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Woods Hole Oceanographic Institution

Advanced Engineering Laboratory Project Summaries – 1989

Edited by

Daniel Frye, Ellen Stone and Ann Martin

May 1990

Technical Report

Funding was provided by theWoods Hole Oceanographic Institution

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ADVANCED ENGINEERING LABORATORY PROJECT SUMMARIES - 1989

Edited by

Daniel Frye, Ellen Stone and Ann Martin

Woods Hole Oceanographic Institution
Woods Hole, MA 02543

May 1990

Technical Report

Approved for Distribution:

Albert J. Williams 3rd

Albert J. Williams 3rd, Chairman
Department of Applied Ocean Physics and Engineering

Abstract

The Advanced Engineering Laboratory of the Woods Hole Oceanographic Institution is a development laboratory within the Applied Ocean Physics and Engineering Department. Its function is the the development of oceanographic instrumentation to test developing theories in ocean physics, and to enhance current research projects in other disciplines within the oceanographic community. This report summarizes recent and ongoing projects performed by members of this laboratory.

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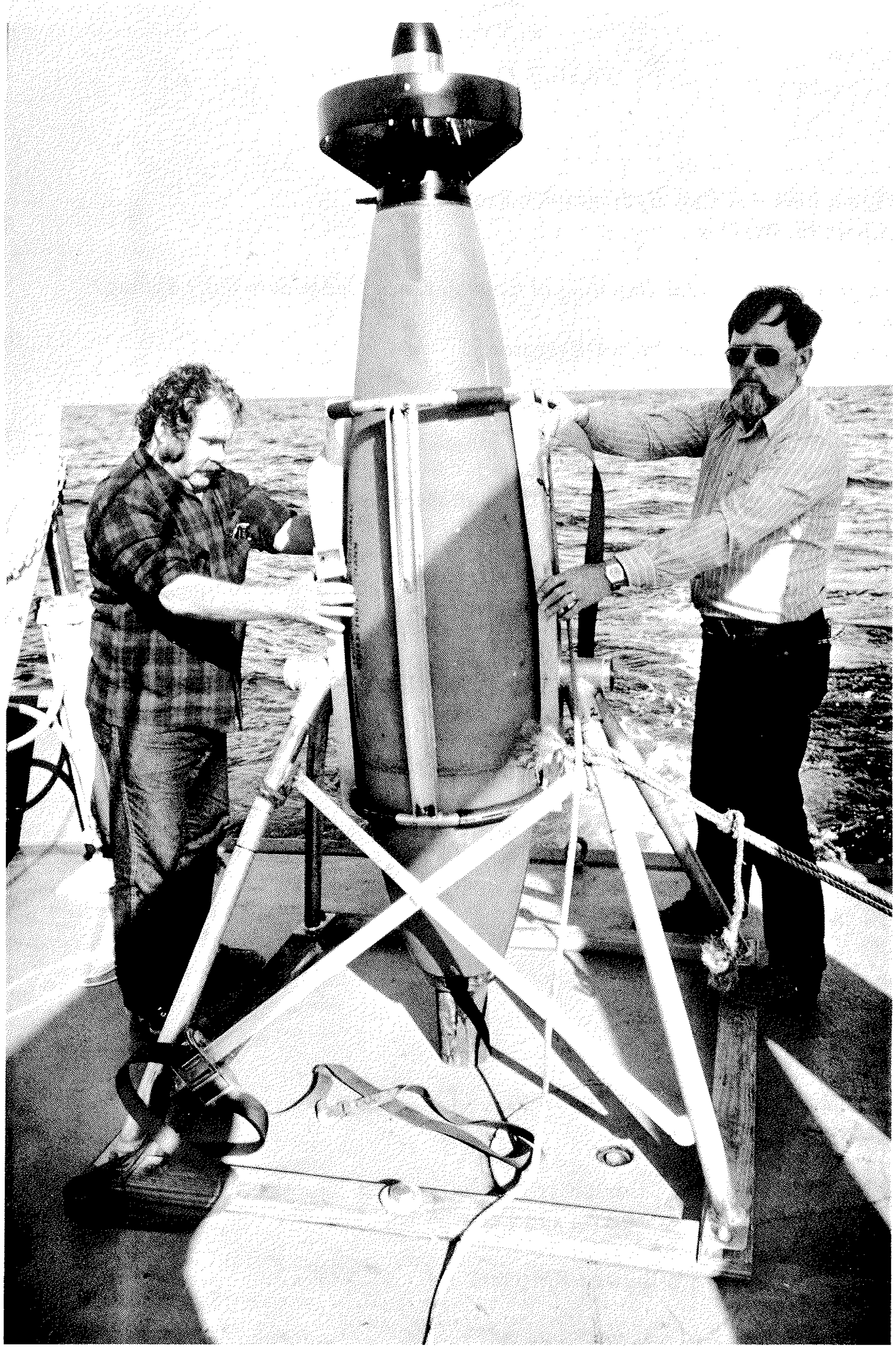

The Flying Fish – A Fast Hydrographic Profiler

Albert M. Bradley

Abstract

The "Flying Fish" is a fast free-fall hydrographic profiler capable of doing a high accuracy CTD section to 5000 meters in only 40 minutes of shiptime. The instrument travels at approximately 5 meters per second on both descent and ascent, and homes on an acoustic beacon near the ship to minimize the pickup time. This system is intended to support large scale hydrographic survey programs where the cost of station time is significant.

Introduction

We are approaching the end of a six-year effort to develop the Flying Fish sensor system and to evaluate its performance as a large scale hydrographic survey tool. The Flying Fish is a streamlined free-fall instrument that achieves a vertical velocity of 5 m/s on both the descent and ascent. This high speed allows a round trip to 5000 meters and back in 33 minutes. The Fish carries a high accuracy CTD and records data on the descent. To eliminate wasted shiptime maneuvering for the retrieval, the Fish can steer itself on ascent to an acoustic beacon alongside the ship. A specialized radio-controlled line tug and small A-frame are used to lift the Fish from the water within minutes of surfacing. The data is read out through a simple serial interface during the battery recharge interval. The turn around time is about 30 minutes, which permits very close station spacing. The basic concept and trade-offs of this type of sensor system are discussed in reference 1.

Progress to Date

Work on the Flying Fish vehicle is nearing completion. The body achieves the low drag and speed we need and the homing system brings the vehicle to the acoustic target. The Fish carries an EG&G Mark V CTD with a modified Mark III sensor head adapted to the shape of the vehicle. We have taken the system to sea and have been working to optimize the homing performance, the handling and the hydrographic data set.

Vehicle Performance

The Fish autopilot operates as a general purpose PID (proportional–integral–differential) controller, with all the gain coefficients left uncommitted. These are passed to the autopilot from the main fish controller at the start of the homing sequence and can be changed at any time. The homing system is based on a 15kHz CW signal which is received by four hydrophones arranged in a ring around the nose of the Fish. We have included the capability to recognize a "lane jump" in the acoustic heading data. This can occur when the Fish is off target by more than 16 degrees. At that point, the phase detectors cannot recognize that the phase change from +179 degrees to +181 is not a jump to -179 degrees. The autopilot correctly identifies these jumps and will center the fins for 16 seconds before resuming homing to allow the fish to stabilize.

In low current areas (i.e., not the Gulf Stream!) the Fish has hit the target on all ascents since we enabled the guidance system. The homing errors appear to be about the size of a wave orbit. The early tests in areas of high current, when the target is moving rapidly away from the Fish, show that the algorithm can't handle this large offset. Our tests in the Fall of 1989 addressed this problem by adding the ability to lead the target by an amount required to compensate for the horizontal motion. The Fish now can come within a few meters of the target under most conditions.

CTD Selection and Interfacing

Originally, the EG&G (formerly Neil Brown Instrument Systems), Sea Bird Electronics and HDW Elektronic of Kiel expressed interest in providing a CTD for the Flying Fish. Sea Bird felt that their slower sensors could only compete if the Fish entrained, stirred, and then measured the water to get real 10 meter averages. We all agreed this was rather difficult and have not pursued this avenue further. HDW is working hard to produce a commercial version of the high speed CT sensors developed by W. Kroebel at University of Kiel and has stated their intention to provide us with a unit to test, but has not done so at this time. NBIS, however, provided us with a fast sampling CTD for our July 1986 tests which, although it had some minor problems with sensing their proper turn-on point, appears to work well. Accordingly, we have purchased one of their units and incorporated it into the Fish. In our '86 test, the CTD had been operated independently of the Fish control system. Since then, however, we have improved the interface to allow the Fish to control the CTD and to use its data. Most importantly, this allows the Fish to use the CTD's measurement of depth as a backup to its own depth sensor (which is of very limited accuracy). We believe this is an important safety feature and vital to the system reliability.

Refractive Index Sensor System

We have been fortunate to have the opportunity to collaborate with Chris Waldmann and Karl Mahart of the University of Kiel to add a high speed refractive index sensor to our vehicle. The temperature and conductivity sensors on the present generation of CTD instruments do not have a short enough response time to resolve the fine details of the density structure that the Fish passes through at 5 m/sec. The Kiel refractive index sensor operates up to 1 kHz, and hence can resolve structures as small as 5mm in the vertical. This is not only valuable to those interested in such small scale structures, but can be used to verify that the density averages calculated from the CTD data are, in fact, correct.

To minimize system interaction in our initial tests, we decided to mount the Kiel sensor in an external "wing tank" with a dedicated data logger in a balancing "tank". We had some trouble adjusting the trim of the augmented vehicle. The Fish came up sideways on the first deployment due to the center of the drag being too far forward. We moved the "wing tanks" further aft and were then able to get excellent data from this sensor. Since we needed to use a separate dedicated data logger because of the speed of the RI data, we have not yet been able to display this data next to the CTD data generated on the same deployment. We can, however, identify similar features in each data set. We will eventually be able to merge these data sets.

Pickup System

Retrieving the Fish at the surface has been one of the toughest problems to solve. Many methods have been considered, but all had significant flaws. The final system must be easy to use, reliable, and able to work in bad weather. We must also have a way to retrieve the fish if the homing fails. This eliminates a whole class of "jump into the net" systems, which would otherwise be attractive. We concluded that a simple battery-powered and radio controlled surface line tug could solve a lot of the pickup problems. Our prototype, the "Grabbit", as it was called, performed surprisingly well and was able to carry a line to the Fish in quite choppy seas. We initially had some difficulty with the attachment system, but were able to improve it to the point where we could attach the lifting line to the tail of the Fish quickly. Both the Grabbit and the Fish are short compared to the typical wave lengths and hence move as a unit in heavy seas. This decoupling from the ship is a great advantage for instrument retrieval.

System Support Components

We have also designed and built a deck support system for the Fish. This unit acts as a junction box for the cables on deck and houses the drier pump used whenever the Fish housing is opened or recharged. This component, now known as the "Great Pump-can", makes life with the Fish easier by automating the somewhat tedious process of drying and evacuating the Fish pressure housing and eliminating much operator intervention in this process.

Data Processing and Display

We have developed a control program which runs in a Macintosh in the main lab to check out the Fish, prepare it for a profile, extract the data, process it to proper units and produce high resolution plots on a multicolor dot matrix printer. The major throughput limitation is now the printer driver that produces the multicolor plots. We expect that the industry will soon eliminate this bottleneck and that we will be able to produce large format plots quickly to allow planning for the next drop.

Future Work

Electronics

Almost all of the circuit cards in the present Fish control system are still the first generation, with many hand modifications. We are working to update them to make them easier to copy.

Bottom-finding Pinger

At this point, we have not allowed the Flying Fish to come close to the bottom for safety reasons. Eventually, we will need to have an acoustic bottom-finding system in order to measure bottom boundary structures. The pinger and receiving hydrophones are already built into the system, hence we only have to add a suitable pulse detector. The processor that controls the pinger already has an input to measure the time of the echo, so there will be only small system modifications required to add this capability.

Kiel Refractometer

We are pleased with the data from the Kiel refractometer, which we believe will make the vehicle useful for studying small density features as well as large scale ones. The "wing tanks" to carry the refractometer, however, make the vehicle difficult to handle and slow it down significantly. While this external position was an excellent choice for early testing of a "long shot" sensor, now that we have seen it succeed, we need to do better. Accordingly, we plan to modify the nose section to accommodate the RI sensor within the main body of the vehicle. The wing tanks required a center section of 18 inches to recover the buoyancy of the system, whereas the internally mounted sensor will only require a 6 inch section, saving 12 inches on the total length.

Integrated Water Sampler

The consensus of the original WOCE hydrographic survey groups chaired by Bob Heinmiller was that some level of water sampling capability would be required in the Flying Fish. Doug Webb (of WRC) originally expressed interest in this portion of the development and did some preliminary studies. Unfortunately he has turned his attention to other areas, and we are left without this important component. Accordingly, we have had several discussions with Bill Jenkins and John Bullister with the goal of defining and building a high performance water sampling system. We plan to explore this further and hope to build a suitable water sampler with about ten 1 liter samples.

The Fast Hydrographic Profiler and WOCE

The exact schedule of the field work for WOCE is somewhat uncertain at this time. Nonetheless, we expect to push the Flying Fish through the gradual process of community acceptance as expeditiously as possible. To this end, we expect to use the existing Fish to support current ongoing projects to "warm up" for future large scale work. As the Flying Fish system matures, we intend that it will "blend into" regular hydrographic work and will represent a significant saving to the community due to the Fish's ability to get the required data in minimum time.

Reference

[1] "High Performance Free–Fall Profiling Vehicles," with Eileen E. Hofmann, Marine Technology Society Journal, Vol. 21 Number 2, June 1987, pp. 33-41.

Funding was provided by a grant from the National Science Foundation, OCE-8612101.

Performance of Sequential Decoding of Convolutional Codes Over Fully Fading Ocean Acoustic Channels

Josko A. Catipovic and Arthur B. Baggeroer

Abstract

Sequential decoding of long constraining convolutional codes is shown to be a feasible technique for digital data telemetry over realistic marine acoustic channels. A computational bound for sequential decoding over a fading dispersive channel is derived for hard limiting and quantizing decoders. The results indicate that a minimum of 8 dB of bit SNR is required for sequential decoder operation. Simulations indicate that 14 dB bit SNR results in simple and feasible implementations. Diversity methods for coded transmissions over Rayleigh fading channels are examined. The optimal diversity level for both minimum error probability of uncoded systems and the diversity level for minimizing the sequential decoder computational load are derived and shown to be different, with the latter requiring a higher order of diversity. Performance differences between fixed-diversity and optimal diversity systems are presented.

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WHOI Acoustic Telemetry Project Interim Report 12/1/88 – 6/1/89

Josko Catipovic and Lee Freitag

Introduction and Progress Overview

This interim report covers the progress of the acoustic telemetry project during the period 12/1/88 to 5/15/89. In general, the work followed the format specified in WHOI proposal No. 5674.1. The major exception was the deletion of the transmitter array development task and a corresponding funding decrease from $242,242 to $170,000. In addition, the period for the funding was extended to June 30, partly due to a two month delay in project startup.

The telemetry project was centered around the construction, programming and testing of a digital receiver prototype capable of supporting future signal processing algorithms in real-time over ocean acoustic channels. The baseline receiver consists of a two-channel analog quadrature demodulator, and interface to a multiprocessor receiver for digital signal processing.

The software developed includes routines for command and control of the analog demodulator, data handling and formatting, and minimal software to digitally implement an incoherent MFSK demodulator, synchronizer and data decoder. Data storage and display programs were also completed to facilitate the performance analysis of the unit during testing.

The system was tested in Woods Hole harbor at data rates up to 4800 bits/sec. The acoustic channel was time-dispersive Rayleigh fading, and performance close to theoretical expectations was achieved. We are confident that the system error behavior is arising from channel-caused effects and known deficiencies in system performance, such as excessive synchronizer steady-state jitter.

System Overview

The acoustic telemetry test bed consists of a digital MFSK transmitter, developed with NSF funding, an analog demodulator, developed with ONR funding, and the signal processing receiver, developed on this project.

The transmitter is diagrammed in Figure 1. It is a small device consisting of a Motorola 68HC11 processor capable of digitally generating analog waveforms for data transmission. It is capable of transmitting 1.5 kbyte prestored buffers for experiments requiring arbitrary waveforms. It can also input a continuous data stream and modulate it in real-time at rates up to 2500 bits/sec. The system is capable of encoding the data with convolutional error correction codes, but this capability has not yet been used for this project. A set of software routines for programming the 68HC11 transmitter and downloading arbitrary waveforms was developed at no cost to this project and is available for use.

The demodulator is diagrammed in Figure 2. It was developed with ONR funds for other telemetry projects, and is available at no cost to this project. A print circuit version is being constructed as a part of this project. The unit is also suitable for multichannel coherent data acquisition and processing. It consists of a piezoelectric crystal and 35 dB signal conditioning preamplifier housed inside a hydrophone mold. The conditioned signal is

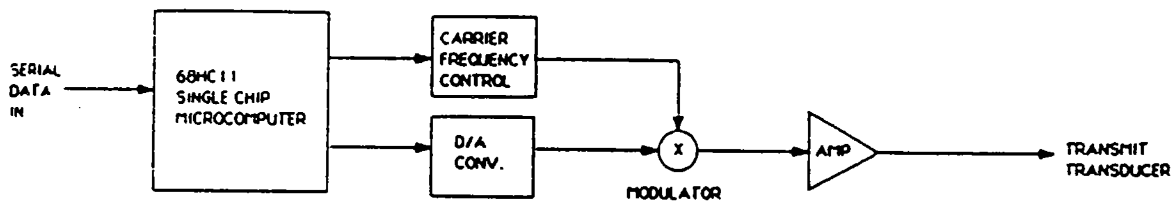

Figure 1: Acoustic telemetry transmitter block diagram

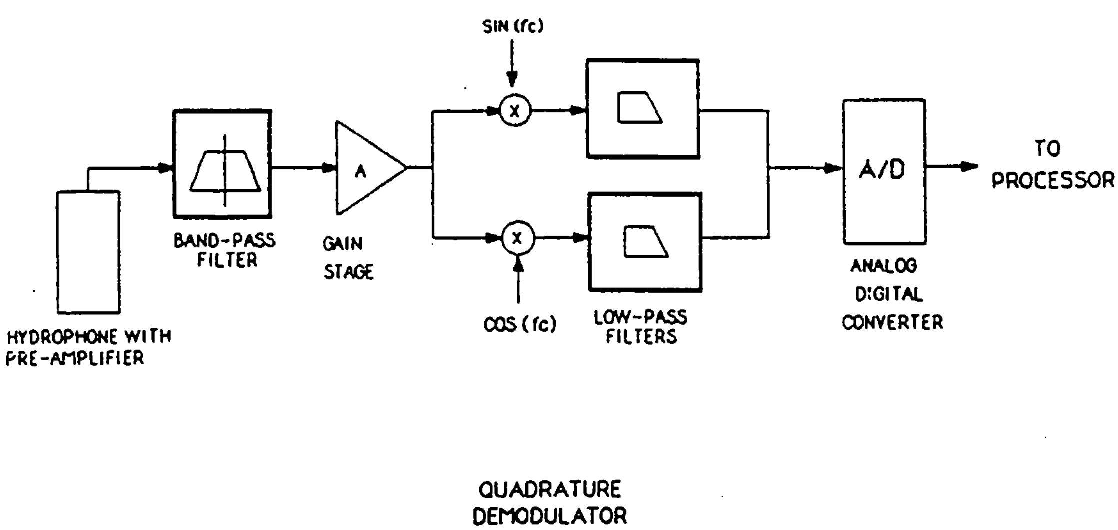

Figure 2: Demodulator block diagram

input to a two-channel surface-housed receiver. Each receiver channel consists of a digitally programmable bandpass filter with 24 dB/octave rolloff on high and low-pass en 90 dB programmable gain amplifier, a quadrature demodulator, sine and cosine anti-alias filters with 48 dB/octave rolloff, 12-bit digitizers and an interface to the digital processor network.

The digital receiver is implemented on an INMOS T800 transputer network and represents the major development effort undertaken on this project. At present 5 processors are used. Any processor can be interfaced to the demodulater unit. In practice, one processor is interfaced to each of the two demodulator channels, and can adaptively reconfigure the demodulator as well a the input data. The other three processors perform signal processing and decoding tasks and output the data.

The transputer array is housed in a portable IBM-compatible personal computer (PC). The PC supplies the code development environment and a disk and monitor for data storage and display. The transputer compiler, linker and loader all reside on the PC disk and run within the MS-DOS operating system. This packaging yielded an easily portable system.

Tests Done

The telemetry project has a permanent mini-laboratory placed at the southwest corner of the WHOI dock, and we have the use of a large harbor barge approximately 700m away from the WHOI dock. These facilities have been used for performance testing of the acoustic telemetry system over actual marine channels. The test geometry yields a fully saturated, fading, dispersive channel, very characteristic of many shallow water and confined geometry acoustic propagation channels, and generally accepted as the worst-case ocean acoustic channel.

Acoustic data was transmitted over this test range at data rates up to 4800 bits/sec. Measurements of the channel scintillation index, impulse response, and channel transfer function have also been made. We are currently attempting to integrate those measurements into a channel model which will be used to improve the accuracy of performance prediction.

Algorithm Work Done

Substantial time and effort were spent writing signal processing and system software for the transputer array. At present, we have a software shell written in *occam* programming language which constitutes the receiver framework. The individual signal processing tasks are integrated into the shell, which provides inter-process data buffering and system control. A rudimentary receiver was programmed and executes in real time at data rates up to 4800 bits/sec. The software is explained in greater detail in the transputer receiver section.

Funding was provided by the Office of Naval Research under contract Number N00014-86-K-0751, and a grant through the Charles Stark Draper Laboratory, Inc.

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Cooling the Waters of the 17-Meter Flume at the Coastal Research Laboratory

Robert J. Chapman and Richard E. Galat

Abstract

The 17-Meter Flume at Woods Hole Oceanographic Institution's Coastal Research Laboratory (CRL) is designed to develop a relatively wide range of flow regimes simulating steady flow environments in the coastal ocean. The ability to control the temperature of the circulating water extends the experimental capacities and enhances the quality of the experiments that can be conducted in the 17-Meter Flume. In the absence of a temperature control unit, the water temperature varies depending upon the line temperature of the water supply used to fill the flume, the ambient room temperature and the amount of time that water has been circulated by the flume pump. It is possible to design experiments that adapt to the first two temperature constraints, but the variation of temperature over time is still a problem. This variation over time is due to the energy that enters the system as the centrifugal pump circulates the water, with an estimated 75% of the energy drawn by the pump converted into heat. This thermal drift can cause changes in viscosity and also may result in a deteriorating biological environment, as temperatures exceeding 30° C may occur if the flume is operated continuously over several days.

The cooling system described here (Fig. 1) acts as a balance for the heat input from the pump and permits the maintenance of a wide range of stable-temperature flows in the flume. Low-temperature conditions can be developed by running the cooling system at full capacity until the desired temperature is reached; then the cooling system will remove just enough heat to balance the heat input from the pump and the heat input from the ambient room conditions to maintain a constant temperature. High-temperature conditions can be developed by running the pump to heat up the water until the desired temperature is reached; the cooling system will then maintain a constant temperature.

Due to the large water volume (~30,000 liters) required to operate the flume, a considerable period of time (on the order of 1 hour per ° C) is required to reach the desired temperature; however, once this is accomplished, the chosen temperature can be maintained to ±0.5 ° C due to the stabilizing influence of the large water mass. The time required for the system to achieve the desired temperature is dependent upon the ambient and line temperatures.

This report reviews the design considerations that led to the final system configuration, and contains a detailed description of the system and the individual components.

Published in:
Woods Hole Oceanographic Institution Technical Report WHOI-88-62/Coastal Research Center CRC-88-1, December 1988.

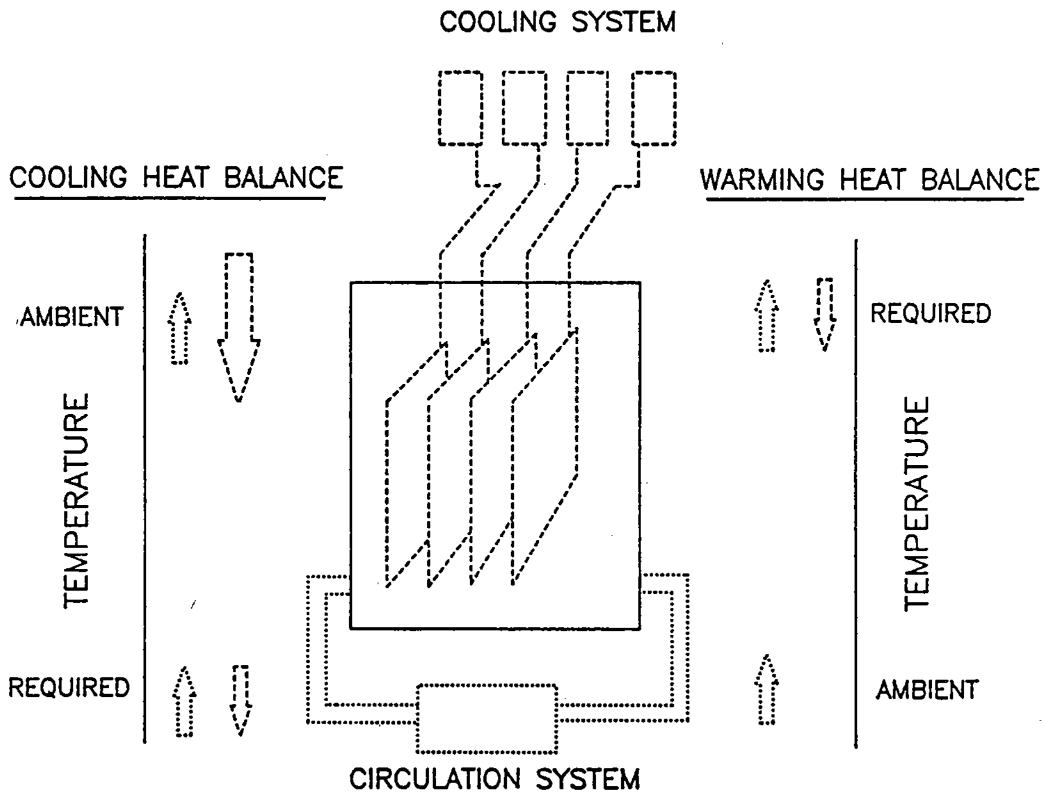

Figure 1: Schematic of the heat balance used to achieve constant temperature in the flume. The arrows represent the amount of energy contributed to the heat balance by the cooling and circulation systems; the dashed arrows show heat removed by the cooling system and the dotted arrows show heat input from the circulation system

A Time- or Event-Triggered Automated, Serial Plankton Pump Sampler

Kenneth W. Doherty and Cheryl Ann Butman

Abstract

This paper describes the development of an "intelligent" Moored, Automated, Serial, Zooplankton Pump (MASZP) for unbiased sampling of zooplankton at relatively fine spatial scales in virtually any flow environment. The MASZP is a moored oceanographic instrument that can be operated in a time-series, an event-triggered, or a combination time/event mode. As presently configured, it can take up to forty 1,000-liter or eighty 500-liter samples and can be moored for up to six months in water depths to 1,500 m. The sample volume and mooring duration are limited only by the present battery capacity supply, and the mooring depth is limited only by the electronics pressure housing; thus, larger sample volumes, longer deployments and deeper depths are possible with relatively simple modifications to the present system. Samples are collected on 100-μm mesh that is stored in a preservative bath using a modified Longhurst-Hardy Plankton Recorder mechanism, originally designed for time-series sampling by towed nets. A positive-displacement pump draws water through the mesh and measures the total flow sampled. A Tattletale Model III computer controls all electromechanical functions, records and stores data, and is programmable. The computer has three auxiliary ports to receive input from external sensors which may be used to drive the sampling regime. The system is presently equipped with an InterOcean S4 (electromagnetic) current meter as the external sensor so that samples may be taken, for example, only when the current exceeds a programmed threshold value. Tests of the MASZP in time-series mode have been successfully conducted at 2-20 m depth off the WHOI Dock. More extensive testing will take place in the summer of 1990 in deeper water using both time and flow events to drive the sampling regime.

Introduction

Field studies of zooplankton processes occurring over relatively short temporal and small spatial scales require the development of new sampling technology. Exciting new developments in remote-sensing techniques (e.g., acoustical or optical) provide the required sampling resolution, but are limited by their taxonomic resolution – they cannot resolve the fundamental evolutionary unit in biology, the species. This limitation may be overcome by coupling remote-sensing techniques with automated, "intelligent", direct-sampling techniques, where samples are taken only when needed (i.e., only when a large patch of organisms is detected). The design of our Moored, Automated, Serial Zooplankton Pump (MASZP) was dictated by this need for moored and efficient instrumentation for unbiased sampling of zooplankton. This research was supported by an NSF Oceanographic Technology grant (OCE-8712186) to C.A. Butman. Initial results were described in Butman & Doherty (1990) and a complete description of the instrument will be given in Butman et al. (in prep).

Sampling Strategy

While previous plankton-pump designs have focused on maximizing the velocity at the intake both for taking large-volume samples and for preventing organism escape, there are advantages to using the smallest acceptable velocity. A low intake velocity considerably decreases the power required by the pump system. Furthermore, since zooplankton are known to respond to pressure gradients, flow accelerations and turbulence (e.g., Singarajah, 1975; Haury et al., 1980; and Légier-Visser et al., 1986), the hydrodynamical signal of the instrument in the flow should be minimized. For a hydrodynamically sound entrance morphology, the smaller the pump intake velocity, the smaller the added velocity to the oncoming flow (i.e., the smaller the flow acceleration) and the smaller the relative streamline deflection (Brooks, 1979). The minimum intake velocity is set by the force required to hold the organisms on the sampling mesh and the time-scale over which the samples are to be taken (i.e., to obtain a significant sample size).

For unbiased sampling in flows, pump intakes were traditionally designed to point into the oncoming flow to minimize instrument-induced flow disturbances. If the flow direction changes on time-scales that are long (hours to days), relative to sampling intervals, then the intake can be placed on a swivel and the instrument fitted with a vane so that the intake always orients into the flow. This design is troublesome, however, in oscillatory flows, such as waves, where the frequency of the oscillation is relatively high (of order seconds to minutes). In this case, the instrument will generate considerable flow disturbance as it quickly moves back and forth with the reversing flow and the intake will constantly be sampling in the highly disorganized flow of the instrument's wake. An intake that is radially symmetric in the horizontal plane eliminates these problems.

Technical Description

The MASZP (Figure 1) is composed of six main parts: (1) sample intake, (2) plankton filter and storage mechanism, (3) pump, (4) controller, data logger and power source, (5) external "event" sensor, and (6) external tension frame.

Sample Intake

The entrance region to the sample intake was designed to minimize flow disturbance and to be radially symmetric in the horizontal plane for unbiased sampling in flows from any direction. The entrance region is formed by two horizontal, circular plates, (60-cm diameter, 5-cm thick, 5-cm apart at center) that are tapered at a 30° angle to a sharp circumferential edge. The intake is a 5-cm-diameter hole in the center of the bottom plate, which channels water to the filter mechanism. The intake is covered by a 1-mm mesh which serves as a prefilter. This entrance and intake design minimizes deflection of flow streamlines as the oncoming flow enters the entrance region, limits boundary-layer growth between the plates and insures that the pump intake velocity is minimal at the entrance.

Plankton Filter and Storage Mechanism

The plankton filter and storage mechanism (Figure 2) is based on the design of the Longhurst-Hardy Plankton Recorder (Longhurst et al., 1966; later modified by Wiebe 1970; Longhurst & Williams, 1973; Haury et al., 1976; Williams et al., 1983). It consists of two mesh supply spools, two idler spools, two mesh support plates and a take-up and storage spool. Water drawn through the intake is filtered through two 100-μm mesh strips covering the intake and exits, via curved channels, through the pump. The mesh, under tension, runs over curved support plates and produces a radial force to seal the mesh against the plates. The mesh originates from the two supply spools and is wound on the single take-up spool which is housed in a preservative bath compartment. A rubber seal where the mesh enters the preservative bath prevents leakage of preservative to the intake region. The idler spools are used to measure the amount of mesh wound on the take-up spool. Between samples, the mesh strips across the intake are exposed to seawater, so the system is presently programmed to advance the mesh before taking a sample and these "contaminated" samples are later discarded.

All spools are machined from acetal plastic. The take-up spool is powered by a gearhead, brushless, d.c. motor and is driven by a titanium shaft. The supply spools also ride on titanium shafts, with shaft seals as friction devices to provide the required tension. The idler spools have rubber elastomer sleeves around their circumference to increase the friction between the mesh and the spool. An idler spool turns a titanium shaft which is coupled to a cam in an oil-filled housing. A microswitch rides on the cam surface and detects one complete revolution of the idler spool. The diameter of the idler spools is such that one complete revolution is equal to one sample.

The main housing for the filter and storage mechanism was machined from a 9-cm-thick block of acetal plastic. The cover plate was made from clear acrylic plastic, allowing visual examination of the flow and the filtering mechanism.

Pump

A positive-displacement pump was used to avoid the requirement of a flow meter. The total revolutions of the pump are recorded and multiplied by the pump's displacement to calculate sample volume. A rotary pump was chosen based on pump efficiencies supplied by pump manufacturers. The pump was modified to be magnetically coupled to a brushless, d.c. motor. This modification allowed for removal of the shaft seal, thereby eliminating shaft seal leakage and reducing start-up torque and running friction. The pump is operated at a flow rate of 30 liters/min, which results in an intake velocity of 20 cm/s. The pump continues to run during mesh wind-up to keep the organisms captive on the mesh.

Controller, Data Logger and Power Source

A commercially available, single-board, Tattletale Model III computer is used as a controller and data logger. This inexpensive computer is easily programmed in TT Basic and includes an onboard temperature sensor. Five boards 7.6-cm wide by 12.7-cm long make up the electronics package. These five board include: (1) Tattletale computer, (2) interface and signal-conditioning board, (3) external event sensor communications board, (4) take-up spool motor drive, and (5) pump motor drive.

The electronics and electromechanical devices are powered from a single battery pack consisting of 180 alkaline D-cells wired into six 45-Volt parallel stacks. The electronics and battery pack are contained in an aluminum pressure case 30 cm in diameter and 53 cm long.

The software is written so that the MASZP will sample based on time alone, on information from an external event sensor alone, or as a combined time-series and event-triggered sampler. In the combined mode, samples are taken based on time or on an event that exceeds a programmed maximum or minimum threshold. Before a sample, the computer advances the mesh to ensure an uncontaminated sample. The computer also monitors the flow rate through the mesh and reduces power to the pump motor if the rate falls below a programmed threshold. This keeps the pressure gradient across the mesh from increasing (due to mesh blockage) to the point where organisms are sucked through the mesh. When the flow rate is reduced to 20 liters/min (intake velocity of 13 cm/s), the sample is wound on the take-up reel and the system records total flow sampled, water temperature and pressure.

External "Event" Sensor

The computer has three auxiliary ports to receive input from external sensors. These sensors convey information to the computer and this information can be used to drive the sampling program. External sensors may include, for example, a current meter, a transmissometer or a remote-sensing (e.g., acoustical or optical) device. The MASZP is presently configured with an InterOcean S4 electromagnetic current meter as the external sensor. The S4 was chosen over other current meters because it is relatively small, has a low threshold (0.1 cm/s), vector averages, is accurate to ±1 cm/s for mean flows, performs well in both waves and steady flows and is more immune to biofouling and mechanical failure. Using the time/event mode, the computer can be programmed, for example, to time-series sample at a programmed interval except when the current speed rises above or below some threshold level, and then it will begin sampling at the programmed sampling frequency for the event mode.

External Tension Frame

The MASZP can be used as a mooring system or on a bottom tripod. It is presently mounted in a mooring configuration in an external tension frame. The light-weight titanium frame is 91 cm in diameter and 200-cm tall. The MASZP is mounted so that the entrance region is above the frame, free from frame-induced flow disturbances. The S4 current meter is centrally located and the pressure housing is mounted at the bottom of the frame. Because the titanium frame disturbs the electric field within the vicinity of the current meter, the frame is wrapped in electrically insulating tape. The frame also generates small-scale eddies that alter the turbulence field within the frame compared to the turbulence of the ambient flow, so in this configuration, the current meter is used only to monitor mean flow speed.

Project Status

Several successful tests of the MASZP have been conducted at 2-20 m depth off the WHOI dock. These tests have confirmed that the MASZP functions as desired in a time-series mode (e.g., Figure 3). Dye studies conducted by SCUBA divers also have shown that the entrance morphology only minimally disturbs the oncoming flow and that the intake velocity has decayed to a negligibly low value at the circumference of the entrance. Future testing during the summer and fall of 1990 will be in deeper water and using the time/event mode.

Future work will include small mechanical-design changes to increase the ease of operation and to decrease machining costs in future units. Improvements will be made to eliminate the necessity of discarding every other sample on the mesh because of exposure to seawater between sampling intervals, and to prevent biofouling of the entrance region. We also plan to develop additional software to increase the intelligence of sampling based on multiple external sensors.

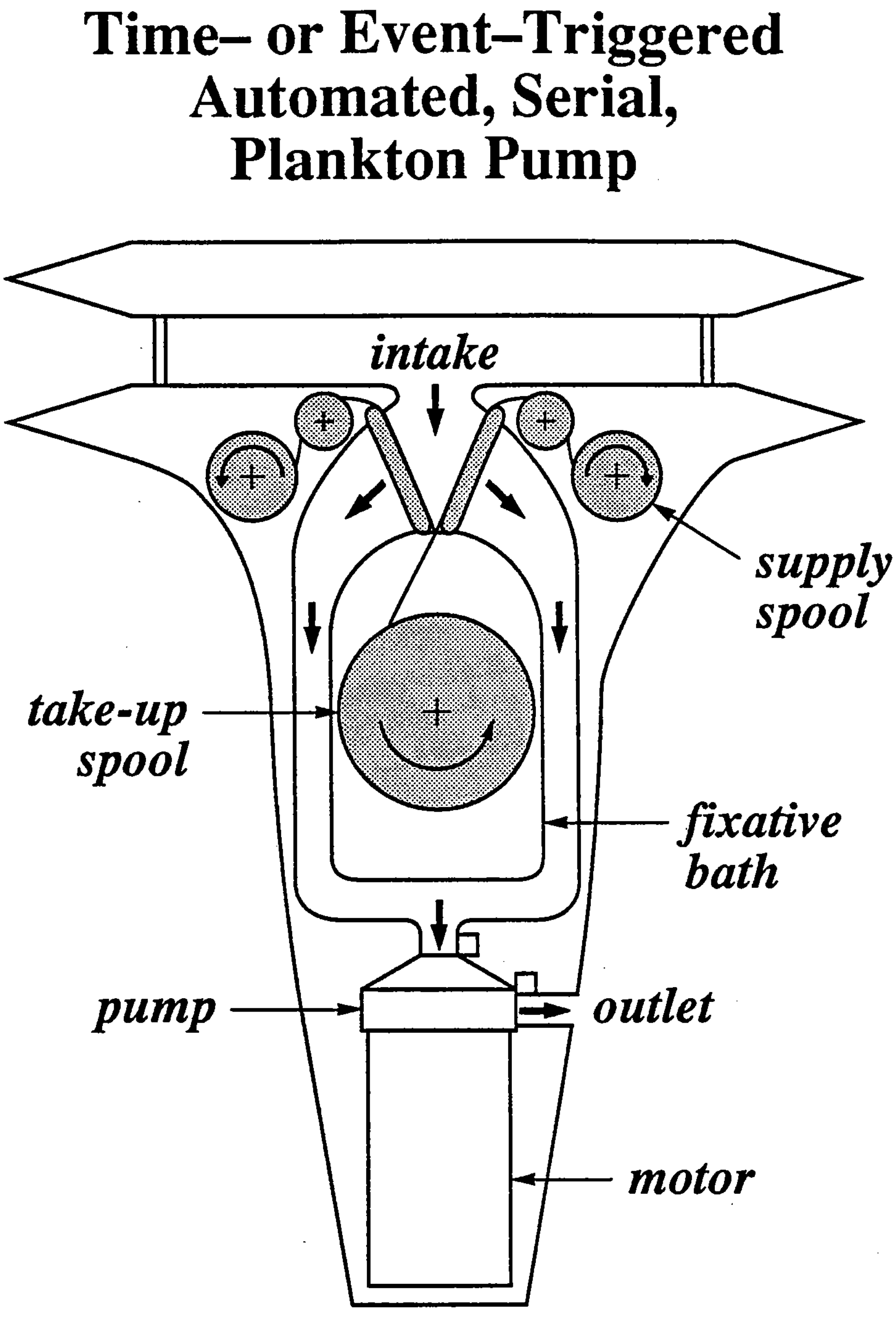

Figure 1: Diagram of the MASZP as it was originally designed. The prototype differs from this design in that idler spools were added next to the supply spools, curved mesh support plates replace the rods shown here, and the pump motor was rotated 90° so that it sticks out behind the main housing rather than hanging down below it.

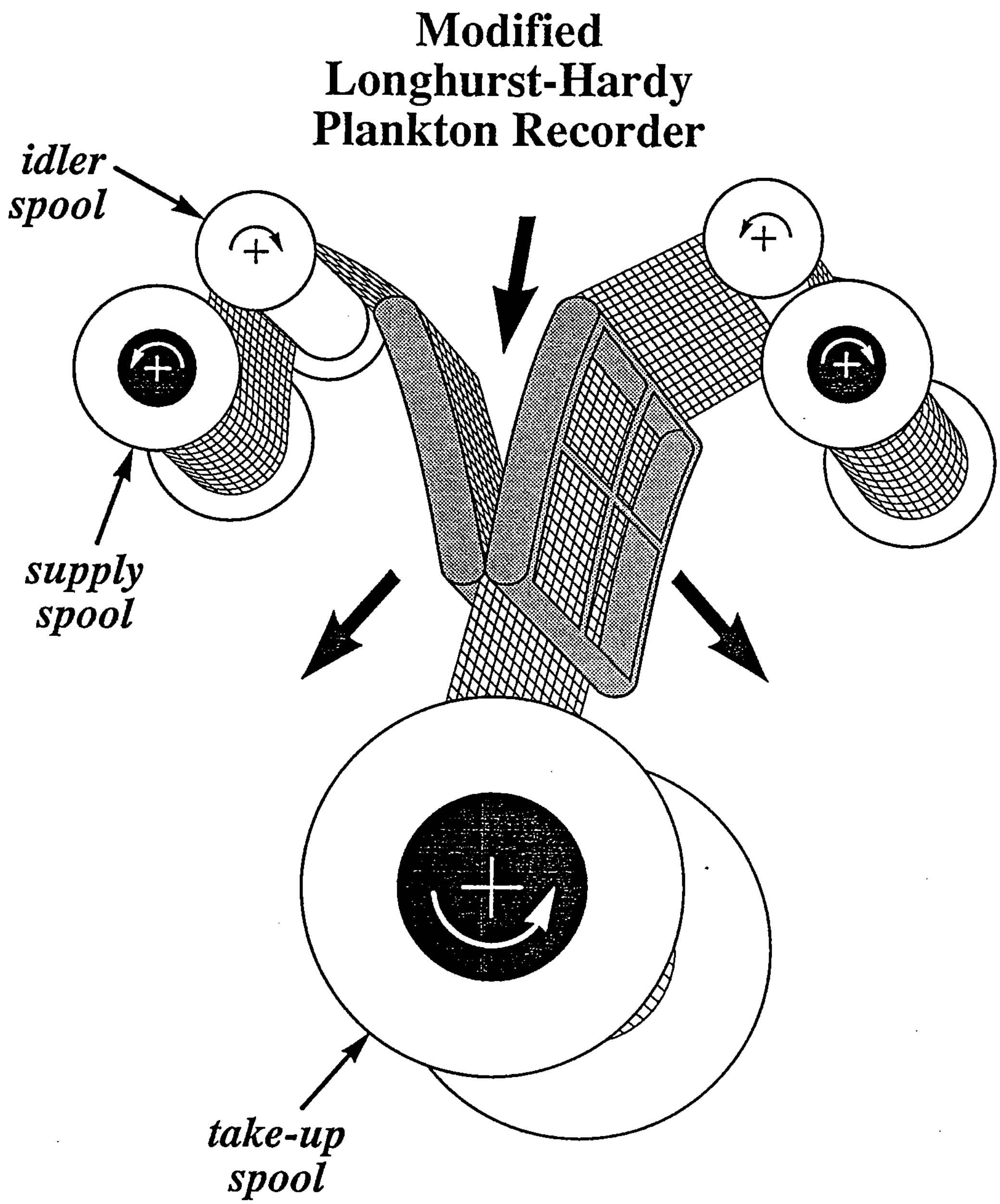

Figure 2: Diagram of the plankton filter and storage mechanism.

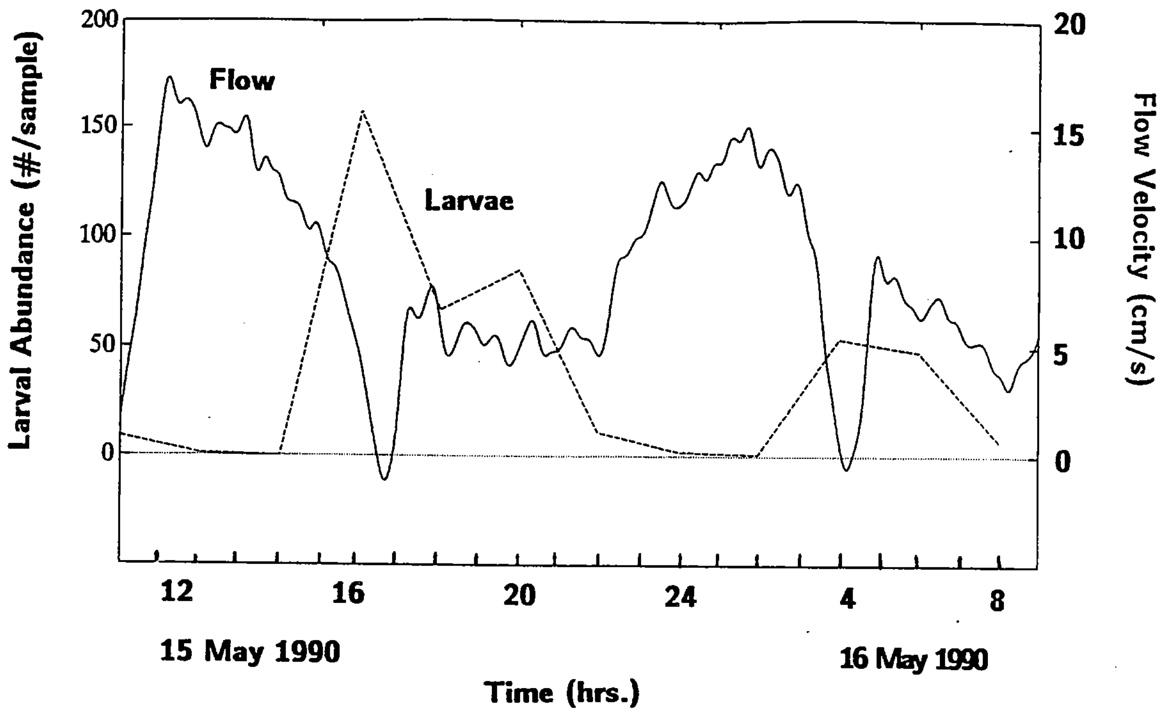

Figure 3: Results of time-series sampling with the MASZP from 10:00 (EDT) on 15 May 1990 to 10:00 on 16 May 1990. The tide was flooding at the start of the experiment and high water occurred at ~16:30 on 15 May and ~04:30 on 16 May. The pump was moored in the instrument well off the WHOI dock at 2 m depth in 60 m of water. Zooplankton were sampled at a velocity of 23 liters/min for 22 min every two hours (sample volume of 500 Liters), beginning at 10:00. Current velocity was measured continuously (2 samples/s) over the interval and 20-min averages are plotted here. The abundance (number/sample) of larvae of the hydroid *Tubularia larnyx* are plotted as the dashed line, and current velocity as the solid line. The source of the larvae are almost certainly the large populations of adults on the dock pilings. Three interpretations of these results are that, 1) larvae are released only at slack high water, 2) the local larval pool is advected away from the dock during flood and ebb tide, 3) as velocity increases, larvae vertically migrate down, probably to far below the pump intake, to avoid being washed away from suitable adult habitat, and then as velocity increases, larvae vertically migrate back up to surface waters.

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A Signal Processing System for Underwater Acoustic ROV Communication

Lee E. Freitag and Josko Catipovic

Abstract

A high performance system for communication with untethered underwater vehicles is presented. The system is centered around multiple digital processors which perform a variety of signal processing tasks. The processors are combined into an array using a flexible architecture designed for communication processing. A basic system has been tested at 5 kbit/sec over the Rayleigh-fading multipath channel in Woods Hole harbor.

To combat the deleterious effects of the fluctuating ocean channel, a series of algorithms designed to produce low error-rate communication is being implemented on the array. The processing elements are INMOS T800 transputers and the number of transputers may be selected at deployment time to meet the requirements of a particular task. The result is a powerful and flexible architecture for underwater acoustic communication.

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An Acoustic Telemetry System for Deep Ocean Mooring Data Acquisition and Control

Lee E. Freitag, Josko Catipovic, Max Deffenbaugh and Daniel Frye

Abstract

An acoustic telemetry system is being developed which will allow two-way communication between subsurface instruments and a near-surface receiver. A high-speed link allows data to be sent from instruments to the surface in real-time, and a slower downlink is available to send commands to the remote units. The objective is to develop a cost-efficient, reliable link which will allow real-time data from anywhere in the water column'to be transmitted to the surface and then forwarded via satellite link to a user anywhere in the globe.

The system operates at 15-20 kHz and uses multiple frequency-shift keying (MFSK) modulation. Bit rates are adjustable, but 1200 bits per second has been selected for this application. The tones which make up the MFSK signal are decoded at the receiver with a Fourier transform implemented on a sophisticated signal processor. The processor can also be programmed to include an error-correction decoder, adaptive equalizer and data packet synchronizer. A simple, low baud rate, command link enables the use of an Automatic Repeat Request (ARQ) strategy which further increases the reliability of the up-link.

A prototype system has been successfully tested at 1200 bits per second over a 3000 meter vertical path. Additional development work on the receiver, command link, and the transmitter is ongoing.

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Recent Developments in Ocean Data Telemetry

Daniel E. Frye and Breck Owens

Abstract

Woods Hole Oceanographic Institution is developing techniques for telemetering oceanographic data from the deep ocean to the laboratory in near real time. Three general solutions to the problem of how to transfer information between subsurface instruments and surface buoys equipped with satellite transmitters are being developed.

- Hardwired systems using electromechanical cables to connect subsurface instruments to surface buoys.
- Acoustic systems using high baud rate acoustic modems to transfer information between multiple remote units and a central controller.
- Inductive systems using standard mechanical mooring lines as the transmission medium between instruments deployed on the mooring and a surface buoy.

Introduction

Ocean data telemetry represents a fundamental change in the way oceanographic data are collected. At the present time, most in situ data collected over any length of time are stored on magnetic tape or other recording medium in the instrument and are not available until the instrument is recovered. The advantages of telemetering these data range from access to the data in real time for operational or forecasting purposes, to speeding up research by making data available sooner, to monitoring instrument performance, to making long term expendable measurement systems possible [1]. The impetus for ocean data telemetry development, however, comes as much from the availability of satellite telemetry as from oceanographers' desire to improve their scientific productivity. The key satellite technology is easy to use, inexpensive, provides global coverage, and can be implemented reliably with low power radio transmitters.

While the basic satellite systems needed to make ocean data telemetry feasible are in place, some of the oceanographic technology to make systems practical and reliable has not yet been developed. At WHOI, the Office of Naval Research is sponsoring a five year technology development effort to address some of these technical problems. This program, the University Research Initiative Program, URIP, has been underway for 3 years. One of its goals is to develop and test practical and reliable methods which allow measurements made anywhere in the water column, almost anywhere on the globe, to be telemetered to scientists in the laboratory in near real time [2]. This paper will describe three technologies under development at WHOI and present results of some initial test deployments.

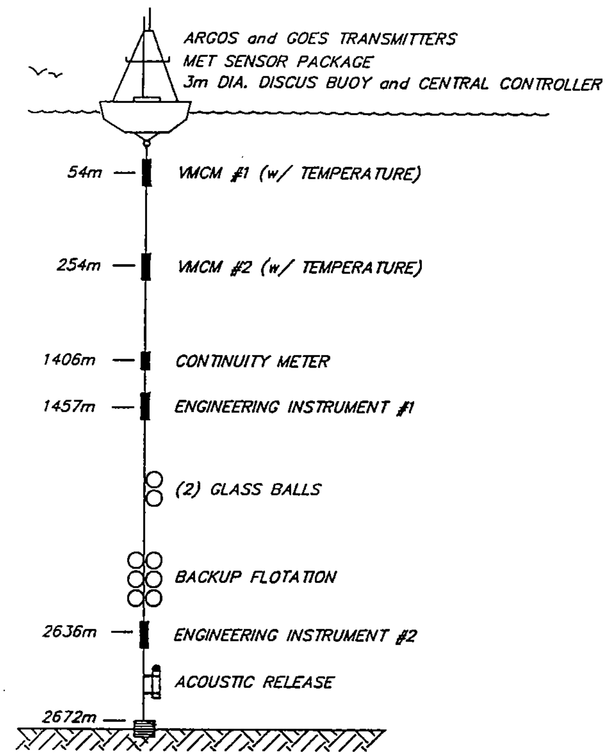


Figure 1: Surface Telemetry Mooring (STEM) deployed at Site D between Nov. 22, 1987, and May 2, 1988. (IEEE)

Hardwired Mooring Techniques

Electromechanical moorings have been used in a number of applications [3], [4], [5], [6], but they have been plagued with poor reliability and standard methods have not emerged from the various projects. The approach taken on the URIP has been to design electromechanical moorings which have general applicability, much like the standard intermediate and surface moorings developed at WHOI and elsewhere in the 1960s [7], [8], [9] and now used with great success all over the world.

The surface mooring problem was addressed in 1987 with the deployment of the Surface Telemetry Mooring [10]. This mooring (Figure 1) used a standard, taut wire design in which a length of nylon line provides the compliance needed to keep the mooring taut under a wide range of current and surface conditions. The key element in the modification of this design to accommodate telemetry of data from subsurface current meters was the replacement of the standard mooring strength member, 3x19 torque balanced wire rope, with a specially designed electromechanical cable. The cable [11] shown in Figure 2 in cross-section, uses the same 3x19 construction as standard mooring wire, but has 3 electrical conductors laid in the grooves formed by the three main strands. The conductors are then held in place with a polyurethane jacket, protected from fish bite with two layers of stainless steel tape, and then further protected by an outside jacket of hytrel. The strength of this cable design

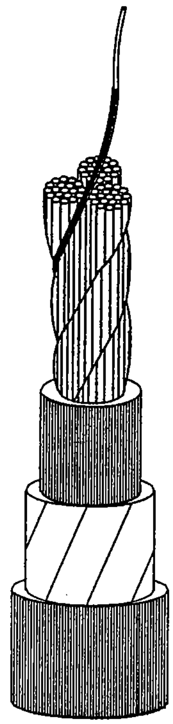


Figure 2: Electromechanical cable used to moor the STEM buoy in 2700 m of water.

is that it takes advantage of the proven reliability of 3x19 wire rope and does not require a separate electrical cable to be paralleled to the mooring's strength member, which is often done with some success for near surface instruments electrically connected to a surface buoy. For instruments positioned below a few hundred meters from the surface, the parallel cable technique becomes difficult to deploy and is often unreliable.

An operational test of the surface mooring technology was deployed at Site D (Figure 3) in November 1987 and retrieved six months later. Current meters were installed at 50 and 250 m below the surface to test the reliability of the cable and its terminations. A meteorological station was installed on the surface buoy and wind and current data were transmitted hourly via the Argos and GOES satellite data collection systems. A WHOI developed controller [12] requested data from each of the current meters four times per hour, from the met station once per hour, and from a number of engineering test sensors once per hour. The communication link between the controller and the various instruments and transmitters was a SAIL loop [13] using FSK communications for the current meters and standard serial links to the meteorological station and satellite transmitters. These data were then averaged and transmitted via satellite once each hour. To increase data flow through the Argos system, the Argos PTT was modified to send 16 separate data records of 256 bits on each satellite pass using two PTT IDs [14].

Results of the STEM deployment demonstrated that the mooring design, cable design and electromechanical terminations were all reliable. The test site is located in 2700 m of water and the test period covered the winter months in the North Atlantic. It also was a demonstration of the reliability of the controller electronics and the Argos PTT

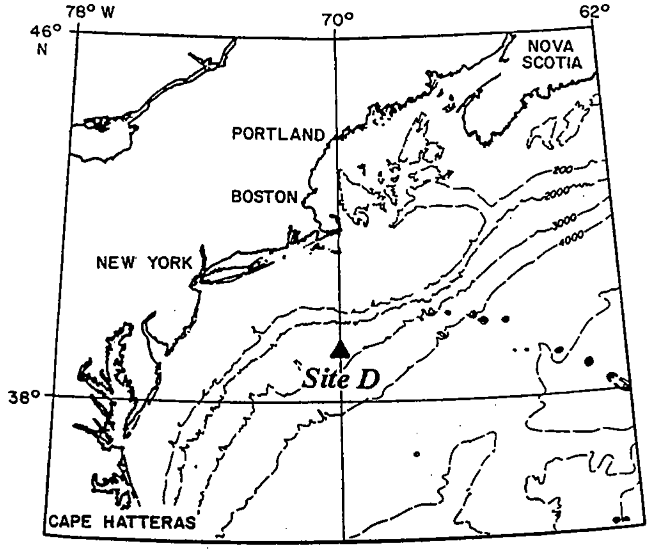


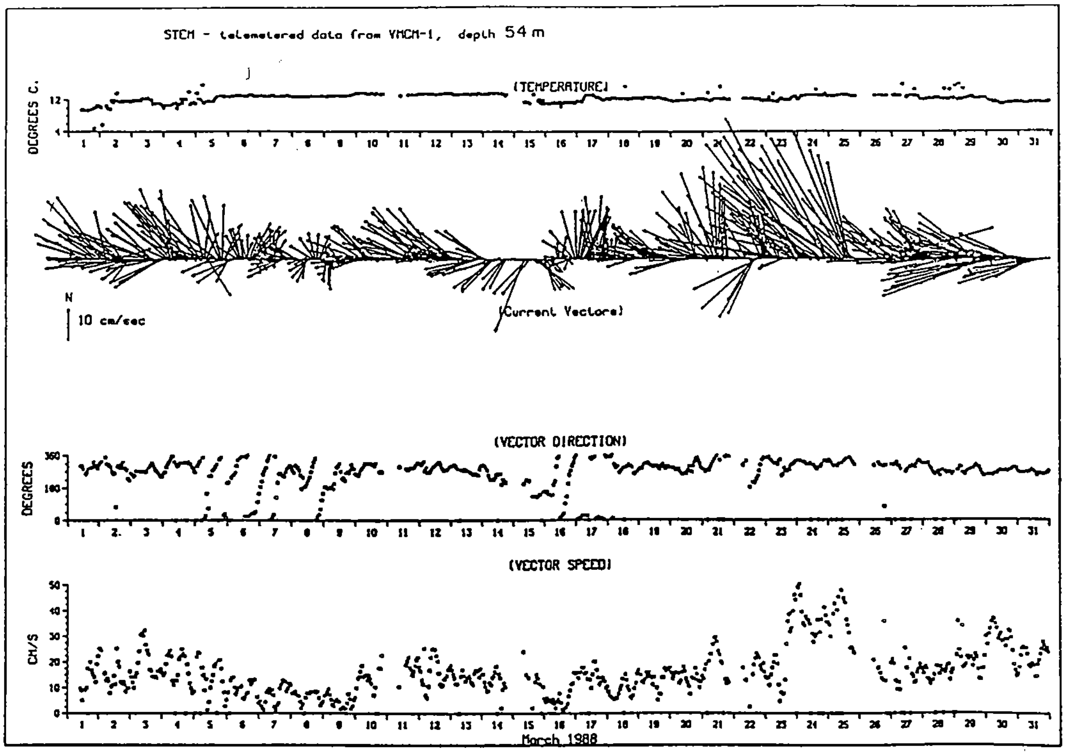
Figure 3: Mooring location of the STEM buoy in the North Atlantic.

modifications. Figure 4 shows an example of the current meter data telemetered in March 1988.

The test mooring was not without problems, however. A wiring error in the E/M cable caused some data to be lost from the lower current meter and a programming error caused the controller to malfunction at midnight on December 31, 1987. In addition, the weather station wind velocity and humidity sensors malfunctioned after two months and two weeks, respectively, and the GOES transmitter failed after only a few days. A trip to the site in a small boat (20 m) was made in February of 1988 to solve some of these problems. The controller and wiring error were corrected in the buoy and these elements functioned flawlessly until the May recovery. The wind velocity sensor was replaced and it also functioned well. The GOES transmitter problem was traced to the battery power supply and because the data path was redundant to the Argos link, no attempt was made to solve this purely electronic problem.

The Surface Telemetry Mooring design is considered operational at this time, and additional development work is not planned. Woods Hole is prepared to transfer this technology to other researchers or to assist investigators needing telemetry with the technical details necessary to design a reliable surface telemetry mooring.

A second approach to electromechanical moorings has been taken for use in applications requiring a subsurface mooring. In this approach standard subsurface mooring designs are used with the addition of a small surface buoy which houses the satellite transmitter and controller. The surface buoy is slack-tethered to the uppermost subsurface float by a specially configured electromechanical cable. The standard 3x19 wire rope normally used as the strength member for subsurface moorings is replaced by the 3 conductor, double armored cable shown in Figure 5. The tether to the surface buoy uses this same cable, but adds a thick TPR jacket to eliminate kinking of the cable under slack conditions. The key design consideration in the S-Tether concept is to protect the E/M cable connecting the subsurface buoy with the surface buoy. This is accomplished by making the surface



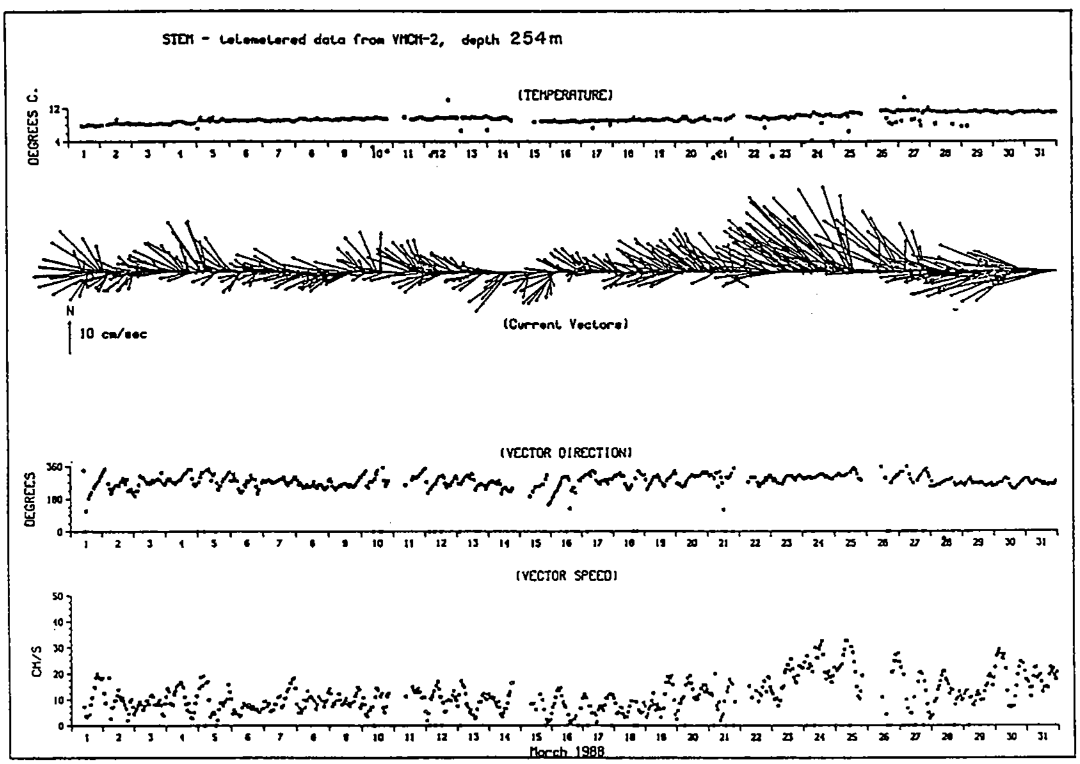
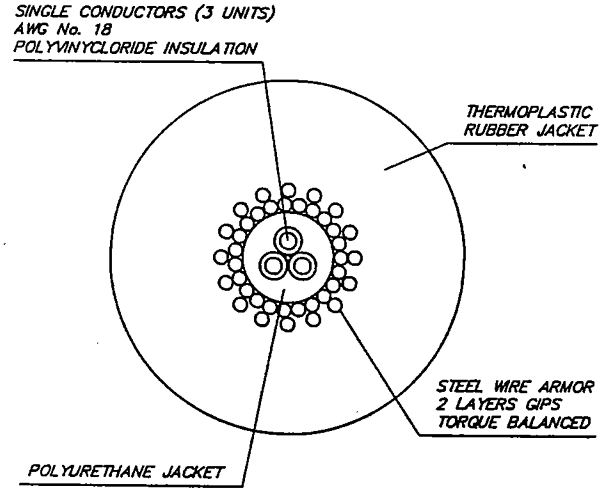


Figure 4: STEM current meter data for the month of March 1988.



NOMINAL O.D.	1.4 in
AIR WEIGHT	741 lbs/Kft
SEAWATER WEIGHT	57 lbs/KFT
MIN. BREAK STRENGTH	10,000 lbs
MAX. WORKING LOAD	1,600 lbs
MAX. PEAK LOAD	2,000 lbs
MIN. BEND DIA	60 in
SPECIFIC GRAVITY	1.08 at 0 PSI

Figure 5: Electromechanical cable used to moor the Tethermoor system offshore Bermuda in 3000 m of water. The outer jacket of TPR is used only for the tether between the surface buoy and the uppermost subsurface buoy.

buoy as small as possible to keep the forces on the tether as low as possible, by installing bending strain relief boots at both tether terminations to protect the cable from small radius bending, by installing a combination of negative buoyancy and positive buoyancy on the tether to help absorb wave energy, and by jacketing the cable with a thick jacket to prevent the cable from kinking or twisting on itself.

After performing a year of testing at a shallow site near Woods Hole, an operational mooring (Tethermoor) was installed in 3000 m of water offshore Bermuda in March, 1989. The mooring configuration is shown in Figure 6. Current meters were installed at 100, 1000, and 3000 m nominal depths. In addition, tension, pressure and acceleration were monitored and internally recorded just below the subsurface buoy at 100 m and tension below the surface buoy was telemetered. The surface buoy contained a system controller (the same type as the STEM mooring), an Argos PTT configured with 16 data buffers and a rechargeable battery power supply. Energy was provided by three, 10-watt solar panels which charged two Gates cell lead acid batteries. The buoy was made from a rigid PVC foam cut into thin disks and glued together over an aluminum frame [15]. It has a displacement of about 510 kg and weighs about 210 kg when fully loaded with instruments and batteries.

While deployed, the controller polled each current meter four times per hour, performed a vector average and transferred the data to the Argos transmitter on an hourly basis along with various engineering data on cable tension, cable continuity, battery voltages, solar panel voltage and current, and other housekeeping data. Figure 7 illustrates some of the telemetered data from Tethermoor during March 1989.

The initial test of the S-Tether design was a partial success. The mooring was deployed in

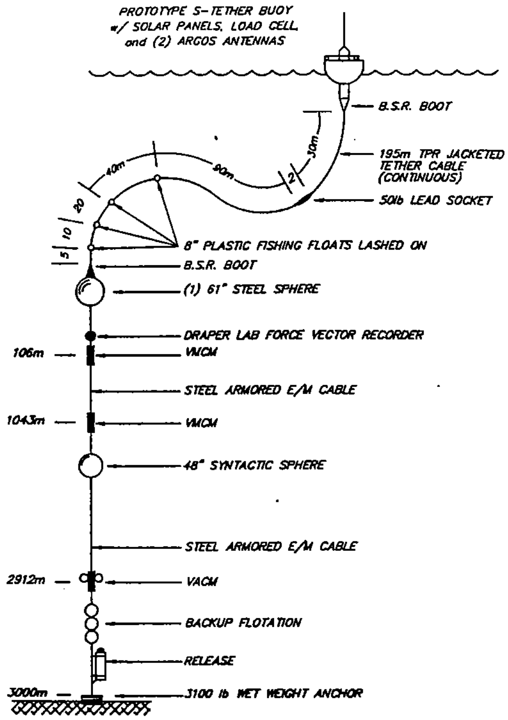


Figure 6: Tethermoor mooring deployed offshore Bermuda from March 4, 1989 to August 22, 1989.

early March 1989. Several problems occurred in the initial two weeks. First, the VACM near the bottom stopped responding to data requests shortly after deployment. This problem was later determined to be in the software on the FSK modem board, a design which has subsequently been modified and used successfully on another project. Second, about two weeks after deployment a period of strong surface currents caused the surface buoy to be pulled under the surface. This caused a loss of data during submersion, but surprisingly did not immediately cause any other problems and when the currents decreased, the buoy resurfaced and continued transmitting. The mooring was designed to operate with surface currents up to 50 cm/sec. When the surface buoy submerged, currents at the upper current meter (now at about 200 m) were 40 cm/sec and increasing (see Figure 7). Based on these real-time data and the fact that the solar panels and one of the two Argos antennas were not protected from pressure effects, a short cruise to the site was organized to move the mooring into slightly shallower water. It was later determined that the mooring was deployed about 50 m deeper than designed. To alleviate the problem, the mooring was towed about 0.5 Km up the steep bottom slope toward Bermuda using the surface buoy as the towing point and dropped in water about 50 m shallower. Subsequent analysis of data from the pressure sensors in the uppermost current meter and the Force Vector Recorder located below the subsurface buoy documented the fact that the subsurface buoy was now at about 100 m (under slack current conditions) as designed. Since the tether to the surface buoy had a 2:1 scope, i.e., it was 200 m long, a change in the nominal depth of the subsurface buoy of 50 m represented a major change in the mooring's response to strong currents.

The towing operation solved the submergence problem and good quality data were telemetered from the upper two current meters during the course of the next 5 months. The mooring was in the path of Hurricane Dean which hit Bermuda on August 6 and 7

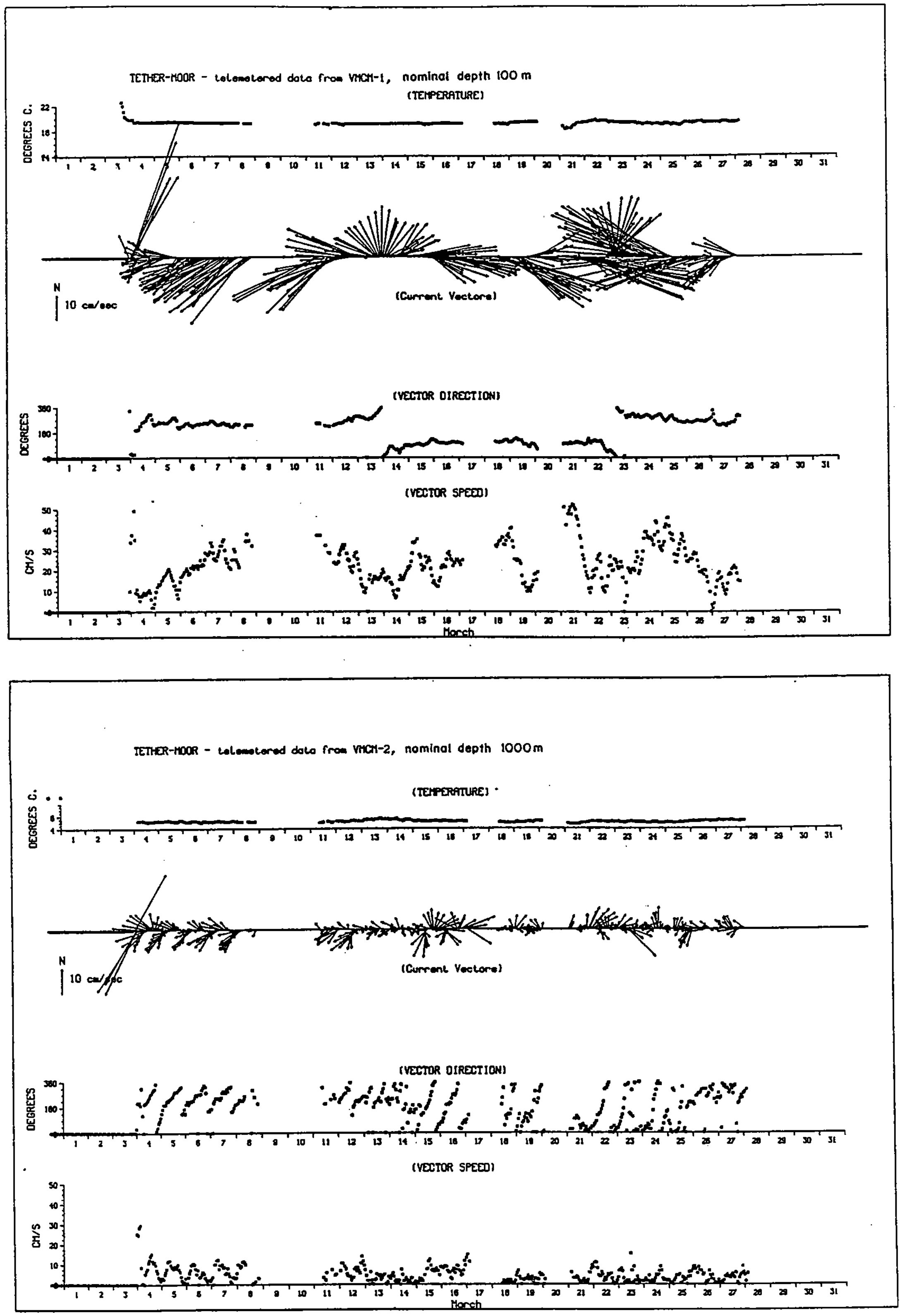


Figure 7: Current meter data from the Tethermoor mooring in March 1989. Data gaps occurred when the surface buoy was submerged.

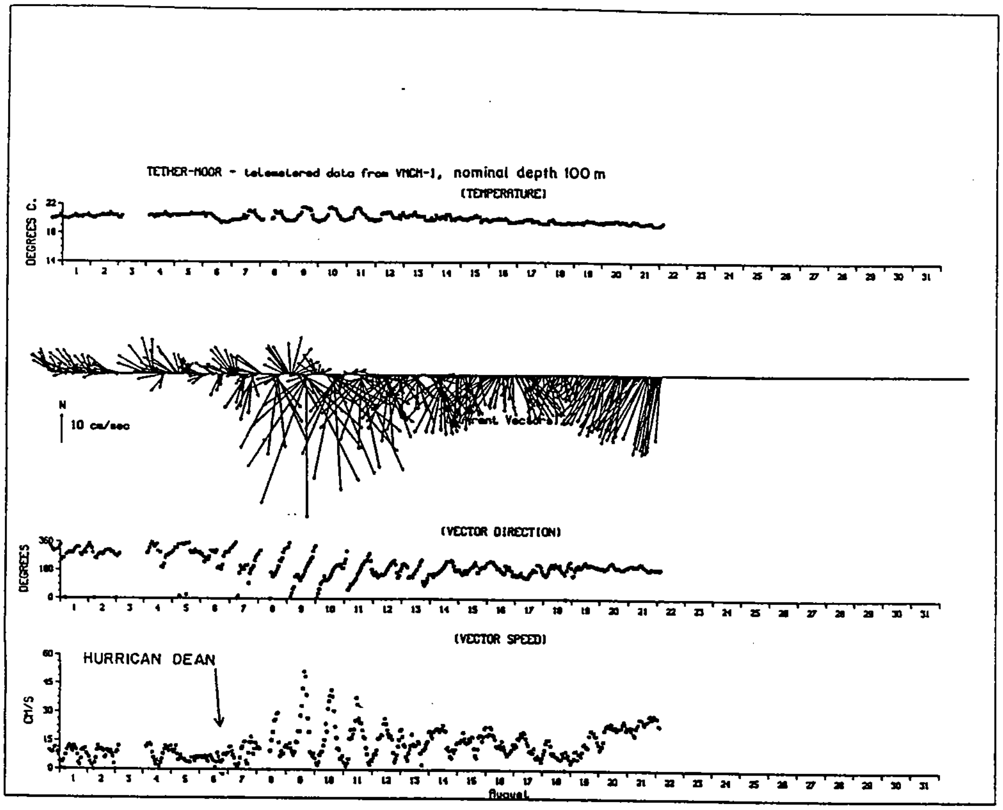
(Figure 8). Winds were reported to be as high as 100 knots on the South Coast. The mooring survived these severe conditions, but parted several weeks later just below the upper current meter, and the surface buoy, upper subsurface buoy and upper VMCM went adrift. These elements were retrieved by the Biological Station's vessel a few days later using the Argos derived positions. Subsequent analysis showed that the mooring failed due to corrosion of the E/M cable below the upper VMCM where a cut in the polyethylene jacket exposed the armor wires to the water [16]. Corrosion at this point was accelerated because the armor wires were in electrical contact with the stainless steel body of the connector located two meters above the cut in the jacket. Contact occurred because of a breakdown in the material separating the armor from the fitting. Cause of the cut in the jacket is unknown, but it may have happened prior to deployment.

Further examination of the mooring after retrieval pointed up two additional problems. Most importantly, the bending strain relief boot below the surface buoy showed signs of stress where it was attached to the buoy. This attachment carries no mooring tension, but it does see bending strain when the cable pulls at an angle and this could lead to failure of the tether at this critical juncture. It is suspected that this failure mode has been experienced by a second S-Tether mooring deployed in August 1989 (prior to the Tethermoor failure) in the Pacific. The Pacific mooring has not been retrieved, but telemetered engineering data on tension and cable continuity are consistent with this failure mode. As a result, the boot at the top of the mooring is presently undergoing a major redesign.

Acoustic Telemetry Techniques

A second general approach to telemetering data from in situ instruments is to use the water as the communication channel between acoustic transmitters at depth and a receiver near the surface. Under the direction of Josko Catipovic, WHOI has developed an acoustic telemetry system with the preliminary specifications shown in Table 1. It has been described in more detail in several papers [17], [18], [19] and is being developed commercially by Datasonics, Inc. A major operational test of the system is scheduled to begin in late April 1990 and is described later in this paper.

The system has been designed so that it can be operated by polling a number of remotes from a single master receiver or in a random access mode where a number of remotes transmit on an individually determined basis. The hardware is compact and relatively inexpensive (Figure 9); in fact one version has been prototyped in a package only 3.5 cm in diameter by 15 cm long including battery and transducer and is meant to be inserted into fish for acoustic tracking purposes [20]. It is anticipated that versions may eventually be installed in existing instrument cases, using power from the instrument's battery, with the transducer attached to the instrument end cap. Other potential uses for the link include Remotely Operated Vehicle (ROV) control and communication systems, drifting buoy applications, fish and marine mammal tracking, and bottom mounted control and data links for installed instruments and machinery. Baud rates up to 4800 bits per second have been achieved over both vertical and horizontal paths of a kilometer. Ranges up to 5 Km and beyond are anticipated in the near future.



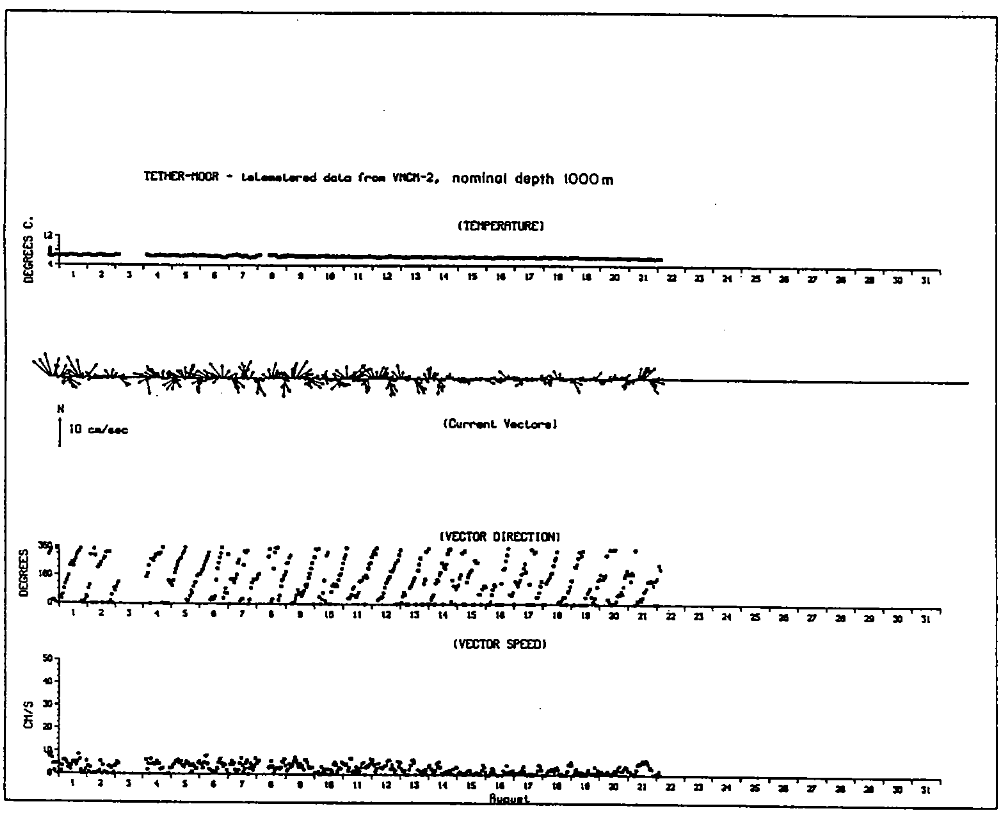


Figure 8: Current meter data from the Tethermoor mooring in August 1989 showing the current response to the passage of Hurricane Dean (Aug. 6, 7). Strong inertial currents appeared two days after the hurricane and decayed over the next four days.

Figure 9: Acoustic modem packaged for long term, deep ocean application.

Table 1
Preliminary Acoustic Link Specification

	Remote Transceiver	Master Transceiver
Frequency	15-20 kHz (data) 12.7 kHz (command)	15-20 kHz (data) 13-14 kHz (command)
Modulation	16 tone MFSK (data) FSK (command)	up to 256 tone MFSK (data) FSK (command)
Data Rate	up to 1200 bps (data) up to 100 bps (command)	up to 4800 bps (data) up to 100 bps (command)
Range	5000 m	5000 m
Acoustic Power	186 dB	186 dB
Size	10 cm diam. x 25 cm long (electronics and transducer)	15 cm diam. x 30 cm long (electronics)

The key element of the acoustic telemetry link is the use of MFSK modulation in conjunction with high speed digital signal processing techniques to decode the data. Rather than sending data using an FSK signal where two frequencies represent 0s and 1s in a binary data stream, data are encoded into a large number of frequency bins and transmitted

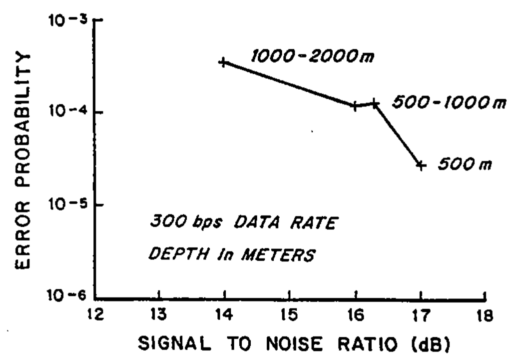


Figure 10: Test results of vertical data telemetry using the 1200 baud modem in conjuction with an omni-directional receive hydrophone and error correction coding.

simultaneously. Multiple FSK allows much higher data rates than a one-FSK system because many bits are transmitted in the time it takes a one-FSK system to send a single bit. The MFSK technique makes use of advances in the computational speed of microprocessors and newly developed digital signal processing chips. In order to transmit the MFSK signal, digital data are encoded into a set of frequencies. These frequencies are then converted into an analog waveform which is transmitted by the acoustic transducer. The receiver recovers the analog waveform, digitizes it, computes an FFT on the result, and decodes the data based on the frequencies observed. In the case of the 1200 baud system, a 68HC11 microprocessor in the remote unit is used to create the transmitted waveform containing 16 frequencies which are transmitted as a single acoustic signal for 12.8 msec. At the receiver, this 12.8 msec tone is digitized at 20 kHz forming a time series of 256 points and an FFT is computed. In fact the receiver, which utilizes an AT&T DSP32C chip to perform the FFT, can generate tones with up to 256 separate frequencies and can decode data at speeds up to 10,000 bps.

In order to determine the reliability, error rates and range of the acoustic link, a major emphasis has been placed on testing the equipment in the ocean. Figures 10 and 11 are reproduced from [21] showing the results of some of the dockside and deep water tests performed to date. In April of this year a major test of the long term performance of the vertical link is planned for waters 3000 m deep off the coast of Bermuda where a mooring of opportunity is being used to support both the remote units and the master receiver. The test configuration is shown in Figure 12 and a block diagram of the basic elements of the system is shown in Figure 13. A controller similar to those deployed in the hardwired applications will be used to initiate requests for data several times per hour from each remote using a SAIL protocol. In addition, each remote will initiate its own message every hour using a Tattletale computer from Onset Computer, Inc. to both time the transmission and collect data on temperature and pressure. The acoustic modems are designed to operate at very low quiescent power by going into a sleep mode between transmissions. They can be powered up either by a local controller such as the Tattletale or acoustically using a command receiver similar to those used in acoustic releases. This command receiver decodes a low baud rate FSK signal from the surface unit and turns on the remote unit only when the correct address has been decoded. This allows a number of remotes to be polled individually by a single master.

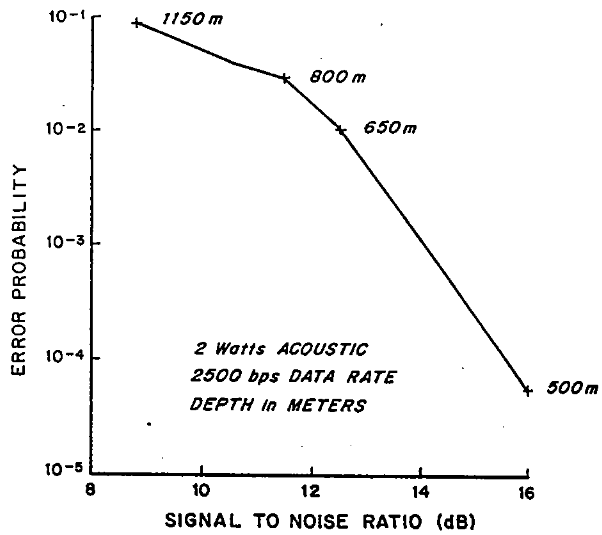


Figure 11: Test results of horizontal data telemetry using the 4800 baud modem with an omni-direction receive hydrophone and a rate one half convolutional code.

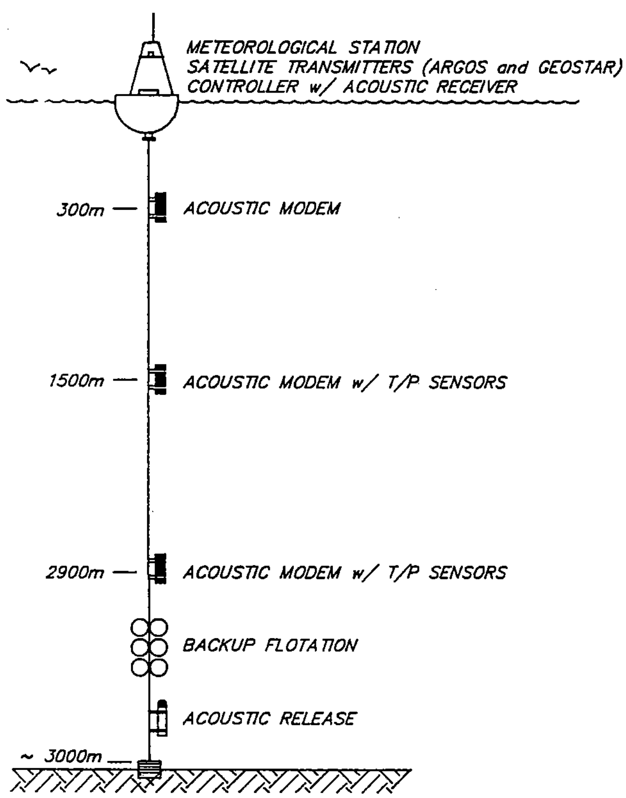


Figure 12: Acoustic telemetry test mooring to be deployed offshore Bermuda in 3000 m of water in April 1990.

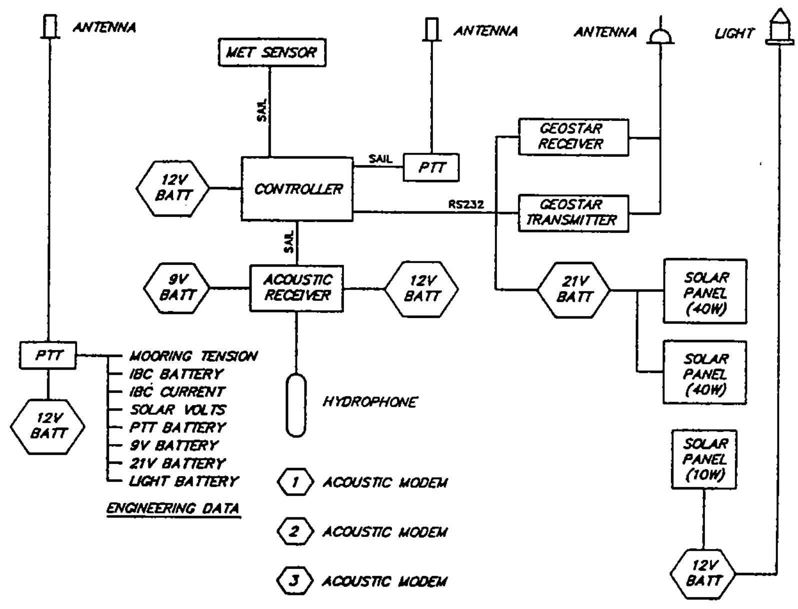


Figure 13: Block diagram showing the main elements of the acoustic telemetry system to be deployed offshore Bermuda in April 1990.

Testing done to date indicates that reliable operation of the vertical link at baud rates up to 1200 bits per second can be achieved with energy levels of about 0.01 joules/bit or better over ranges of 1500 m. These results were obtained using non-optimal receiver hydrophones. Improvements in hydrophone design, primarily directivity and baffling to reduce the level of surface noise, are being implemented and are expected to provide an improvement in range of from 3000 to 5000 m. The April deployment is designed to answer this critical question and to see how error rates vary as a function of sea conditions. For the purpose of comparison, a standard Argos PTT draws about 120 mwatts average power and transmits about 2000 bits/day of information to shore. This works out to about 0.023 bps or 5 joules/bit. Of course the Argos PTT actually sends about $4x10^5$ bits/day so each transmitted bit actually requires only about 0.02 j/bit; still at least as much power per bit as the acoustic modem.

As a point of interest, a Geostar transceiver will be used as one of the satellite telemetry methods employed on the April deployment. Geostar is a commercially available two-way satellite communication link which has been developed for use in the transportation industry [22]. We are planning to use the satellite downlink to initiate an acoustic poll from our Woods Hole laboratory. The data request will be processed on the buoy and relayed to one of the three remote units on the mooring. The response will then be decoded and passed back to the Geostar transceiver. It will then transmit the response received from the remote unit back to our lab in near real time via the satellite uplink. These Geostar polls will be in addition to polls generated locally by the buoy controller. The interfaces required to achieve the satellite polling are still under development at this stage and may or may not be ready in time for the April deployment.

Inductive Modem Approach

A third general technique being investigated to transfer data from in situ sensors to

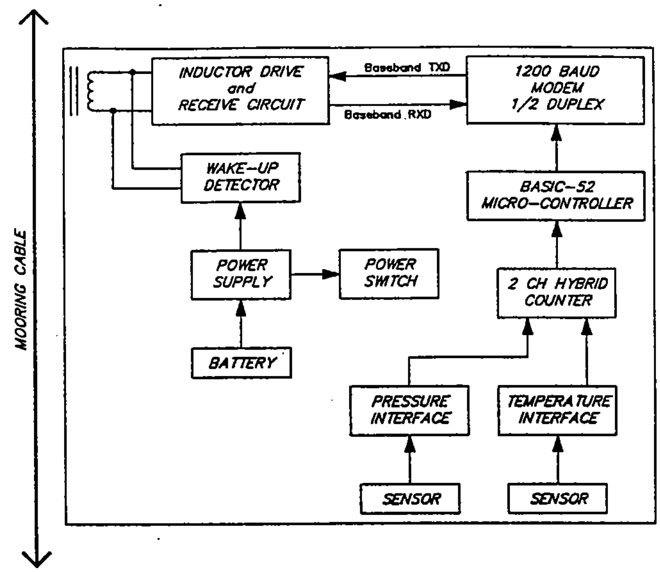


Figure 14: Block diagram of the inductive modem.

surface satellite transmitters is the inductive modem approach [23]. This technique makes use of the fact that standard jacketed 3x19 wire rope can be used to transmit electrical signals along a mooring using seawater as the electrical return. Small holes or cuts in the wire's insulating jacket increase signal attentuation, but not to the point of blocking the signal [24]. A detectable signal is induced in the mooring wire by placing a ferromagnetic core around the wire and inducing a fluctuating magnetic field in the core. This is done by putting a number of wire turns on the core and applying a fluctuating voltage to these wires. Energy transfer efficiency is low, perhaps 0.1% or below [25], but noise levels and cable attentuation are also low and the signal can be detected thousands of meters along the wire.

This idea, which has been used a number of times before, is being pursued because it offers a low cost alternative to hardwired or acoustic systems. It is particularly advantageous where a large number of sensors may be installed on the wire (towed array for example), in expendable systems with telemetry (drifting buoy with thermistor chain) or for expendable telemetry moorings. It is being designed in anticipation of low cost, clip-on sensor modules for ocean moorings, which are in fact being developed for temperature and pressure at WHOI [26].

The design approach for the inductive modem is to make use of single chip modems developed for the telephone industry. This has been possible because typical steel mooring cable has a frequency versus attentuation response quite similar to twisted pair telephone cable and as a result the frequencies used in the modem chip are compatible with standard 3x19 mooring wire [27]. Figure 14 is a block diagram showing the preliminary design of the inductive modem. Like the acoustic link, the inductive link is two way, operating in a SAIL-like mode with unique addresses at each of a number of remotes. It operates at 1200 bits per second in each direction and has a low power sleep mode which is used to reduce power consumption between transmissions.

The toroid which fits around the wire is made in two pieces so that it can be clamped around the cable wherever a sensor is required. Figure 15 is a drawing of the toroid, clamp, and end cap attachments for the modem/sensor pod. The initial test configuration for this system will incorporate an inductive modem with toroid, temperature and pressure sensors

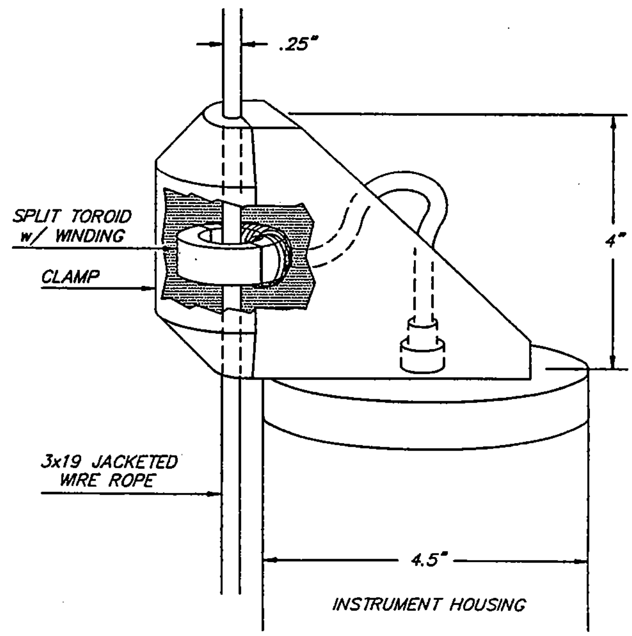


Figure 15: Inductive modem split toroid, clamp and pressure housing.

with sampling and digitizing electronics, and battery supply all housed in a package about 30 cm long and 8 cm in diameter for use on a drifting buoy or mooring without intermediate terminations. The modem at the receiving end of the system will be located in a buoy on the surface and will be hardwired to the mooring cable to enhance signal detection. A design capable of operating on a mooring with numerous terminations has not been developed to date. Table 2 lists the preliminary specifications of the inductive modem. Initial tests have been positive, but results are not yet available on in-water performance.

Table 2
Preliminary Specifications for the Inductive Modem

Frequency	1200/2400 Hz
Modulation	FSK
Baud Rate	1200 half duplex
Power Requirement	200 mwatt active 1 mwatt sleep
Size	30 cm long x 8 cm diameter
Mooring Wire	64 mm jacketed 3x19
Estimated Range	10,000m
Power/Bit	.0001 j/bit

Summary

The Surface Telemetry Mooring has proven to be a reliable method for providing real time data from in situ sensors. It is a general purpose method which can be used in most areas of the deep ocean to provide surface and subsurface operational data. The same techniques can be applied for use with the inductive modem using subsurface instruments that do not require a break in the mooring cable. The surface controller, which is available from a commercial vendor, has also proven to be reliable in the ocean environment on the STEM project as well as a number of other projects at WHOI and elsewhere.

The telemetering intermediate mooring, S-Tether, has shown promise, but modifications to the critical termination at the surface are necessary to ensure long term survival. The ultimate design goal for this mooring is a mean life of 2+ years when equipped with solar panels and reliable long term sensors. A modified tether termination is planned for deployment in the Pacific in the fall of this year which will provide an important test of the new design over a 12-month period in moderately rough conditions. Other applications including real time tomography are in the planning stages.

The acoustic telemetry work at WHOI is proceeding on a broad front. The particular goal of reliable in situ ocean observations and telemetry will be tested this spring during a 6-month deployment of several acoustic modems in 3000 m of water. Our goal in this effort is to eventually have a commercially available acoustic link which is easy to use, inexpensive and power efficient. It is anticipated that an acoustic link with baud rates up to 1200 bps can be achieved over full ocean depth using no more power than a standard Argos PTT. Other applications for the acoustic modems which are being actively pursued include a CTD with acoustic telemetry, a SOFAR listening station with acoustic and satellite telemetry, ROV control and data transfer, video image transmission, small scale tomography, and high baud rate horizontal telemetry.

The inductive modem project is still in the early stages. A prototype modem has been built and tested on the bench but field tests have yet to be performed. These critical tests are planned for this summer using a horizontal test wire deployed in Woods Hole Harbor. If these tests go as anticipated, a full scale deep water test will be conducted, probably in conjunction with an existing mooring of opportunity.

Acknowledgment

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A Low Power 16 Bit A/D Converter Module with Preamplifier, Multiplexer and SAIL Interface

Richard Koehler

A low power 16 bit analog to digital converter module was designed to place the A/D conversion close to the sensor to reduce noise pickup on the sensor leads, and to send the converted digital data on the long wires to the central data collection point. The idea was to provide an inexpensive low power A/D converter near each sensor or sensor cluster to reduce noise pick-up on the low level analog leads by having them short, and to transmit high level digital signals to a remote data collection point. Distances can be several hundred meters.

A multiplexer selects up to 8 inputs from bridge circuits (for thermistors) or voltage inputs from other sensors. On board resistors representing near minimum and maximum temperature can be switched to any input for in field calibration. They can be left connected to two channels for continuous calibration while deployed. A single fixed gain amplifier (to keep it simple) provides the voltage levels required by the A/D converter. A 16 bit triple slope low power A/D converter integrates the signal for 1/60 of a second for noise rejection, and makes the conversion in 0.1 second. The Teledyne low power TSC7652 amplifier and the TSC850 A/D converter are used.

The popular 68HC11 series microprocessor is used to control the multiplexer and A/D converter, to recognize the SAIL address and provide the data when requested. The program fits into the 2 kbyte on chip EEPROM. Al Bradley wrote the software, which makes 8 conversions and sends the data out when requested. The UART built into the 68HC11 drives one of 3 outputs: open collector SAIL (half duplex), CMOS level full duplex, or RS-485 balanced line SAIL (half duplex). It can also be programmed to communicate over the master/slave serial port built into the 68HC11.

The system runs internally on ±5 V , provided by on board low power series regulators. The local regulation reduces locally generated noise, and lowers noise introduced from the outside. Power to the analog portion of the system can be switched off under microprocessor control in order to save power. Current drain during operation is about 12 mA on the positive supply and 3 mA on the negative supply. In standby the current is 2 mA on the positive and 0 mA on the negative supplies, respectively.

The analog pc board and the microprocessor pc board plug together on opposite sides of a central metal support structure, which also acts as an electrostatic noise shield. The boards are 8.9 cm by 6.5 cm, and about 2.5 cm thick, designed to fit lengthwise inside a 10.2 cm ID tube. In other applications, the analog board can be used as a standalone unit with other systems where a controller is present.

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A Software Guide to Using an IBC with VRTX

Ann Martin

Abstract

The Instrument Bus Computer (IBC) developed at WHOI is used to control a variety of oceanographic instruments deployed at sea. Because the computer is available to users from all disciplines at the Institution, a need exists for guidelines to its use. This user's manual addresses the minimum instructions necessary to enable the IBC to collect data and interface with peripheral instruments. The computer, which is housed in a card rack designed to fit into 6" I.D. pressure cases, has an 80C86 CPU and currently uses the VRTX multi-tasking operating system; VRTX has built-in time services for scheduling the collecting of samples from deployed instruments and for transmission of data to external receivers. The guide discusses the computer code which controls the functions of the IBC, and describes how the code is installed in an IBC embedded system. Specifically it provides information on: communicating with the IBC via a monitor; compiling C application code, and linking and locating code; and downloading the code to IBC memory.

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VOICE – A Spectrogram Computer Display Package

A. Martin, J. Catipovic and P. Tyack

Introduction

A real-time spectrogram instrument has been developed to provide an inexpensive and field-portable instrument for the analysis of marine animal sounds. Named VOICE, the instrument integrates a computer graphics display package with a PC-AT computer equipped with an A/D board and a digital signal processing board. It provides a real-time spectrogram display of frequencies up to 50 kHz in a variety of modes: a running display, a signal halted on screen, successive expanded views of the signal. The software has been designed so that a user with minimal computer experience can integrate this tool with a suitable application. VOICE displays both spectrograms and waveform displays in real time on a computer screen. Live animal calls or sounds prerecorded on an analog audio tape can be channeled simultaneously into both an amplifier and the VOICE computer. The ability to see the spectrograms of the sounds at the same time that they are heard greatly facilitates the identificaion of patterns that might go unnoticed when scanning depends solely on the human ear.

Some of the instrument's capabilities are listed below:

Continuously digitize up to 2 analog channels with an aggregate acquisition rate of 100 k samples/sec.

Compute and display in real time up to 2 spectrograms, or one spectrogram and its envelope waveform with a clipping indicator at screen scroll rates up to 7 sec per monitor width.

Halt the screen so that a spectrogram can be viewed as long as desired, or sent to a printer.

Delimit a spectrogram signal with cursors for successive expansions of events too detailed to be examined in real time.

Customize the screen display by controlling the sample frequency, setting the number of points per transform, setting the interval between time ticks marking the elapsed time for the data to scroll across the screen, modifying the levels at which colors change, and modifying the color spectrum.

Save delimited segments of digitized data to disk. The maximum save buffer length is 384 kbytes.

Replay spectrogram data which has been saved during an earlier session.

The hardware unit consists of a PC-AT with an EGA display and hard disk, an analog-to-digital (A/D) converter board and a digital signal processing board. The cost is low compared to commercial spectrogram machines. The package was tested on a number of portable PC's (such as the NEC PowerMate Portable), which are well suited for field instrument use. This allows powerful signal processing and data acquisition capabilities to be brought into the field at modest cost.

The instrument development was motivated directly by the need of WHOI biologists to scan extensive analog data sets of marine mammal vocalizations, where the goal is to extract digital representations of exemplary marine mammal calls. It is difficult for many researchers to afford the spectrogram analysis workstations that are available commercially. In any case, such instruments are not suitable for field use, particularly in the remote locations frequented by WHOI researchers. The developed package allows for efficient data analysis and acquisition capabilities by Institution researchers at a reasonable cost, and thus contributes to their overall observational capabilities.

System Overview

The main hardware element is a PC-AT compatible personal computer with either an 80286 or 80386 CPU. The PC Intel 80286 or 80386 CPU is used as the display and storage controller and system supervisor. Display on a compatible monitor uses the EGA graphics standard with 640x350 pixel resolution.

The VOICE spectrogram uses the SKY321-PC fixed-point (integer) digital signal processor, which includes the Texas Instruments TMS32010 digital signal processing chip as the numerical engine. As the data memory is double ported, it can be accessed simultaneously by the PC and the TMS320. An efficient memory controller can accomplish simultaneous accesses with only occasional wait states issued to the PC or the TMS320. This efficient memory management scheme was the primary motivation for selecting the SKY321-PC add-in board. The analog data is acquired and digitized by the MetraByte DASH-16 A/D board at acquisition rates of up to 100 kHz.

For spectrograms to be displayed in real time along with an audio signal, a fast scrolling and processing rate is critical; details of the spectrogram would be lost without this turnaround speed. To achieve this during real-time mode, there are three independent subsystems operating: the DMA activity, the CPU data transfer and screen display routines, and the TMS320 numerical data processing. Care was taken to balance the load between the TMS and the Intel 80286 processors; the efficient coupling of these two processors largely determines the ultimate speed of the real-time display and the usefulness of the spectrogram. The 80286 is concerned primarily with data formatting and display, the TMS with the numerical routines.

To reduce acquisition overhead, the A/D board is used in a continuous DMS mode, where a circular buffer is repeatedly loaded with newly acquired data. Up to 384k (six 64k pages) of memory storage is made available to the acquisition DMA, and it is continuously filled with the data. The DMA is redirected to a new page after a terminal count (TC) is received upon completion of a page. The TC is wired to a system interrupt; the interrupt routine assigns a new DMA page to the data acquisition buffer, and updates the buffer list. Only one instruction is required to reassign a page: only the page register needs to be modified. The principal advantage of this scheme is the availability of a relatively large buffer, with no requirements for external memory cards. The CPU polls the DMA IC for the most recently written address and downloads the most recently written data segment to the TMS. When signal editing mode is entered, the DMA activity is stopped, and the memory buffer referenced from the last address written. This method is relatively simple to implement, and guarantees that there will be no lost samples, since the DMA is writing continuously. This allows for work on complex data sets, such as high bandwidth dolphin vocalizations or long whale songs.

The PC transfers the data between the circular data buffer and the TMS320. The TMS320 operates on a data buffer downloaded to its memory and outputs a flag signifying that a completed data buffer has been placed at a predetermined location in its memory. The location of the input and output buffers is controlled by the PC microprocessor, which implements a double buffering scheme so that a set of output and input buffers is manipulated by the PC while the TMS320 is operating on a distinct set. The buffers are flip-flopped at each frame.

A sine table and the appropriate program are downloaded to the TMS320 at system initialization. A library of programs is available, reflecting such parameters as the number of channels to be processed simultaneously, the display complexity and color maps, and the data buffer/FFT size. The PC microprocessor selects the appropriate program based on the configuration parameters. The TMS320 programs are written in TMS320 assembly language and carefully optimized, as their execution can be a significant bottleneck to processing speed. While the processing program is runnning, the TMS is stopped briefly by the PC once per data frame in order to update the input/output buffer locations for the next frame.

Program Structure

The software was developed within the MS-DOS 3.2 operating system using Microsoft Version 5.0 C compiler and Microsoft Macro Assembler Version 4.0. The Version 5.0 C compiler was used specifically to take advantage of the graphics functions which were introduced at this version level. In addition, routines unique to the SKY signal processing board are integrated into the VOICE software structure. The SKY321 environment includes a host-resident SKY321 macro operating system, a SKY321 macro preprocessor, and a SKY321 assembler.

The primary functions of the main program are to control interaction with the users via the initial command line and the keyboard; output processed data to the screen and, optionally, to save raw data to a disk file; and to accept and transfer data addresses. In the initialization section, the program also loads program and data files to the TMS board and turns on the digitizing card.

The CPU controls all output to the monitor. The EGA driver is accessed directly with register commands; a fully register-compatible graphics subsystem is required. To address the hardware through DOS interrupts would reduce the display speed at least threefold, rendering the system useless for practical bioacoustic analysis. Significant effort was spent to insure careful optimization of the video routines.

The dimensions of the displayed screen affect the rate at which the image crosses it, so dimensions were chosen to facilitate screen speed and to allow sufficient space for annotations on the margins of the screen. The EGA map allows for a screen display of two windows, each with 128 pixel rows, one above the other, along with system configuration information. The writing of pixels directly to the EGA video RAM is a two-step operation. When each 256-point array has been returned to main memory from the TMS board, with each element of the array coded for color, half the array (128 points) is sent as a column of pixels to the righthand end of the display area, where there is space available for eight pixel columns.

When this group of columns is filled, the entire display is moved left by eight pixel columns, so that the lefthand array set scrolls off the screen, and room is provided on the right to receive new pixel columns of data. The factor 8 was chosen because EGA treats 8 horizontal pixels as a unit; each EGA unit is 8 pixels wide by 1 deep. This characteristic enables smooth scrolling from top to bottom of a display. However, the application for which VOICE was developed required scrolling from right to left, the usual convention with bioacoustic/speech analysis display tools.

The scrolling routine required optimization, as each data point representing a screen pixel must be physically remapped to a new location at each screen scroll. As the screen windows are 128 x 480 bits each, and a screen scroll time represents the time for a single pixel to move across all 480 columns, the screen scroll routine could be a system bottleneck. Fortunately the EGA standard provides for a 32-bit (8-pixel) move with a single (block move) instruction, and this allows the screen to be scrolled in three seconds when there is no other system activity on an EGA system with no wait states at 10 mHz operation.

The screen write commands are not as critical as the scrolling. The bit-mapped data are written to the screen with direct register command, and the stationary information outside the windows is handled through the high level graphics library provided with the Microsoft Version 5.0 C compiler. These screen annotation functions are used to display cursors, draw and fill color-coded boxes, and to write prompts and data values to the screen margins surrounding the spectrogram display.

Interaction between the PC and the SKY321 occurs on two levels, through programs executed on the PC, and through those executed in the SKY board. Main program VOICE executes SKY321-PC routines hsmos.def, a definitions and addresses file, and hsmos.h, a C program for control of I/O to the SKY board. The hsmos routines are executed by the host C program; the file hsmos.h includes functions which start and stop TMS processing and transfer data between the TMS and the PC.

SKY Computers also supplies a library of functions, including signal processing routines, and a data file which is a sine table for all transforms up to 1k. The data file and the appropriate function are downloaded to the SKY board at initialization. The program remains active in the SKY board throughout a session, repeatedly processing data sent to it from the PC, and returning the output values on command from the main VOICE program.

The SKY library function used by VOICE is FT256, a complex Fast Fourier Transform. The functions are written in TMS320 assembly language. In order to optimize the division of processing resources between the PC and the SKY board, code to find the magnitude square of the FFT values and to assign color codes to the processed data was added to the SKY library function instead of being part of the main program on the PC. Values then returned to the PC from the SKY board could immediately be sent to the EGA display without further processing. Two versions of the FFT library function were adapted, one for single channel display, the other for display of two channels.

Operation of the digitizing card is controlled by a group of C functions from the main program. They turn the digitizer on or off and read the last address accessed by the CPU's DMA. Input data are sent directly from the DMA board to the SKY board, with the main program VOICE specifying the addresses of the input buffer and the TMS buffer. The digitizing card and the TMS board thus are coordinated so that data values are transferred to the main program only once – when they are ready for display.

Future Development and Applications

The VOICE program, which initially was developed to answer a specific need, has evolved into a versatile tool for a growing number of applications. At present the program can display up to two channels of data. The program already has the "hooks" to add the capability of a four-channel display. Sampling frequency is now limited to a maximum of 50kHz by the A/D board; since the rest of the system can handle up to 100kHz, this constraint could be removed by use of a different A/D input board and the replacement of the present data acquisition subroutine in the software package. Presently the largest section of data that can be saved with a single command is 384K (six 64K pages), but subsequent saves can append data to the same file. With the addition of extended memory to the PC and some changes in the code, a larger section of data could be saved in a single operation. These are a few possibilities for expanding the capabilities of VOICE. In the short time that it has been available to WHOI investigators, we have made a number of adaptations, some as simple as changing the defaults. We encourage potential users of the system to use VOICE in its present form, or to adapt it to different PCs or boards.

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Surface Waves and Wave-Related Processes

R. Singer

A group of physical oceanographers at WHOI, led by Robert Weller, are investigating the role of surface waves and wave-related processes, such as Langmuir Circulation, in the upper ocean layer. In particular, they are studying how these waves and processes affect the vertical structure and temporal variability of the velocity and density fields in the upper ocean. In order to provide measurements of sufficient vertical and temporal resolution for this task, the investigators decided to enhance the communication capability of Vector Measuring Current Meters (VMCMs). The goal was to enable 20 VMCMs to deliver data to a MASSCOMP MC5600 computer every 2 seconds, for real time data acquisition and display.

We determined that each VMCM needed the capability of telemetering its data at 9600 baud over up to 200 meters of sea cable. To accomplish this objective, we designed an additional circuit board for the VMCM, to acquire data serially from the current meter at its maximum speed of 300 baud, and off-load it at 9600 baud in response to a SAIL query over an EIA-485 link. The board is based on an MC68HC11A2 microcontroller (with an on-chip UART) operating at 921.6 KiloHertz. It also contains a second UART(82C50), a low-power EIA-485 transmitter and receiver made up of discrete components, and a jumper block for setting the SAIL address. To maintain consistency with VMCM's which use an FSK circuit board for communication, the High Speed Buffer Board (HSBB) CMOS serial interface uses the same backplane modifications as the FSK card, which do not interfere with the VMCM's use as a 20 mA current loop device.

The microcontroller firmware is contained in the 68HC11A2's 2 kilobytes of on-chip EEPROM. It was written and assembled on an IBM-PC compatible computer and downloaded to the 68HC11 through a Motorola Evaluation Module using the Motorola S19 file protocol. Implementation of the SAIL synoptic set command allows the SAIL controller to command all VMCM's simultaneously to freeze a data buffer in preparation for transmission when addressed individually. Triple buffering was used to ensure that no data would be lost when the two second interval of the VMCM data stream and the two second interval of the SAIL controller queries were skewed in relation to one another.

We also designed a resynchronization module to offset the drift between the VMCM clock and the clock in the central SAIL controller. In response to a SAIL command, the 68HC11 resets the VMCM, which allows the SAIL controller to simultaneously resynchronize all the VMCM's in a given experiment at any time. During laboratory tests and a one week test cruise on R/P FLIP, it was determined that resynchronization every 12 hours is sufficient to acquire synchronous data using the MASSCOMP MC5600 as SAIL controller.

The EIA-485 interface provides a useful multipoint communication method for data transmission over long cable lengths. The EIA-485 circuit on the HSBB was designed specifically for low power operation. There are EIA-232 to EIA-485 converters available commercially which run on A.C. power and these were used to interface the MASSCOMP's serial ports with the VMCM's and other SAIL instruments.

The power consumption for the HSBB is 10 milliamps. Since the VMCM transport card and tape recorder can be removed when the HSBB is used, the power consumption of the

VMCM in this mode averages less than 20 milliamps. A VMCM battery stack provides on the order of 168 Amp-Hours, which allows a deployment of 6 months using only half of the battery capacity.

In order to test the operation of the HSBB's, two test programs were developed. One runs on the Onset Corporation Tattletale Model IV and the other is for use on an IBM PC compatible computer. A report is being prepared which provides the details necessary to operate a VMCM with an HSBB and to use the test programs to verify proper operation.

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The Advanced Engineering Laboratory of the Woods Hole Oceanographic Institution is a development laboratory within the Applied Ocean Physics and Engineering Department. Its function is the development of oceanographic instrumentation to test developing theories in ocean physics, and to enhance current research projects in other disciplines within the oceanographic community. This report summarizes recent and ongoing projects performed by members of this laboratory.

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