IM instruments to the same time and date, or to instruct all IM sensors to begin sampling now or at some future time. Addressed commands can be used to instruct individual sensors to acquire data, check sensor status, or extract stored data.

IM instruments have three operating modes: sleep, command, and acquire. Normally, and throughout most of each deployment, they will be in sleep mode. Upon command from the buoy CPU, the SIM sends a *wake-up* signal that sets all IM instruments to command mode. In command mode, the instruments will respond to global or individual commands; if no commands are sent for two minutes, an internal time-out re-establishes sleep mode. The third mode (acquire) is entered either by command from the buoy CPU and SIM, or as a result of the internal clock and the sample program optionally stored in each IM instrument. Typical battery drain in the three modes is 80 microamps (sleep), 3.5 milliamps (communication), and 35 milliamps (acquire).

f. Surface Buoy

The surface buoy houses the Surface Inductive Modem, Buoy Controller/Data Logger, telemetry transmitter/receiver, and necessary batteries (Figure 19).

This item is not presently supplied by Sea-Bird.

g. Shore Installation

Located on shore is the telemetry receiver (and in some cases a transmitter permitting shoreside control of buoy function), and a computer for logging, processing, and displaying buoy data.

These items are not presently supplied by Sea-Bird.

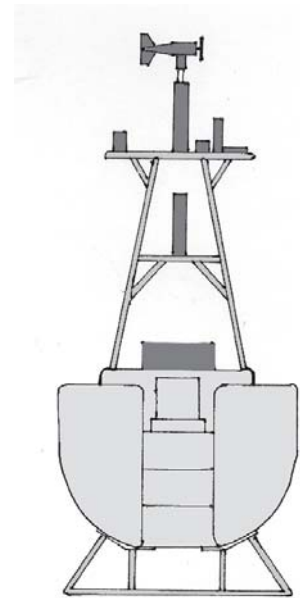


Figure 19: Typical Surface Buoy

VI. Resources for Mooring Cable, Cable Assemblies, and other Mooring System Components

Two sources for suitable jacketed wire are listed below. Similar cable may also be available from other sources.

- a. 3X19 Galvanized Oceanographic Cable, Plastic Impregnated. Loos & Co., Wire Rope Division, Pomfret, CT USA. Phone 800-533-5667. Fax 860-928-6167. Web www.loosco.com/index3.htm.

Loos & Co. Part Number	Wire diameter (mm)	Jacket diameter (mm)	Break strength (kg)
GM 1253901	3.18	4.76	848
GM 1563901	3.97	5.56	1061
GM 1883901	4.76	6.35	1814
GM 2503901	6.35	7.94	3016
GM 3133901	7.94	11.11	4490
GM 3753901	9.52	12.70	6305

- b. 3X19 Space-Lay Plastic Impregnated and Coated Wire Rope from Macwhyte Company (part of Wire Rope Corporation of America). Phone 816-233-0287. Web www.wrca.com.

Wire diameter (mm)	Jacket diameter (mm)	Break strength (kg)
3.18	4.76	848
3.97	5.56	1061
4.76	6.35	1814
6.35	7.94	3016
7.94	11.11	4490
9.52	12.70	6305
11.11	14.29	8527
12.70	16.67	11067
14.29	18.26	13925
15.88	19.84	17100
19.05	23.81	24448

Terminated wire, cable assemblies, other mooring hardware, and mooring design assistance are available from Mooring Systems, Inc., Cataumet, MA USA. Phone 508-564-4770. Fax 508-564-4773. E-mail sales@mooringsystems.com. Web www.mooringsystems.com.

Custom mooring systems incorporating Sea-Bird Inductive Modem components have been manufactured by:

- a. METOCEAN Data Systems Limited, Dartmouth, NS Canada. Phone 902-468-2505. Fax 902-468-4442. E-mail sales@metocean.com. Web www.metocean.com.
- b. Coastal Environmental Systems, Seattle, WA USA. Phone 206-682-6048. Fax 206-682-5658. E-mail pkelly@coastalenvironmental.com. Web www.coastal.org.

VII. OEM Components Available from Sea-Bird

Qualified manufacturers of serial-output sensors can obtain OEM Underwater Inductive Modem (UIM) circuit cards and other components needed to convert new or existing instruments to IM operation. The present circuit card format is a 4.33 inch (110 mm) long three-board rectangular card set for longitudinal (lengthwise) mounting in 2 inch (51 mm) housings. Sea-Bird will make UIM board sets in a format to suit OEM requirements for minimal expense.

The card sets operate from supply voltages in the range of 7 to 16 volts and are compatible with the battery packs typically used in ocean instruments. Data interface is full-duplex RS-232 (9600 baud standard; other baud rates available).

In addition to the UIM boardset, a split toroid core and transformer winding is required. In designing the mechanical mount for the IM coupler, note that one half of the toroid is to be captured within the instrument and surrounded by the free-standing winding. Single-pin seal pins (not supplied) are typically used to support the winding and bring the electrical connections into the instrument. The winding and core half are then urethane potted. The potting material must adhere to the seal pins; no other adhesive bonds are critical. An important feature of this configuration is that the winding is entirely surrounded by the potting material so that water intrusion along the toroid surface is of no consequence. The toroid itself is unaffected by water exposure.

The OEM must make provisions to lightly clamp the other toroid half into position. Figure 20 shows various aspects of the basic design. Additional details and design assistance are available from Sea-Bird.

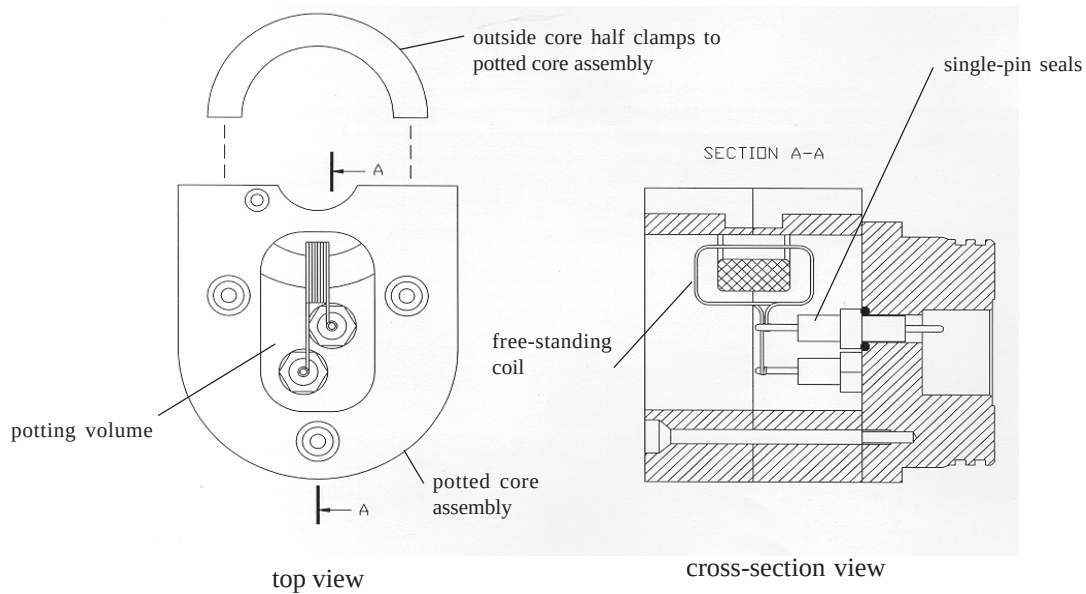


Figure 20: Typical IM Coupler Installed in Instrument End Cap

As an alternative to making the IM coupler an integral part of an end cap, the Inductive Cable Coupler (ICC, Figure 18) can be connected to a bulkhead connector on the OEM instrument (Figure 21), making the IM coupling a flexible lead of any convenient length.

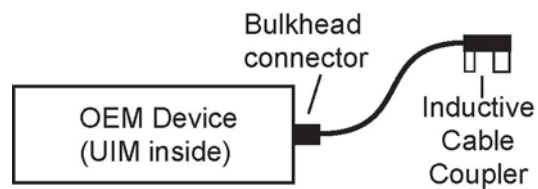


Figure 21: IM Coupler on Flexible Lead