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Woods Hole Oceanographic Institution

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Advanced Engineering Lab
Project Summaries 1991

by

Daniel E. Frye, Editor

January 1993

Technical Report

Funding was provided by the Department of Applied Ocean Physics and Engineering at Woods Hole Oceanographic Institution.

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Approved for Distribution:

George V. Frisk

George V. Frisk, 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 development of oceanographic instrumentation to test developing theories in oceanography, and to enhance current research projects in other disciplines within the community. This report summarizes recent and ongoing projects performed by members of this laboratory.

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A LONG-TERM EVALUATION OF NEW MOORING COMPONENTS AND UNDERWATER TELEMETRY TECHNIQUES

Alessandro Bocconcelli, Henri O. Berteaux, Daniel E. Frye and Dr. Bryce Prindle

ABSTRACT

An Engineering Surface Oceanographic Mooring (ESOM) program was initiated in 1989 by the Woods Hole Oceanographic Institution for the purpose of evaluating the long term, in situ performance of new moored array materials and sensors.

For logistic and practical reasons, a site 12 miles southwest of Bermuda, with a water depth of 3000m was selected to deploy the mooring. Following well established design practice, the upper part of the mooring down to a depth of 1900m was made of plastic jacketed, steel armored wire ropes and cables. Groups of test samples were attached at different depths to the main mooring line. The lower part of the mooring was made of compliant, plaited nylon rope.

The mooring was deployed in March 1989. It was recovered and reset, with a vertical acoustic telemetry prototype system, in April 1990. The at-sea phase of the program ended in November 1990 when the termination of a test cable failed and the mooring broke loose. The entire mooring was recovered and all of its samples and components were carefully inspected and tested. In addition to the novel acoustic link, mooring components tested included new wire ropes, new electromechanical cables and their terminations, low drag fairings, fishbite resistant jackets, and a new type of surface buoy. This paper describes the experimental mooring and the results obtained after 18 months of exposure.

Funding was provided by Office of Naval Research, Contract No. N00014-90-J-1719 and N00014-86-K-0751.

Published in Marine Technology Society, pp. 848-857, 1991.

MEASURING OCEAN SURFACE WAVES

Erik Bock and Jia Qin Zhang

The Scanning Laser Slope Gauge (SLSG) is a system designed to measure capillary and capillary-gravity waves on the surface of the ocean, and thus to enable study of the micro structure of the surface.

The system includes a laser scanning device, a DE2000 scanner; a head unit, a WHOI-3000 data collection board, and a 386 PC-AT which controls both the laser scan and the storage of received data (Figure 1).

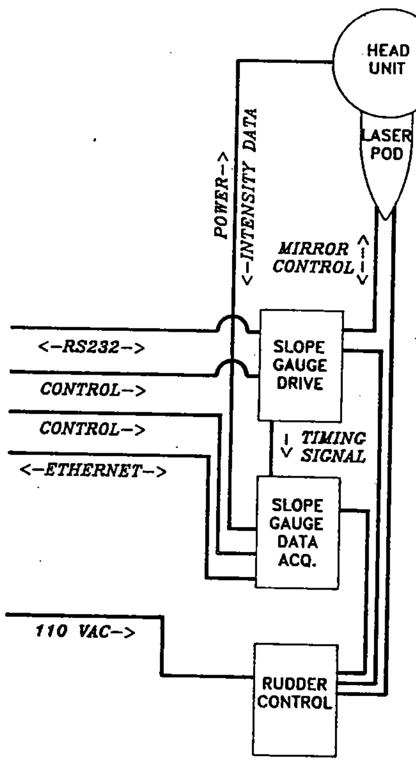

Figure 1: SLSG System Components

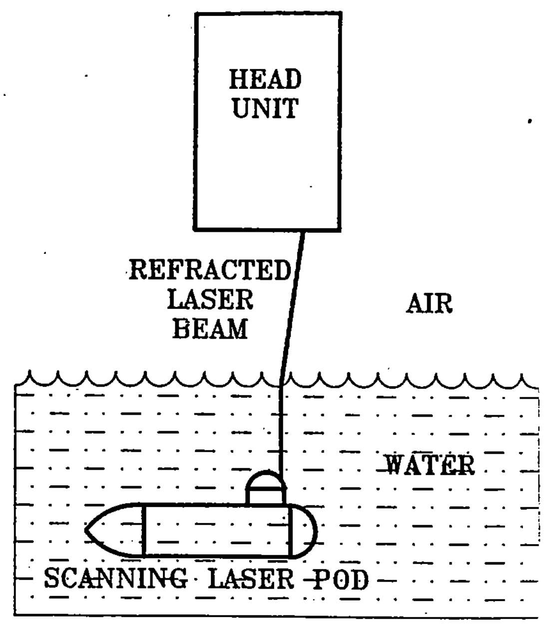

Figure 2: Physical Layout of SLSG

The scanner directs a laser beam upwards from beneath the water surface (Figure 2); the refracted angle caused by the water surface boundary produces the data which will be used to study the waves. The scanning device is controlled by a program on the PC-AT, which can determine the scanning pattern and period, limited by the linearity and dynamic range of the scanner. The scanning speed is about 15 ms per cycle.

The scanning beam is received by the head unit, which includes a set of lenses, a filter, four photodiode receivers, and an amplifier. The amplified beam is then fed directly into an A/D converter (8 bits resolution) on the WHOI-3000 data collection board.

The data collection board has an Intel 80C196KC microcontroller with an embedded program to control the data collection. It samples the wave slope data at a rate of 84.79 microseconds when the laser beam is scanning, and stores the data temporarily in RAM.

At each laser synchro pulse, the WHOI-3000 interrupts the PC-AT, and transfers a data block to it through a Metrabyte interface board via a network cable. The interrupt is given the highest priority on the PC, and a special mask mode is used to mask the interrupts within the service routine so that the timer interrupt can occur at any time; this enables tracking of the real-time clock.

Each transferred data block is 64K bytes long, and is written to one of two data buffers. The other buffer, which contains data from the previous transfer, is written to a disk file. This use of alternating buffers, with data collected and saved at the same time, approaches a system of continuous data collection limited only by the capacity of the recording media. We have found that the data collection rate is more than 16 kbytes per second.

The user specifies the disk driver, virtual or physical, and the program creates files named "XY_POS.nnn", where nnn ranges from 000 to 999. As each file is opened, it is time-stamped with the current DOS time in ASCII 24-hour format. Each file is open for one minute or less. When a file is closed, the new file is named with the next sequential file extension so that in later data analysis the data sequence is continuous.

Funding was provided by the Office of Naval Research under contract number N000-14-J-1717

Published in SPIE Proceedings, July 1992.

A FAST HYDROGRAPHIC PROFILING SYSTEM

Albert M. Bradley, Alan R. Duester and Stephen P. Liberatore

ABSTRACT

The Fast Hydrographic Profiler (FHP) is a fast free-fall hydrographic profiling system developed at Woods Hole Oceanographic for large scale synoptic ocean surveys where the cost of ship station time is significant. It is capable of doing a high accuracy conductivity-temperature-depth section to 5000 meters in only 45 minutes of ship time on station. The instrument travels at approximately 5 meters per second on both descent and ascent. On ascent, it homes toward an acoustic beacon near the ship to minimize the pickup time. A unique suite of support equipment allows rapid, convenient and safe handling. A specialized radio controlled line tug and small A-frame are used to lift the FHP from the water within minutes of surfacing. The data is read out through a simple serial interface during the battery recharge interval. The on-deck turn around time is about 30 minutes which permits very close station spacing.

The entire system can be broken down for air shipment and can be operated by a team of two or three people.

Funding provided by National Science Foundation under contract numbers OCE-83-10168 and OCE-86-12101.

Published in: IEEE Proceedings, Oceans 91, Vol 3, pp. 1246-1252, October 1991.

LOW POWER NAVIGATION AND CONTROL FOR LONG RANGE AUTONOMOUS UNDERWATER VEHICLES

Albert M. Bradley

ABSTRACT

This paper discusses the ultimate limits to the range of conventionally powered deep ocean Autonomous Underwater Vehicles (AUVs). It is intended as an introduction to the unique problems of vehicles designed for the 0.2 to 2 knot speed range. We first present the relationship between range, size, non-propulsion energy requirements and flotation efficiency for vehicles using various common battery technologies. We then demonstrate that, in this speed range, the non-propulsion requirements severely limit the ultimate range. We next discuss strategies for implementing navigation and control systems at power levels of 0.1 to 1 Watt. We present systems which are based on existing technologies in use in various areas of oceanographic research but not generally utilized in the AUV community. Last, we present a design example of a vehicle suitable for economical monitoring of a hypothetical deep ocean dumpsite.

Funding was provided by National Science Foundation under contract No. OCE88-20227

Published in: Proceedings, 2nd International Offshore and Polar Engineering Conference, San Francisco, June 1992.

SURFACE SUPPORT FOR A FREE-FALL HYDROGRAPHIC PROFILER

Albert M. Bradley, Alan R. Duester and Stephen P. Liberatore

ABSTRACT

High-speed, free-falling profilers present problems in recovery. Because they are streamlined for fast operation, they provide little in the way of conventional handholds for recovery. We have developed a practical, safe, and fast method for recovering these vehicles. This method is applicable in other recovery scenarios.

Funding provided by National Science Foundation under contract numbers OCE-83-10168 and OCE-86-12101.

Published in: IEEE Proceedings, Oceans 91, Vol 3, pp. 1253-1257, October 1991.

A SIMPLE LOW COST ACOUSTIC CURRENT METER

Neil Brown

ABSTRACT

This paper describes an experimental acoustic current meter presently under development. The objective of the program is to develop a current meter that is inherently low cost, low power consumption, small and yet is capable of excellent performance, both static and dynamic. The rationale for this development is as follows.

If the science of climatology and oceanography is to advance significantly, it is essential that observations at sea be obtained more frequently and at shorter geographic intervals. The high cost of existing current meters, mooring systems and the ships to deploy them is limiting our understanding of oceanography and climatology. Satellite telemetry has facilitated obtaining data from remote sensors. Hence the oceanographic community is considering expendable moorings, air-dropped moorings and possibly moorings deployed from "ships of opportunity". Regardless of which method is used, current meters must be much less expensive, consume much less battery power, be much smaller, lighter and reliable than existing instruments. It should be noted that the size and weight of current meters adversely effects the size and cost of the moorings and the cost of deploying the resulting system.

Current meters in routine use today have relatively large, expensive electronics and battery packages and have limited operational life. Current meters using mechanical sensors (rotors or impellers) are vulnerable to damage and are easily stalled by marine fouling or flotsam of various kinds. Existing acoustic current meters using two orthogonal pairs of transducers and an acoustic mirror have poor vertical and horizontal cosine response due to flow interaction with the mirror and the struts used to carry the mooring tension around the pressure housing. These instruments also consume excessive power and hence have limited operational life. All of the above instruments use gimballed compasses (magnetometer or mechanical with optical readout) which tend to be fragile, expensive and of limited accuracy.

Existing acoustic instruments transmit pulses or continuous wave bursts simultaneously in opposite directions and then compare the difference in arrival time or phase difference of the received signals to determine the current velocity. They require two receivers, and tend to have errors due to changes in phase shift or time delay differences of the two receivers. Consequently these receivers must be very carefully designed and adjusted to avoid these errors. Typical acoustic path lengths are 10 cm, where an uncertainty of one nanosecond in the measurement of time results in an uncertainty of approximately 1.1 cm/sec in velocity. Hence the pulse type sensor requires two wideband receivers and very fast circuitry to measure extremely small time differences. Williams, in his BASS design, eliminated this particular problem by reversing the receivers and transducers to determine any differences in time delays.

The continuous wave type sensor described by the author eliminated the need for very high speed circuits by heterodyning the two received 1.6 mHz carrier frequency signals to obtain a beat frequency of 34 Hz and by measuring the phase difference at 34 Hz with low power CMOS logic circuits. However, this required a second oscillator phase locked to the first at a frequency difference of 34 Hz. The requirement of two receivers, the second oscillator and the phase locked loop required a substantial amount of circuits, with a corresponding contribution to overall size, cost and power consumption.

The direction sensors in previous designs used either gimballed compass cards with optical readout or gimballed 2-axis fluxgate magnetometers. The compass card design was fragile, expensive and did not have good dynamic response due to inertia of the card and the low magnetic torque inherent in compass cards. Similarly, the gimballed fluxgate designs required jewel bearings to minimize errors due to imperfect leveling caused by bearing stickiness, and this in turn required enclosure in an oil filled chamber to provide damping.

Funding provided by Office of Naval Research under Contract No. N00014-86-K-0751.

Published in: Proceedings, Oceanology International 92 Exhibition and Conference, Brighton, England, March 1992.

MULTIPLE CONVERGENCE ZONE ACOUSTIC TELEMETRY FEASIBILITY TEST REPORT

Josko A. Catipovic, Keith von Der Heydt, Steve Merriam and Geir Helge Sandsmark

ABSTRACT

This report describes a multiple CZ acoustic telemetry experiment conducted off the coast of California 1/28/90 - 2/2/90. The goal was to design a maximally robust high speed underwater modem suitable for data telemetry for submerged platforms and moorings.

Six modulation methods were used to transmit data at rates from 1 to 1000 baud, corresponding to bit rates up to 3 kbit/sec. The modulation formats were:

1. Multiple Frequency Shift Keying (MFSK) and Binary Expurgated Modulation (BEXPERM)
2. Duobinary Frequency Shift Keying
3. Quadrature Phase-Shift Keying (QPSK)
4. 8 Quadrature Amplitude Modulation (8QAM)
5. Continuous Phase Modulation (CPM) 2DPM4 and 2CPFSK4
6. Trellis coded 8 PSK

In addition, a large number of channel probe sequences was transmitted in order to estimate channel multipath, fluctuation dynamics and spatial diversity characteristics relevant to acoustic data telemetry.

The data was transmitted from a 1 kHz source suspended from the R/V McGaw, and received on a multichannel vertical array tended by the R/V Point Sur. The multichannel data was digitally recorded using floating-point digitizers and stored on optical disk for further processing. Approximate transmission ranges were 70, 140, 200 and 250 km. Approximately 8 hours of transmission were recorded at each data range.

Funding was provided by Office of Naval Technology, Contract No. N00014-90-C-0098.

Published in Woods Hole Oceanographic Institution Technical Report, WHOI-91-38.

UNDERWATER ACOUSTIC LOCAL AREA NETWORK FOR ROV AND INSTRUMENT COMMUNICATIONS

Josko Catipovic, Lee Freitag and Steve Merriam

ABSTRACT

An underwater Acoustic Local Area Network (ALAN) for real-time data communications with ocean-bottom oceanographic instruments and underwater vehicles is presented. The network is centered around one or several central moorings which function as node controllers for the underwater communications network. Each node can communicate with numerous underwater modems. It is equipped with an acoustic cellular communications controller and a satellite, packet RF or commercial cellular telephone for above-surface communications. The underwater acoustic modems are low-power acoustic transceivers with network and communication capabilities similar to RF cellular telephones. They are interfaceable to underwater vehicles or instrumentation packages. The ALAN allows real-time two-way communications with and control of underwater devices within a 5-10 km range of at least one surface station. Power budgets allow one year deployments.

The system has undergone a six-month deep-water deployment near Bermuda and has been tested in Monterey Canyon, CA. This paper presents system design details, including the acoustic telemetry protocols, electromechanical implementations of various subsystems, maintenance/deployment methods, and performance results from previous and current deployments. Current and future system application and research/development issues are summarized.

Funding was provided by Office of Naval Technology under Contract No. N00024-90-C-0098.

Published in Proceedings, AUV '91 Conference, Washington, DC, pp. 447-461, August 1991.

DIGITAL OUTPUT TEMPERATURE SENSING MODULE FOR OCEANOGRAPHIC & ATMOSPHERIC MEASUREMENTS

Alan J. Fougere, Neil L. Brown and Edward Hobart

ABSTRACT

The authors have developed a physically small high accuracy Temperature Sensing Module (TSM) for use in oceanographic and atmospheric temperature measurements. Using internally calibrated electronic measurement techniques to interface to a Platinum Resistance Thermometer (PRT) the development team was able to combine measurement, computation, and digital transmission electronics into a compact module. The TSM's operating system allows for continuous, polled, and calibration mode operation with calibration coefficients being stored in internal EEPROM. Data is output using one of several optional interfaces in ASCII encoded degrees Celsius. All temperature computations are performed by the embedded processor in the module. The unit attains both high initial accuracy and long term stability through the use of a newly developed pressure protected PRT. The PRT was developed specifically to meet the demanding requirements of environmental measurements under harsh conditions. System overview, test data, sensor data, and calibration results are presented.

Funding provided by Office of Naval Research under Contract No. N00014-86-K-0751.

Published in Proceedings Marine Instrumentation '90, pp 46-51, 1990.

INDUCTIVE MODEM FOR OCEAN DATA TELEMETRY

Alan J. Fougere, N. L. Brown, Ed Hobart

ABSTRACT

This paper describes the development of a power efficient Inductively Coupled Modem, (ICM). A prototype set of ICM's has been built which allows for 1200 Baud Data transfer. The ICM uses standard plastic jacketed mooring cable as the data transmission channel. The seawater is used to form the return electrical circuit. This results in a system where data is transmitted directly on the mooring cable supporting the instrumentation, eliminating the need for expensive multi-conductor cables and terminations. The ICM used industry standard modems operating in a half duplex transmission mode.

Funding provided by Office of Naval Research under Contract No. N000-14-86-K-0751.

Published in IEEE Proceedings Ocean '91, Vol. 3 pp. 1165-1170, October 1991.

MICRO-CTD INSTRUMENT DEVELOPMENT FOR THE OCEAN SCIENCES

A. Fougere, N. L. Brown, D. Frye and J. Toole

ABSTRACT

Scientists involved in climate related research problems are increasingly in need of long-duration measurements of ocean characteristics such as temperature and salinity. Available instrumentation for these tasks is severely limited by accuracy, power, long-term stability, and high cost. We have developed a very small, low cost, deployable CTD (the Micro-CTD) to meet these increasingly important needs. In addition to small size and high sampling speed, the Micro-CTD incorporates a new inductive conductivity sensor which is highly accurate and can be treated with an anti-foul coating to minimize the effects of bio-fouling. This is a major advantage for long duration observations over existing high accuracy conductivity sensors. Size and measurement performance of the instrument allow use with a wide variety of new sensing system platforms such as drifters and pop-up buoys. Micro-CTD architecture allows for either data storage or data telemetry by acoustic, inductive, or hardwired telemetry. The paper covers system architecture, physical calibration data, and field data.

Funding provided by Office of Naval Research under Contract No. N00014-86-K-0751.

Published in Proceedings, AGU Conference Poster Session, New Orleans, January 1992.

A LONG-TERM, DEEP-WATER ACOUSTIC TELEMETRY EXPERIMENT

Lee Freitag, Steve Merriam, Dan Frye and Josko Catipovic

ABSTRACT

Between April and November of 1990 an acoustic telemetry system was deployed on a surface mooring 12 miles south of Bermuda in approximately 3000 meters of water. The purpose of the experiment was to perform a long-term test of a low-power data link which can be used to collect data from a number of subsurface instruments, forward it acoustically to a surface buoy and then via satellite to shore. Data was transmitted to the surface buoy at 600 b/s from acoustic modems placed on the mooring cable at 300, 1500 and 2900 meters below the surface. The modems were equipped with command receivers and were polled by the surface unit several times per hour with a request for data. They were also programmed to transmit data in response to an internal interrupt once each hour. The received information was processed at the surface by a compact, low-power DSP-based receiver, then passed to an oceanographic instrumentation computer for processing and forwarding to shore using the ARGOS data collection system. Operation of the telemetry system was monitored remotely in near real-time over the course of the experiment. The modem at 1500 meters provided data for six months, the entire period the mooring was in place. Twenty million bits were received from this unit, at an average bit error rate of 1.5×10^{-3} for the 180 day experiment.

The system as deployed is discussed in detail and performance results are presented. Additional work on the system which has resulted in improvements in reliability and data rate are also presented.

Funding was provided by Office of Naval Research under Contract No. N00014-86-K-0751.

Published in Proceedings, IEEE Oceans '91, Vol. 1, pp. 254-260, October 1991.

PASSIVE ACOUSTIC LOCALIZATION OF THE ATLANTIC BOTTLENOSE DOLPHIN USING WHISTLES AND ECHOLOCATION CLICKS

Lee E. Freitag and Peter L. Tyack

ABSTRACT

A system for localization and tracking of calling marine mammals was tested under realistic field conditions which include noise, multipath and arbitrarily located sensors. Experiments were performed in two locations using four and six hydrophones with captive Atlantic bottlenose dolphins (Tursiops truncatus). Accurate hydrophone position estimates are achieved by pinging sequentially from each hydrophone to all the others. A two-step least-squares algorithm is then used to determine sensor locations from the calibration data. Animal locations are determined by estimating the time differences of arrival of the dolphin signals at the different sensors. The peak of a matched filter output or the first cycle of the observed waveform is used to determine arrival time of an echolocation click. Cross-correlation between hydrophones is used to determine inter-sensor time delays of whistles. Calculation of source location using the time difference of arrival measurements is done using a least squares solution to minimize error. Experimental results show that realistic trajectories for moving animals may be generated from consecutive location estimates.

Funding was provided by Andrew Mellon Foundation and the National Institute of Health Grant No. 5-R29-DC00429.

Submitted to J.A.S.A. Bioacoustics, 1992.

A TRANSPUTER-BASED SYSTEM FOR UNDERWATER ACOUSTIC COMMUNICATION

Lee E. Freitag and Robert L. Eastwood

ABSTRACT

A transputer-based system for real-time underwater acoustic communication has been developed as a research testbed for testing computationally intensive signal processing and communications algorithms. A simple yet powerful shell provides inter-process communication and allows each processor access to host resources. The actual application algorithms are modules written in C which may be developed and tested on a workstation and then ported to the shell. Up to ten processors plus a vector coprocessor are currently used to perform the different tasks required for robust underwater communication. These tasks include signal synchronization, demodulation, error-correction, spatial diversity (use of multiple receive hydrophones) and transmit-signal generation.

The system has been designed to provide a platform for testing signal processing strategies and communication algorithms which will be able to operate under potentially difficult conditions in shallow water between a moving host and an underwater vehicle. This is a demanding real-time processing application which requires flexibility on the part of the processing network as algorithms are developed, refined and put into use.

Funding was provided by Office of Naval Technology under Contract No. N00014-90-C-0098.

Published in Proceedings, Transputer Applications 91 Conference, Glasgow, August 1991.

PROTOTYPE EXPENDABLE SURFACE MOORING WITH INDUCTIVE TELEMETRY

D. Frye, A. Fougere and S. Kery

ABSTRACT

A lightweight, inexpensive surface mooring designed for general purpose telemetry has been deployed at Site D (39° N, 70° W) to test its reliability in the ocean environment. The mooring incorporates telemetry from instruments in the water column using inductive modems to transfer information via standard, plastic-jacketed wire rope. An inverse catenary design eliminates the need to accurately measure water depth prior to deployment and allows deployment to be carried out from a ship of opportunity. Mooring component size has been minimized to reduce costs and handling requirements. Inductive modems are installed at three depths to telemeter data from digital temperature and pressure sensors clamped to the wire. Data rates are 1200 b/s for data sent up the wire and 300 b/s for commands sent down the wire. Power required for the inductive link is modest; 350 mW when transmitting, 5 mW when quiescent. The paper describes the mooring and telemetry systems in detail and summarizes the results obtained to date.

Funding was provided by Office of Naval Research under Contract No. N00014-86-K-0751.

Published in Proceedings, AGU Conference Poster Session, New Orleans, Louisiana, January 1992.

REAL TIME TOMOGRAPHY MOORING

Daniel E. Frye

ABSTRACT

A tomography transceiver and a satellite telemetry link are interfaced to provide real-time data from the ocean's interior. The system includes a tomography transceiver with associated control and communication electronics, acoustic navigation subsystem, high accuracy clock, acoustic projector and receiving hydrophone array. A three-conductor electromechanical cable is used to transfer digital tomography data via the subsurface mooring to a tethered surface buoy. In the surface buoy a controller collects and formats the data from the tomography transceiver for satellite transmission. In addition to its function as a satellite telemetry platform, the surface buoy contains a GPS receiver which is used to collect highly precise timing signals from the navigation satellite constellation. These timing signals allow a comparison to be made between the tomography transceiver clock and UTC. This time difference is inserted into the satellite data string several times per day to provide real time corrections to the tomography data to compensate for instrument clock drift.

Funding provided by Office of Naval Technology under Contract No. N00014-90-C-1098.

Published in: Proceedings, MTS Buoy Technology Workshop, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, April 1991.

RECENT DEVELOPMENTS IN OCEAN DATA TELEMETRY AT WOODS HOLE OCEANOGRAPHIC INSTITUTION

Daniel E. Frye and W. Brechner Owens

ABSTRACT

Woods Hole Oceanographic Institution in developing techniques for telemetering oceanographic data from the deep ocean to the laboratory in near real time. Three general approaches that provide a link between subsurface instruments and surface buoys equipped with satellite transmitters are being pursued. These approaches are cabled systems that use electromechanical cables to connect subsurface instruments to a central controller; high data rate acoustic modems to transfer information between multiple remote units and a central controller; and inductive modems that use standard mechanical mooring lines as the transmission medium between instruments deployed on the mooring and a central controller.

These telemetry systems are targeted for general use by the oceanographic community and are designed to be power efficent, low in cost, and capable of integration with most oceanographic data collection systems.

Funding provided by Office of Naval Research, Contract No. N00014- 86-K-0751.

Published in IEEE Journal of Oceanic Engineering, Vol. 16, No. 4, October 1991, pp. 350-359.

A CURRENT METER WITH INTELLIGENT DATA SYSTEM, ENVIRONMENTAL SENSORS AND DATA TELEMETRY

James D. Irish, Kenneth E. Morey, Gerald J. Needell, and Jon D. Wood

ABSTRACT

To measure oceanographic parameters such as currents, temperature, conductivity, pressure, and suspended sediment concentrations, two film-recording current meters were upgraded with microprocessor-controlled data recorders and additional sensors. A Savonius rotor, vane and compass measure the current speed and direction, which are then converted to vector-averaged velocities over a user-selected sample interval. Averages of temperature, pressure, conductivity, optical backscattered energy, tilt, direction and battery voltages are also calculated, and the results stored internally in RAM. Additionally, the instrument burst-samples pressure (to estimate the surface wave energy spectrum), and conditionally samples the pressure, Savonius rotor and optical sensor observations to identify unusually high suspended sediment concentrations due to a dredged sediment dumping or resuspension event. Although capable of being used in a conventional current meter mooring, these instruments were tested in bottom-mounted configurations in the Gulf of Maine, New York Bight and Massachusetts Bay.

Two telemetry links relay data and allow the in situ operation of the remote instrument to be checked. In one configuration, the bottom-mounted current meter communicated by a 35-meter-long wire to a small surface spar buoy, and then by a packet radio link to a nearby ship. In another development, the current meter relays data to a controller and buoyant data capsule on the bottom instrument package. The controller collects and processes the data from the current meter, and periodically transfers this processed data to a data capsule and releases it. When released, the capsule rises to the surface and transmits its data to shore via the ARGOS satellite, while acting as a satellite tracked-drifter.

This work was supported by the New York District of the U.S. Army Corps of Engineers, by the National Science Foundation under Grant OCE-8716018, by the WHOI ONR telemetry URIP, by the Environmental Protection Agency under the Mass Bays Program and by the University of New Hampshire Hubbard Funds.

Funding provided by US Army Corps of Engineers (NY District), Mass Bays Program (under the Mass. Coastal Zone Mgmt.), National Science Foundation under Contract OCE-87-16018 and Office of Naval Research under Contract N00014-86-K-0751.

Published in: IEEE Jour. Oceanic Eng., 16(4), 319-328, 1991.

LABORATORY CALIBRATION OF THE 5 MHZ ABSS SENSOR FOR STRESS

J.D. Irish and J.F. Lynch

A 5 MHz acoustic backscattering sonar, built to measure the time history of suspended sediment concentration profiles in the bottom meter of the water column, was successfully deployed in the 1990-1991 STRESS experiment on the northern California shelf, and data were obtained from two 2-month deployments. The sensing element was a Panametrics Model V307 transducer driven with both a low power (24 volts) and a high power (96 volts) supply, producing pings of 20 microsecond duration. The sampling program measured the acoustic pressure of the return at 127, 1 cm long intervals. Four of these returns were averaged together into one profile. The first 12 profiles were taken at low power, the next 40 profiles taken at high power and the last profile was made with no transmitted pulse to obtain an estimate of the system's noise level. An average of the 40 high power profiles made over an 80 second interval was used for the STRESS time series.

In order to understand and reduce the 5 MHz acoustic data from STRESS, calibrations were performed in a 77 cm long x 62 cm wide x 92 cm deep laboratory tank to measure: (1) the transducer's beam pattern, (2) the attenuation (absorption and spreading loss) and (3) the system's sensitivity with sediment samples obtained at the site during STRESS. For all calibrations the system was powered by batteries to simulate deployed conditions.

Transducer Beam Pattern

In seawater at 5 MHz, the acoustic wavelength is 0.3 mm. With the 2.54cm diameter transducer, the beam spread (to the 6 db points) is calculated to be 0.7 degrees (ASTM, 1987) beyond the near field region. Within the near field region, the beam width may actually decrease to the near field distance (which is the natural focus of the transducer). Calculating on the basis of theory, the near field distance was estimated to be 54 cm (Kinsler, et al., 1982), or nearly half the range of interest in STRESS. Measurements of the beam pattern were made in a laboratory tank by placing the transducer at the bottom of the tank transmitting upwards, moving a 0.6 cm and a 0.3 cm diameter 5 MHz transducer through the beam at different ranges, and measuring the peak-to-peak amplitude of the observed signal. The results were repeatable in time and similar for both receiving transducers, indicating that the beam width of the receiving transducer (3 or 6 degrees respectively) was not critical to the results.

The acoustic beam (1) was radially symmetric (Figure 1), (2) had sharp edges in the near field region (Figure 2), (3) had varying amplitude (and phase) structure across the beam in the near field region (as shown in Figure 2, this structure was somewhat smoothed by the size of the receiving transducer), and (4) changed from

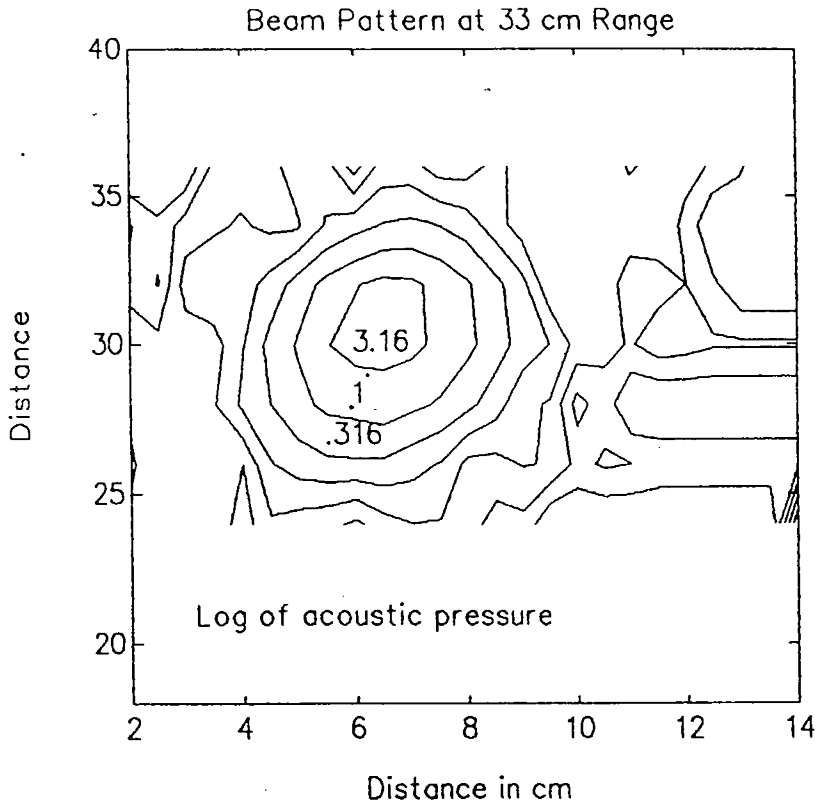

Figure 1. A contour plot of a section across the acoustic beam at 33 cm range from the transducer. The log of the acoustic pressure is contoured. (The skewness seen in the plot is due to the grid locations being skewed, not the beam pattern which is circular to the accuracy of the measurement.)

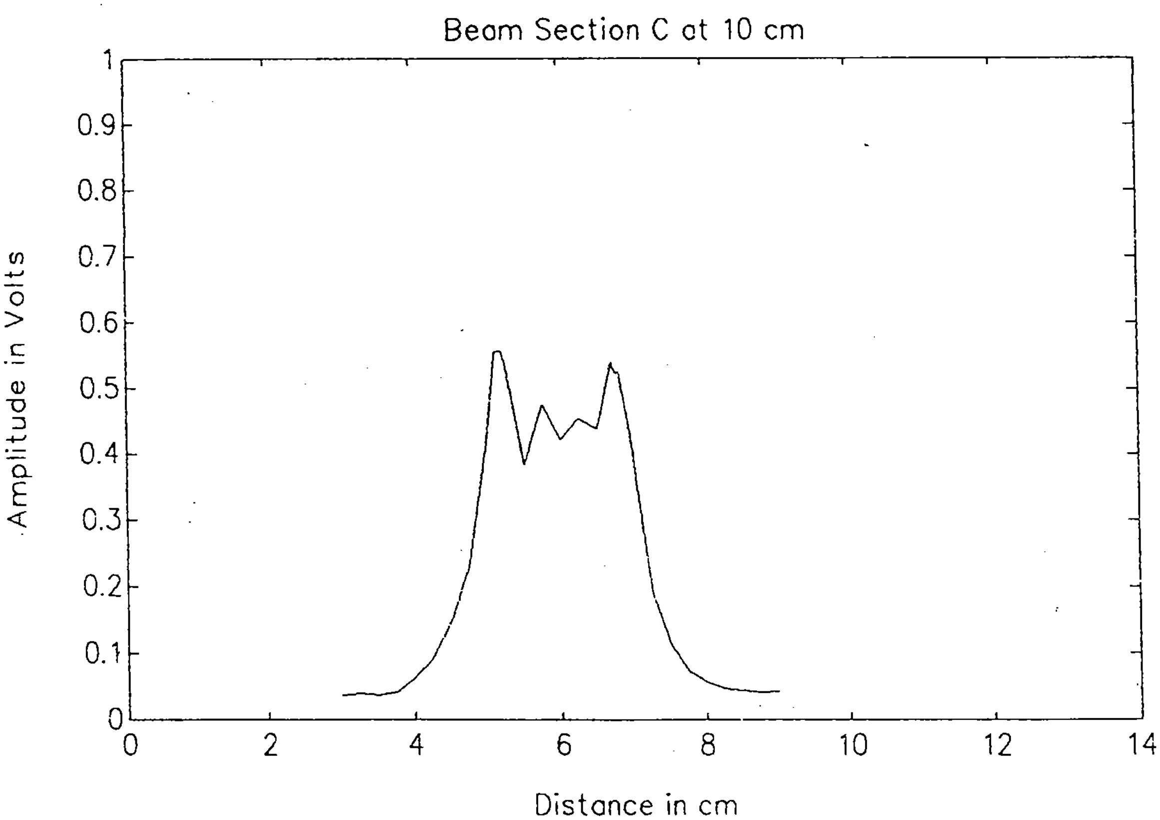

Figure 2. A transect through the beam at a range of 10 cm from the transducer. The acoustic pressure (in volts) is plotted against distance across the beam.

a flat topped section (with structure) to a single peaked section between 40 and 50 cm range. This is slightly closer than the 54 cm near field range predicted by theory. (Due to lack of tank depth, measurements could not be made beyond the usable depth of 57 cm, so the 0.7 degree theoretical spreading angle at greater ranges could not be checked.) Therefore, a single transect through the center of the beam represents the structure in the beam and was used to estimate attenuation.

Attenuation

The total acoustic energy in the beam at a fixed range was estimated by integrating the observed acoustic pressure squared (acoustic intensity) over the area. The center of the beam was determined by "folding" the beam to align the two edges. Then the observed acoustic intensity was multiplied by the area at the observed radius and summed over all observations out to a radius of 3.0 cm, which was determined to be beyond the main lobe of the transducer. Although the energy at large radii is low, the area is large, and can bias the integrated intensity estimate. Plotted versus range (Figure 3), the attenuation of the intensity was linear and about 16 db/meter one-way over the first 55 cm. This observed attenuation was about twice as high as expected from theory, and may, in part, be due to driving the transducer with the 96 volt supply which may over-drive the transducer and generate higher harmonics. These harmonics would be attenuated faster, causing the observed greater attenuation. The attenuation measured in a similar manner for the 24 volts supply was about 5 to 6 db/m, as expected, indicating that at high power something different was occurring that was not directly related to the calibration technique.

The attenuation was also estimated from the laboratory calibration with suspended sediments and from in situ observations made during STRESS. Unlike the above calibration which directly measured the signal strength with a second transducer, this method used the entire system with the same transducer and electronics as was used to record the STRESS data in the field. The main assumption required is that the suspended sediment concentration in the tank or in the field is uniform so the expected acoustic return should be constant with range. The estimation process consists of four steps: (1) subtracting a system "noise" level from the observed profile, (2) applying an adjustable two-way loss to the low and high power pulses, (3) correcting for the difference in power between the high and low power pulses, and (4) adjusting the attenuation so the profiles were constant with range, and the high and low power profiles were of the same level.

The system's receiver "noise" profiles were measured by the system at the end of each measurement ensemble, by recording a profile without transmitting. This profile (Figure 4, dashed curve) is relatively flat with a mean value of 315 counts. The variation about the mean is due to the low statistical confidence in the single estimate shown. The system's background noise while transmitting (Figure 4, solid curve) shows a peak close to the transducer due to transducer "ringing", then a rapid

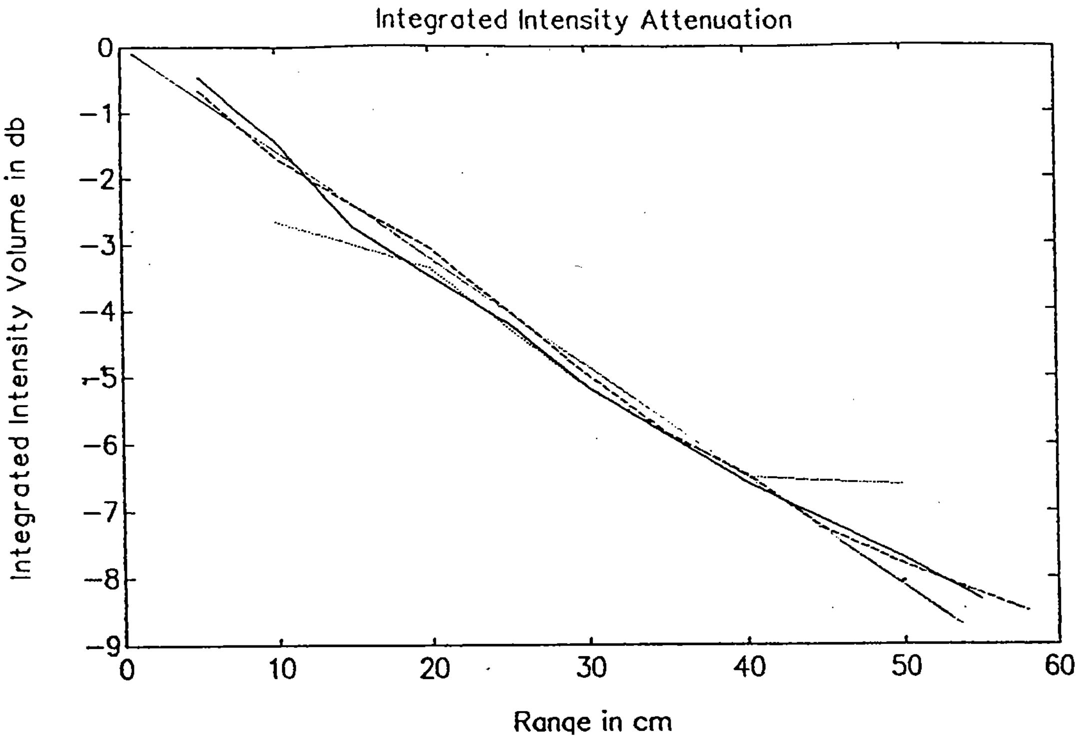

Figure 3. The integrated acoustic intensity (acoustic pressure squared times cm squared) is plotted versus range in cm. The solid and dashed curve are for two separate runs with the 0.6 cm transducer, and the dotted curve is for the 0.3 cm transducer.

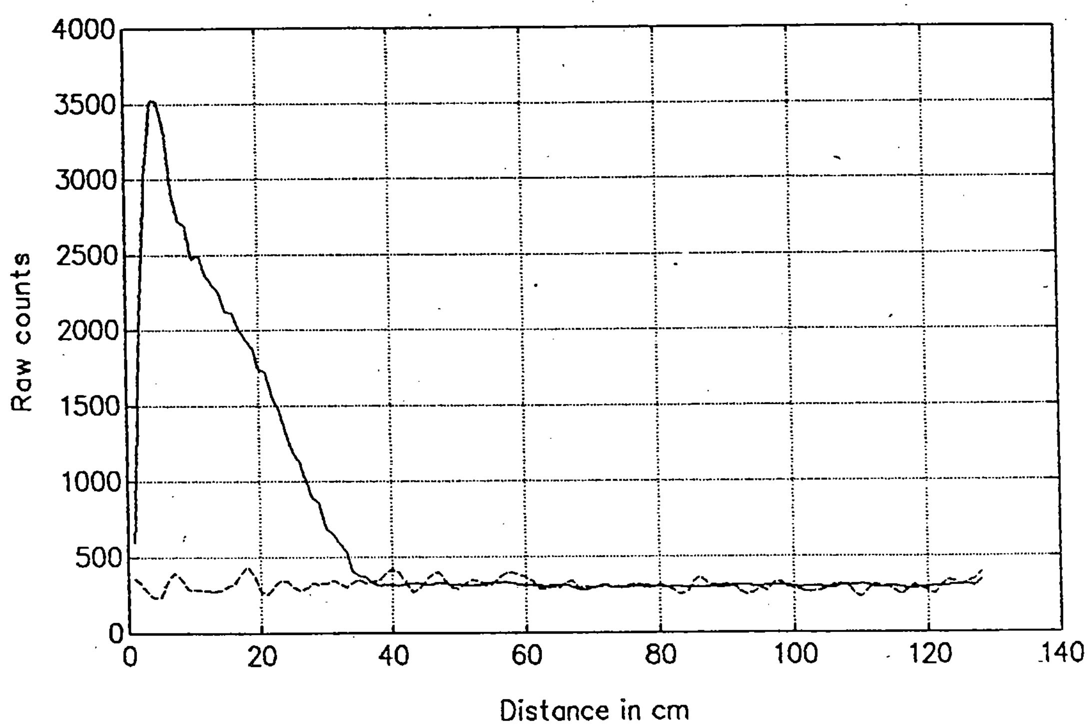

Figure 4: The background pulse taken when the system transmits into air (solid curve) is shown versus range and shows the transducer ringing at ranges below 30 cm. The lower or bottom plateau (dashed curve) is the system's noise level determined from one profile made when the system was not transmitting.

drop to the system's receiver noise level. These ringing profiles made in the laboratory agreed with the profiles taken on shipboard before the instrument was deployed. After deployment, when the transducer was subject to 90 decibars ambient pressure, the ringing component of the noise during the first 30 cm was reduced. This indicates that there is a pressure effect on the transducer's response. The system's noise plateau remained the same regardless of applied pressure, and is probably related to electronic noise in the system.

The laboratory background level was subtracted from the laboratory observations, and the field background level (determined at times of lowest suspended sediment concentration) was subtracted from the field observations. Since the observations were recorded in db, in order to subtract the noise, the data was converted to relative acoustic pressure, and the background profile (also converted from db) subtracted from the averaged return signal. Finally the corrected results were converted back to db.

The tank was well stirred with a canoe paddle during the calibrations. Profiles made with a Downing and Associates Optical Backscattering Sensor (OBS) showed no vertical gradient. As a starting point a 14.0 db/m attenuation was applied to the 96 v pulses, and 5.5 db/m to the 24 volt results. The 24 volt results were also adjusted upwards by 12 db to correct for the drive voltage difference. The results from a sediment calibration at 0.23 gm/l (Figure 5) show that the 14.0 db/m attenuation correction for the 96 v profile (solid line) is too large, and the 5.5 db/m for the 24 v profile (dashed line) is a bit small. Adjusting the attenuation for best "overall visual agreement" for all the calibration profiles, an attenuation of 8.25 db/m was selected for the 96 v profile and 6.0 db/m for the 24 v profiles. Figure 6 shows the final correction for the calibration profiles applied to the profiles shown in Figure 5. The best correction between power levels was 7 db. That this offset differs from 12 db again indicates that there was some non-linear effect taking place in the transducer and system when it was driven at 96 volts.

These same corrections were then applied to the STRESS data during two periods, one of low concentration (Figure 7a) and another during a long high suspended sediment concentration event (Figure 7b) when active mixing was assumed to produce a uniform distribution and profile. The correction for attenuation is consistent with the laboratory results, and produces flat or uniform profiles during times when it is reasonable, although another db or two added to the low power profile would align the low- and high-power STRESS profiles.

Sediment Calibration

The sediment concentrations used in the laboratory calibration were selected to match the range of concentrations seen by the OBS sensor at the STRESS site. Sediment samples taken at the site were used and calibration baths made up with three concentrations (about 0.1, 0.25 and 0.50 grams/liter). The sediment was soaked

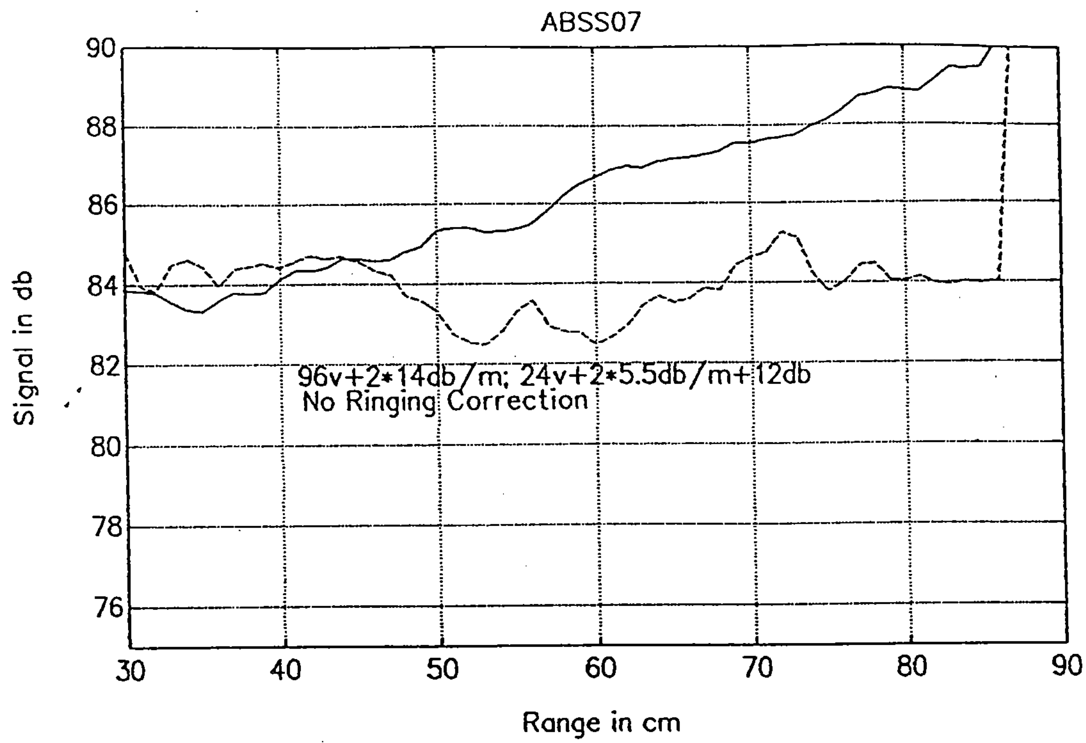

Figure 5. The corrected acoustic profiles in the calibration tank at 0.23 gm/l concentration showing the over correction when using the measured tank attenuation. The solid curve is at 96 v drive and the dashed one is at 24 v.

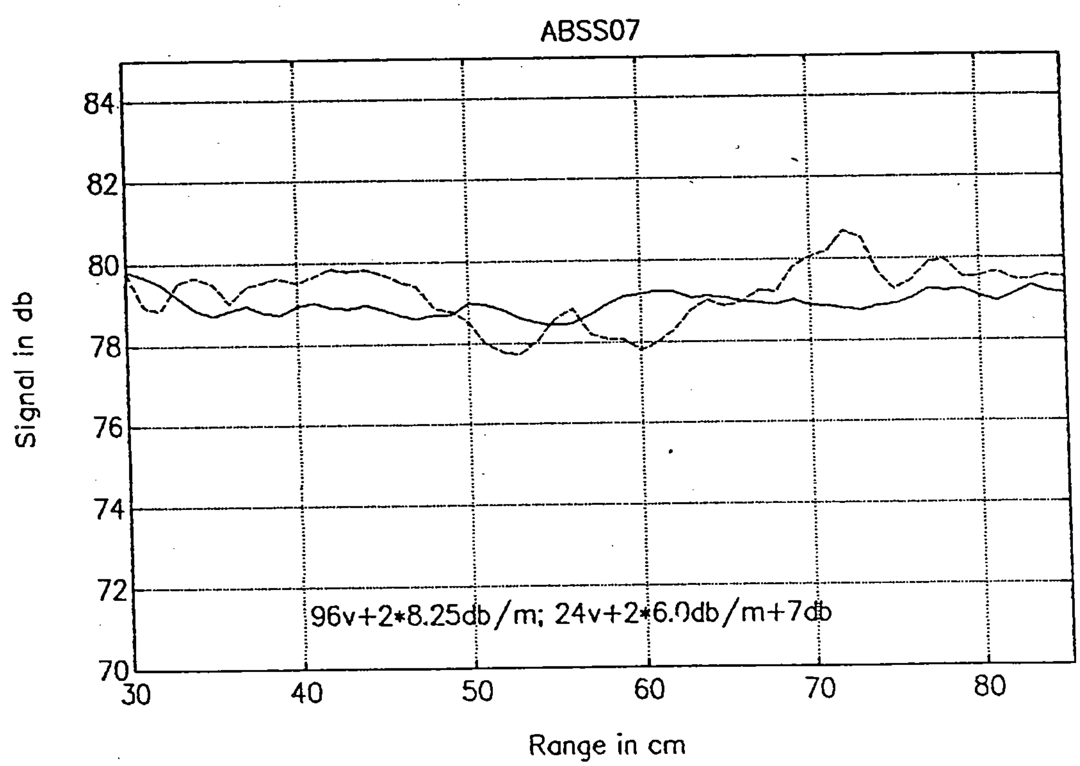

Figure 6. The corrections giving the best visual fit for all calibration profiles is applied to the same profile shown in Figure 5. The sensitivity of the acoustic sensor picks out structure in the acoustic signal not seen in the optical OBS.

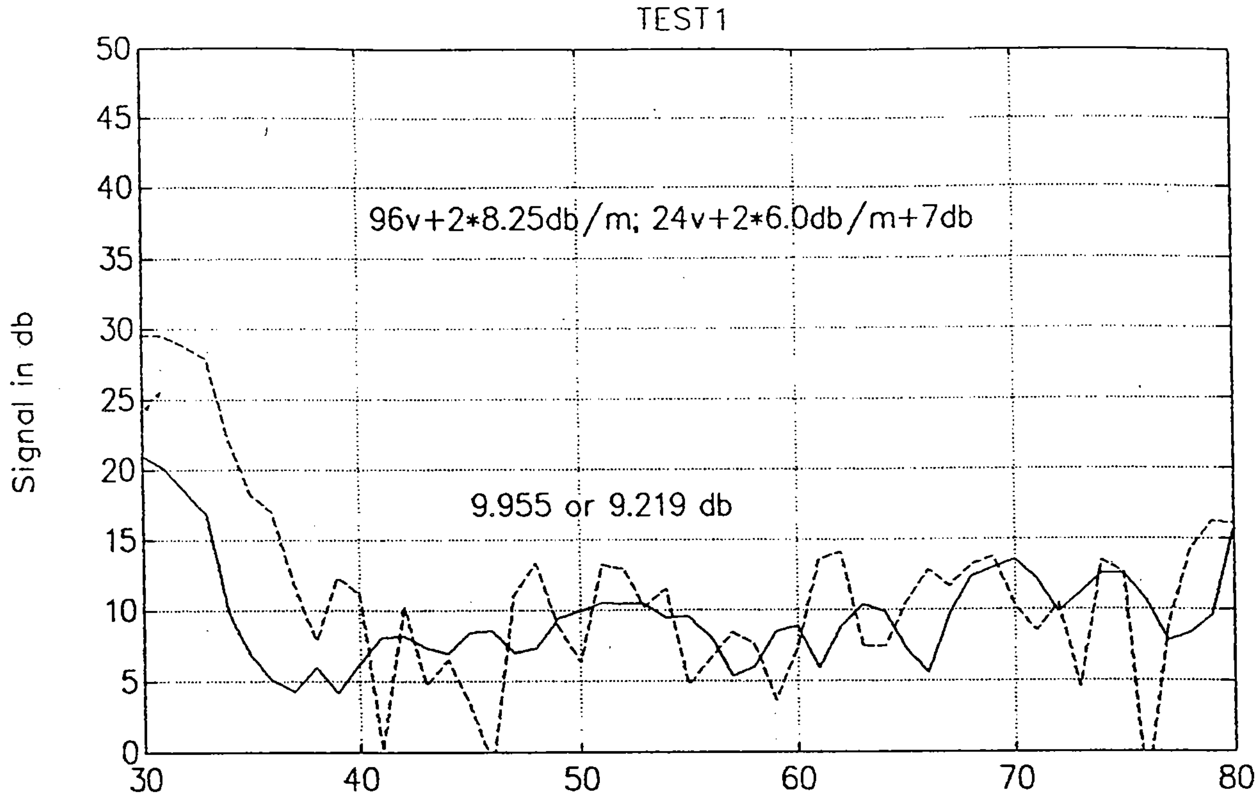

Figure 7a. The corrections applied to a low concentration profile from STRESS.

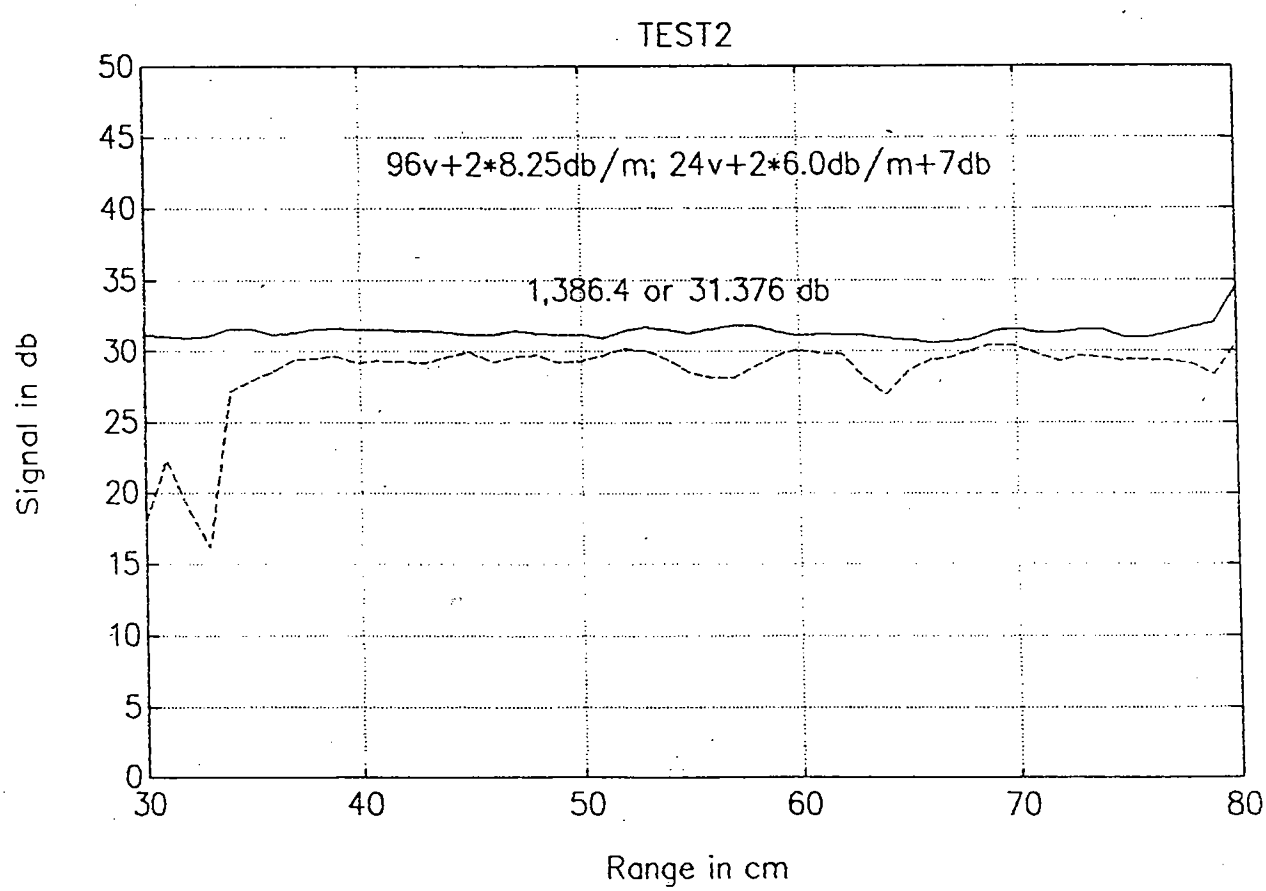

Figure 7b. The corrections applied to a high concentration profile from STRESS.

overnight in a bucket of tap water, then suspended in the tank by slowly stirring with a canoe paddle until the signal seen by an OBS sensor at about 30 cm depth was constant. Then the OBS sensor was profiled to make sure that the tank was well mixed. The paddle was moved in a manner that minimized the amount of bubbles that might be mixed into the water.

After the recorder had written a standard record with the sampling program used during STRESS, a 255 ml sample was taken at 30 cm depth. Three samples were taken at each of three concentrations. All the samples were filtered, dried and weighed. The observed concentrations were 0.089, 0.231 and 0.436 gm/l. These concentrations are slightly less than predicted, and are probably due to (1) not knowing and underestimating the exact amount of water in the sediments used, and (2) the larger, heavier particulate material not being completely suspended by the mixing techniques used. When plotted versus acoustic intensity (Figure 8), a sensitivity of 3e-9 grams/liter/acoustic signal intensity was obtained.

However, the signal strength seen in the laboratory calibrations (Figure 9) was much larger (by more than a factor of 2 to 3 in db) than those seen in STRESS at comparable concentrations (Figure 10). This is probably due to the aggregation of sediment used in the tank calibrations, which, having large particle size, scattered more acoustic energy and gave the higher signal levels seen. It is not clear how to make a laboratory calibration without this aggregation problem, and since the acoustic scattering is not geometric, but Rayleigh, the results can differ significantly. However, we also note that the observed range of values in STRESS is about a 22 db, and a similar range of sediment concentrations, the laboratory tank calibrations varied by 20 db.

The background, or "clear water", profiles were also significantly different. Some of this difference may be due to reduced transducer sensitivity when loaded with the 90 dbars ambient pressure. Therefore, assuming that the "clear" Falmouth tap water should have the same scattering as the clearest STRESS profiles, the two background profiles were aligned to get a 52.5 db signal offset during STRESS. Reducing the sensitivity by 1.5e5 (52.5db), a corrected sensitivity for the 5 MHz sensor in STRESS of 5.3e-4 grams/liter/acoustic intensity was obtained. This sensitivity is nearly the same as a scale factor previously selected to visually align some of the broader peaks of the simultaneous OBS and ABSS data. Therefore, a sensitivity of 5.3e-4 grams/liter/intensity was used to normalize the STRESS data.

Conclusions

A calibration of the 5 MHz STRESS sensor was made in the laboratory and the results compared with field observations. The system behaved differently at low- and high- power and in the laboratory and in the field. The results from the laboratory could not be used alone to understand the field observations, but were useful in understanding system behavior. In using acoustic systems for the determination

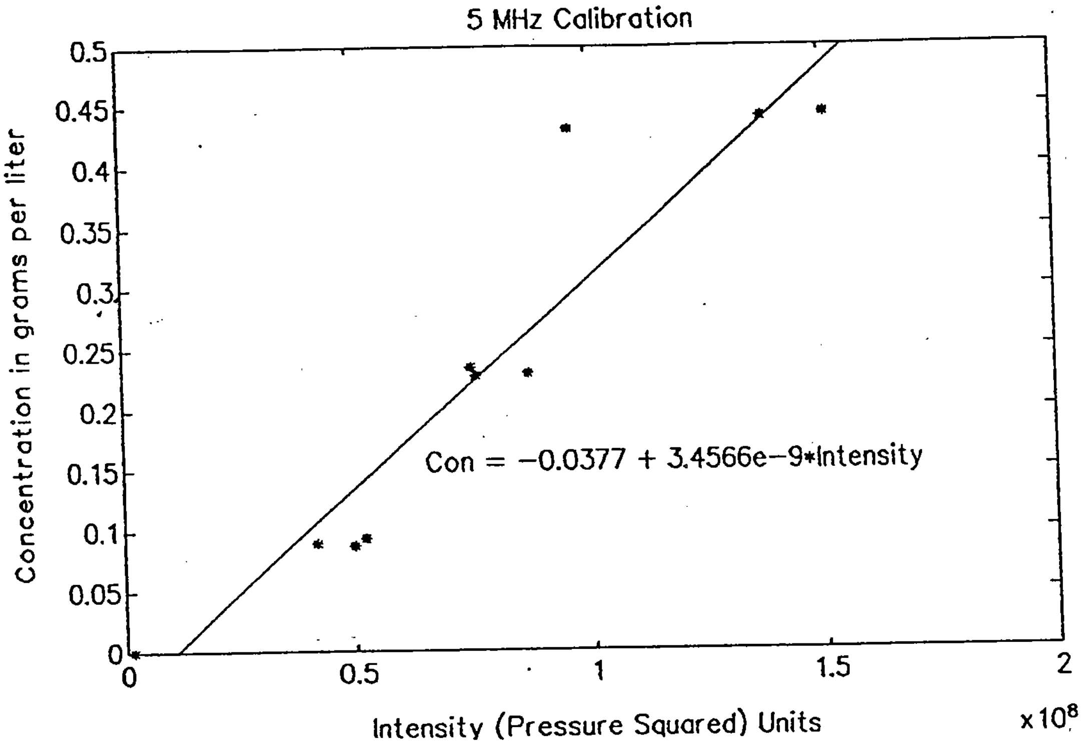

Figure 8. The calibration of the 5 MHZ ABSS sensor of acoustic intensity versus grams per liter concentration. The point near zero is Falmouth tap water.

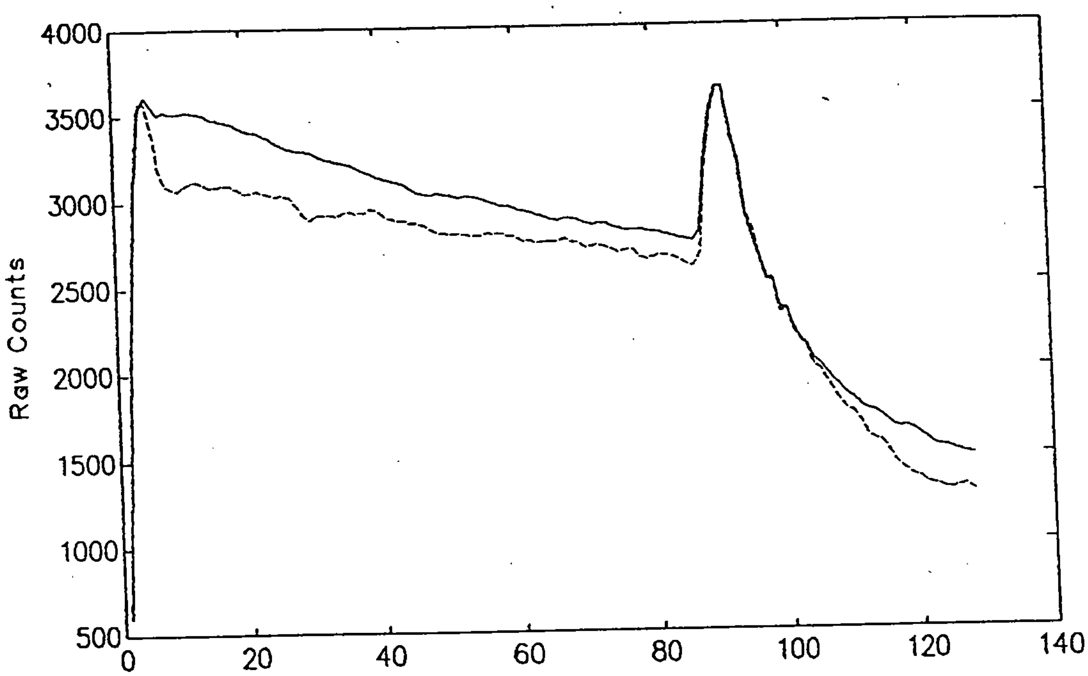

Figure 9. The raw or uncorrected counts as recorded during the 0.436 gm/l calibration run for the 96 v (solid) and 24 v (dashed) profiles.

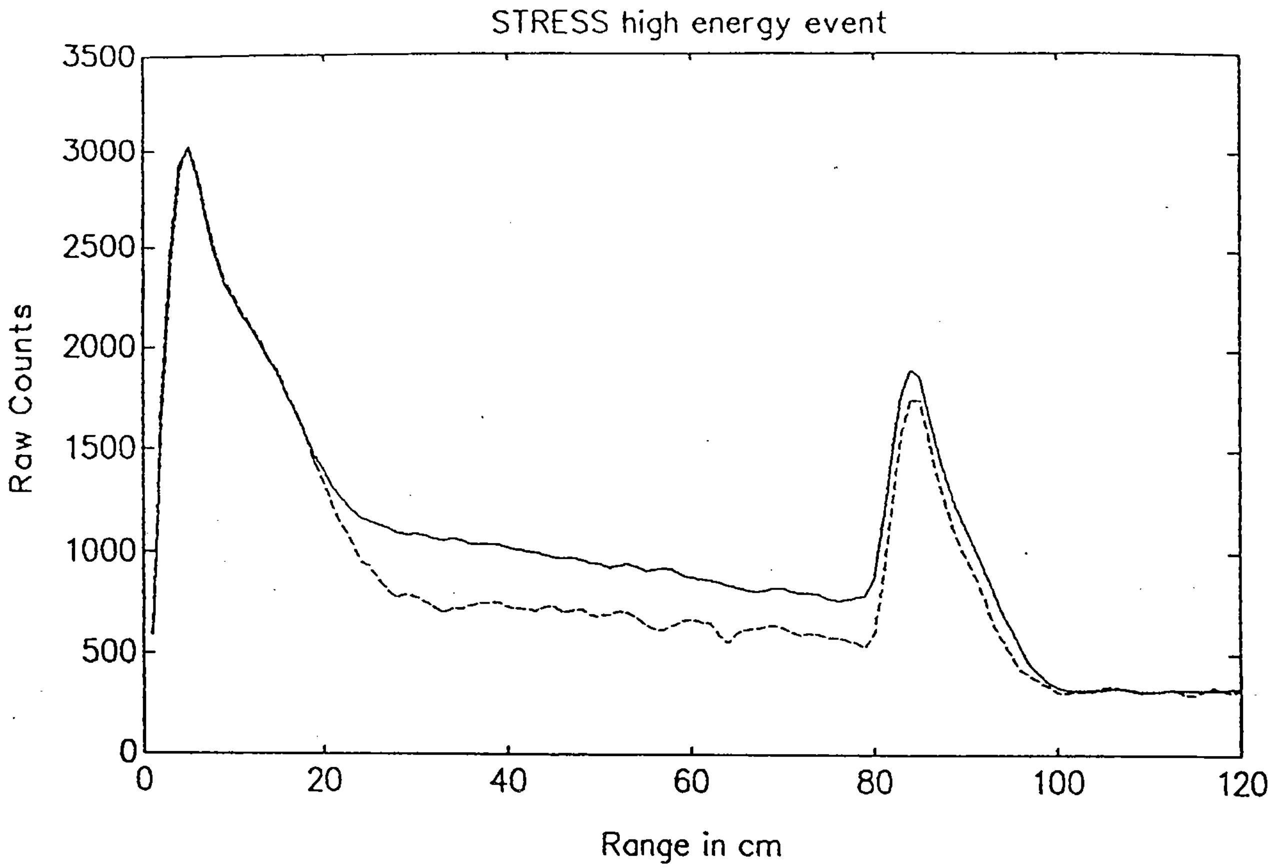

Figure 10. The raw or uncorrected counts as recorded during a high suspended sediment concentration event during STRESS for the 96 v (solid) and 24 v (dashed) profiles.

of suspended sediment concentrations, system calibrations and understanding the scattering process are the weak link in the processes and can use more research and study.

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[1] American Society for Testing and Materials, Standard Guide for Evaluating Characteristics of Ultrasonic Search Units, E1065-87a, Philadelphia, PA, 24pp, 1987.

[2] Kinsler, L.E., A.R. Frey, A.B. Coppens, and J.V. Sanders, Fundamentals of Acoustics, John Wiley & Sons, New York, NY, 1982.

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DATA DIRECT FROM THE OCEAN BOTTOM TO THE LABORATORY USED IN THE STRESS EXPERIMENT

Richard Koehler

Data has been sent from a current meter mounted on the ocean bottom to the user's laboratory within 20 minutes of the data collection. The communication system used a 1185 bits/second acoustic modem to send the data to a nearby surface buoy. VHF packet radio sent the data at 1200 bits/second from the buoy to a shore station, where it was stored. The stored data was transferred by telephone modem to a remote computer in the laboratory. Commands could be sent from the laboratory to the ocean bottom along the same path. The whole system worked for three weeks until the buoy mooring was damaged. The difficult parts of the system, the acoustic modem and the packet radio, worked on real data. A few improvements are necessary to make the data easily readable, and the mooring fault must be corrected. Many improvements have been made to the acoustic modem since this experiment was conducted. A number of other refinements are suggested for the communication system.

Overview of the Experiment and Communication from the Ocean Bottom to the Laboratory

The STRESS experiment, a group of experiments to measure the movement of sediment along the California coast near Sea Ranch (Figure 1), included two BASS current meter arrays on bottom tripods, spaced 5 and 10 miles from shore. The 5 mile site was 90 m deep and the 10 mile site was 130 m deep.

Figure 2 shows the communications path from the ocean bottom to the laboratory. Data at each site was processed by a low power computer and stored on its 20 Mbyte hard disk. The processed data was also transmitted to a surface buoy by an acoustic modem and then transmitted to shore by VHF packet radio. The data received by radio on shore was stored on an optical disk by an AT type computer.

The shore computer could communicate through a telephone modem to the laboratory, where the user could receive the data almost as soon as it was measured. The user could also control data processing on the bottom of the ocean from the laboratory. The slower reverse channel could command the instrument on the bottom to send raw current meter data when desired.

The user would monitor the bottom currents to determine when they were strong enough to suspend bottom sediment. Then the user would send a signal to the current meter on the bottom instructing it to send a 20 minute interval of raw data. A different command would send 20 minutes of raw data every hour for eight hours. The processed data was sent as well. If the raw data were recorded on the bottom continuously, it would have filled up the 20 Mbyte disk in two days. Thus the user

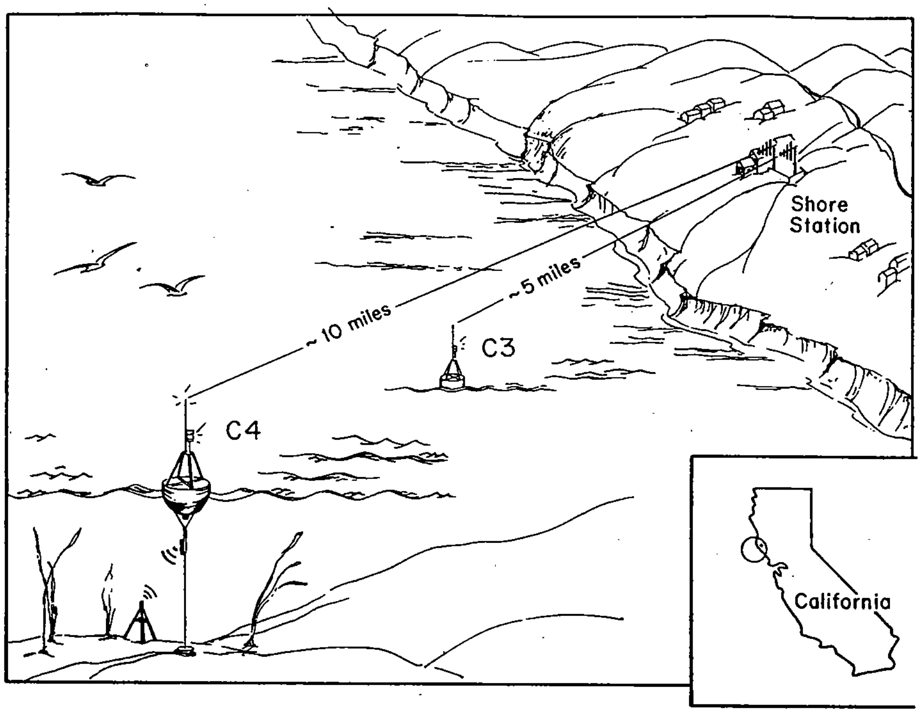

Figure 1: Location of STRESS experiment. Sea Ranch is 100 miles north of San Francisco.

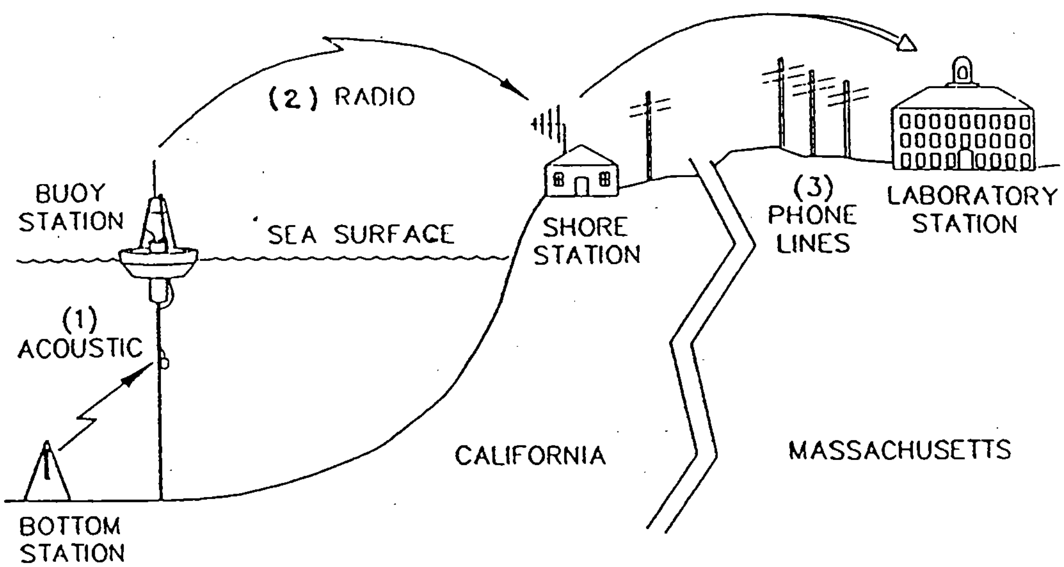

Figure 2: Overall communications path; (1) by acoustic modem from the ocean bottom to the surface buoy, (2) by VHF packet radio from the surface buoy to the shore station, and (3) by telephone from the shore station to the laboratory

could receive raw data during bottom storms even though there was not enough space on the bottom hard disk for the data.

Description of each Station of the Communications Channel

Bottom station

The bottom tripod is shown in Figure 3. The vertical column in the center of the tripod measures current at six points. The acoustic transducer for the acoustic modem is near the top of the tripod. The block diagram for the bottom station is shown in Figure 4. The BASS 6-head current meter generated data from all the current meter sensors every half second. This data was processed by an Onset Tattletale model VI low power computer, and the processed data stored on its 20 Mbyte disk every 30 minutes. The processed data was also sent to the Josko Catipovic acoustic modem, Datasonics model ATM 840, in a burst of 2304 bytes at 9.6 kHz. The tripod-mounted ATM 840 sent the data at 1185 bits/sec to the acoustic receiver, an ATM 850, on the buoy. No data error detection or correction was used by the data source or the acoustic modem, in part because of the high data rate desired for the raw data. There was no data transmission capacity left for error correction.

Buoy station

A sketch of the buoy is shown in Figure 5. Starting at the bottom of the figure, the acoustic transducer for the acoustic modem is 14 feet below the surface to avoid the bubbles in the water. Bubbles could block acoustic transmission. The acoustic transducer cable runs to the top of the buoy center well in the center of the buoy. The center well contains the acoustic modem, VHF packet radio and battery. The VHF antenna is mounted on the top of the buoy tower.

A block diagram of the buoy station is shown in Figure 6. Acoustic data transmissions from the ocean bottom mounted acoustic modem are received by the acoustic transducer mounted 10 feet under the buoy. The acoustic transducer is connected to the Datasonics ATM-850 acoustic modem. Data received by the acoustic modem is sent through an interface circuit to the PacComm Micropower-2 Terminal Node Controller (TNC). The interface circuit turns the TNC on when the TNC is needed by the acoustic modem or the VHF transceiver, and turns the TNC off when finished to save energy.

The TNC divides the data up into 256 byte blocks and adds housekeeping information. This added information includes the station name, the length of the data block, and an error detection code. The data was sent without request for acknowledgement from the destination. This speeded up the data transmission by not having to wait for an acknowledgement. The data goes through a 1200 baud modem to the transceiver. The three Watt VHF transceiver, Kantronics model drr 2-2, sends

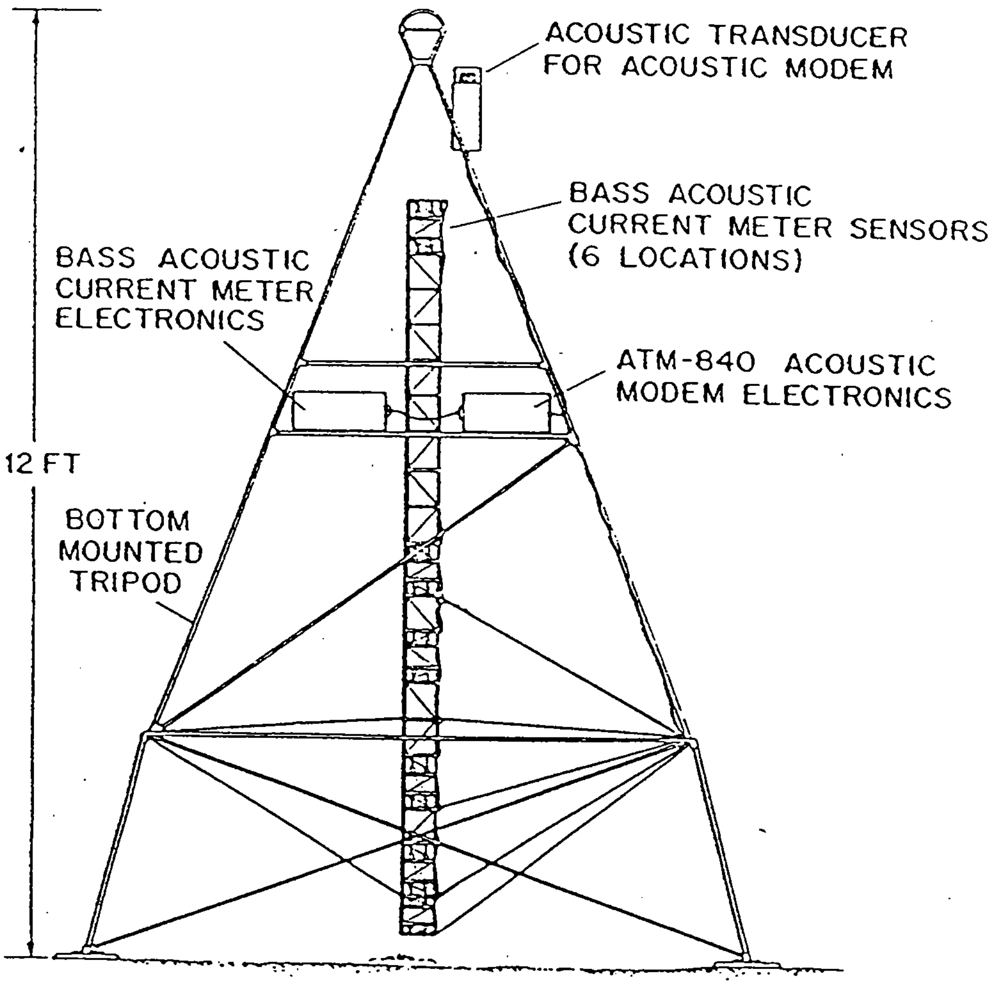

Figure 3: Bottom tripod with BASS acoustic current meter and ATM-850 acoustic modem.

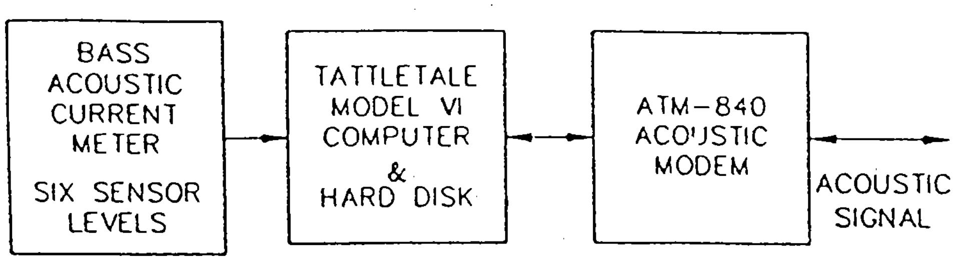

Figure 4: Block Diagram of the bottom mounted current meter and acoustic modem.

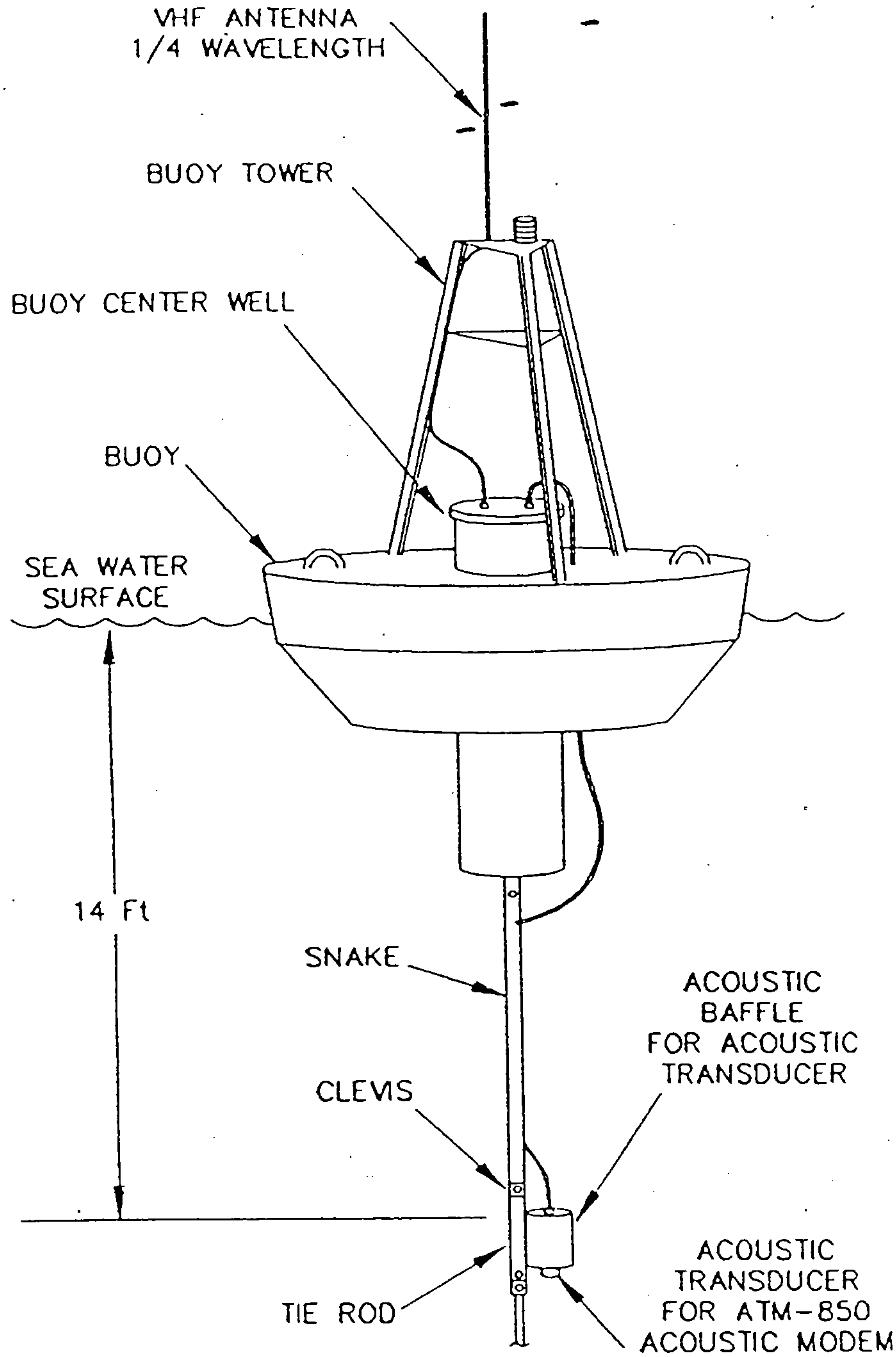

Figure 5: The buoy station. The ATM-850 acoustic modem, the TNC, VHF transceiver, and 250 pound battery are in the waterproof center well. The acoustic transducer is located below the bubbles that are near the surface. The flexible non-twisting snake connects the acoustic hydrophone to the buoy.

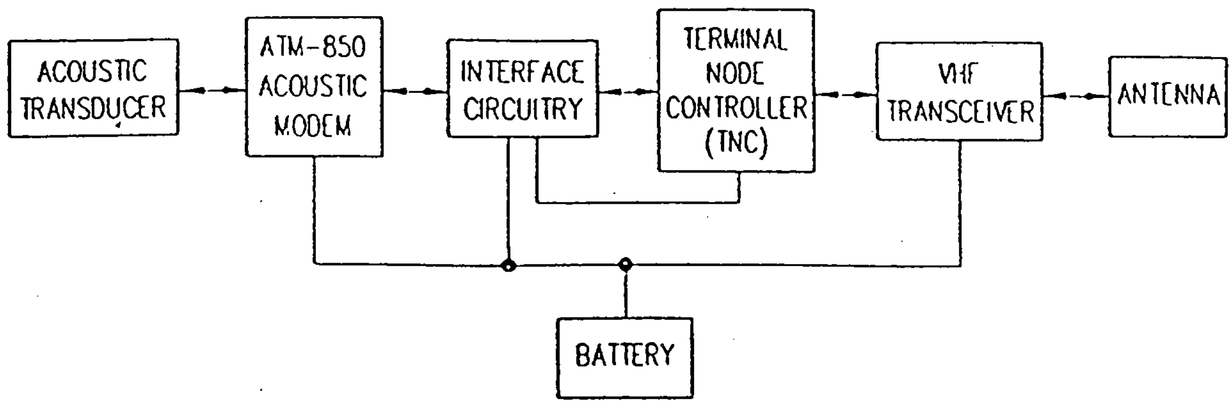

Figure 6: Block diagram of the buoy station. Data flows from the acoustic modem to the VHF transceiver. Commands flow in the opposite direction.

its signal to a quarter wave whip at the top of the buoy tower. The radio signal is transmitted from the buoy to a similar transceiver on shore.

Shore station

A block diagram of the shore station is shown in Figure 7. There was a separate radio frequency for each of the two buoys. The shore station uses a yaggi antenna connected to the same model transceiver and TNC for each frequency channel. Data reception at the shore station used error detection, rejecting data packets with errors. Although error correction using acknowledge and retransmission was available for the radio and TNCs, it was not enabled in order to obtain a higher data rate.

The shore based computer had a separate RS-232 input for each channel. The 286 AT type personal computer stored the data as received onto optical disk, with channel identification and time appended. The custom program stored the data and also displayed selected portions of the data from each buoy on the screen.

The shore computer had an internal Intel 2400B MNP (Hayes compatible) 2400 bits/s telephone modem, with error detection and correction. This modem was connected to the telephone network so it could be connected to another computer at a remote laboratory. Satellite and BLAST, a remote control and data transfer program, was running in the background on the shore computer. The Satellite program allowed the shore computer to be operated from a remote location, and BLAST allowed data to be transferred to a remote location.

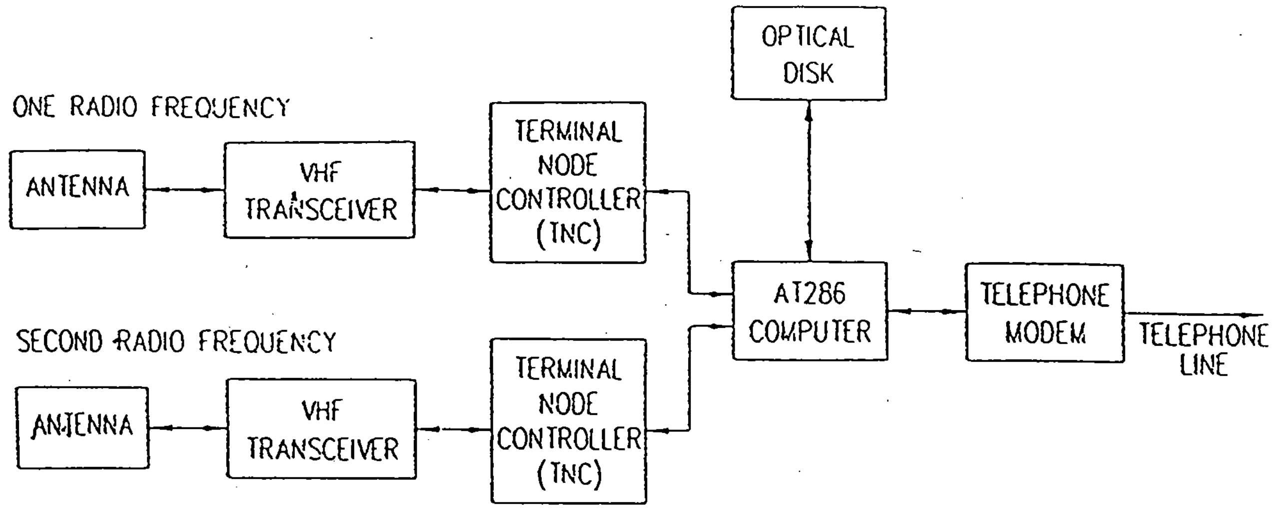

Figure 7: Block diagram of the shore station. The shore station communicates by packet radio with the buoys and by telephone to the laboratory.

Laboratory station

The laboratory station block diagram is shown in Figure 8. The same type telephone modem as used at the shore station is used in the laboratory station. It is connected to a 286 AT type personal computer. The BLAST program, running on the laboratory computer, can telephone the shore computer, establish connection first with the modem, then between the BLAST data transfer programs. Data files stored on the shore computer's optical disk could be transferred to the laboratory computer. These files could be inspected to see if there was any ocean bottom storm activity.

The shore computer could be commanded to start the remote control program. Then the screen on the shore computer would be reproduced on the laboratory computer. The screen could be read to see if any ocean bottom storms were brewing. If so, commands could be sent back through all the previously described paths to the bottom of the ocean. The ocean bottom computer could be commanded to send 20 minute segments of raw data from the current meters. The data would be stored on the optical disk at the shore station, and then could be transferred to the laboratory computer laboratory.

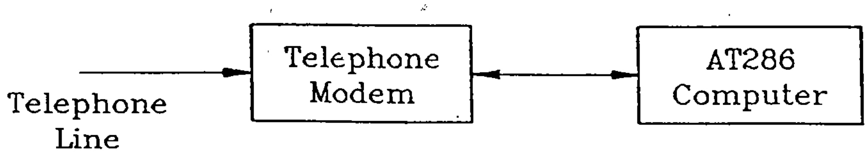

Figure 8: Laboratory station block diagram

Performance and Evaluation of the Communication System

Communication system performance

After a harrowing final debugging phase, the system solidly logged data on shore from the tripod that was 10 miles off shore. The reverse channel commanding the tripod to send raw data worked well. Communication was achieved from the shore station to the laboratory, where many files were transferred and the shore computer was operated remotely from the laboratory.

After 3 weeks of operation, data from the acoustic modem was interrupted during a storm. A 1/4-20 bolt acting as a pin that held a threaded clevis onto a threaded tie rod came out, allowing the tie rod to turn and twist the hydrophone cable until the wires broke. The radio modem link continued to work. The same problem with the bolt occurred with the buoy that was 5 miles offshore while its electronics were ashore being serviced. The clevis completely unscrewed and the buoy was lost.

What was still not performing well.

Data was received onshore and at the laboratory from the bottom and commands were sent to the bottom successfully, but there were still a few problems. The data format was not the same as the specified format. The data header was about half way into the data block instead of at the beginning. The data display on the shore computer screen was nonsense because actual data format was not what the display program expected. The display program could not be changed easily.

Even the displaced data header was present only one-third of the time. This made it difficult to read the data from data dumps of the stored files. We do not know whether the headers were not sent from the bottom, or if they were lost by the acoustic modem. It is unlikely that the data header was lost in the radio transmission. If the radio modem found an error, the shore TNC was set to reject the 256 byte block that had the error. An error in radio transmission would have shown up as a shortened data reception. I found a shortened transmission only one or two times in all the data received in the laboratory. So the radio portion of the data transmission worked well.

The BLAST data transfer program, which connected the shore station to the laboratory station over the telephone, transferred the data very well once it made connection. The connection sequence failed about half the attempts. During one period of several weeks, I was unable to connect at all; then it started to connect again. The BLAST remote control program, which allowed you to operate the shore computer from the laboratory, worked but was painfully slow in screen update and response to keystrokes. It took 1 second to respond to a key stroke, and 5 seconds to update a screen.

The fatal problem was the failure of the clevis securing pin, which resulted in losing connection between the acoustic transducer on the buoy and the acoustic modem inside the buoy. The clevis should be welded to its tie rod instead of threaded and pinned with a bolt.

Evaluation of the communication system

The main electronic parts of this system that are difficult, the acoustic modem and the radio modem, have been demonstrated to work. There are necessary improvements in the system: a survivable mooring and connection to the surface hydrophone, error detection and correction in the acoustic link, correction of the data header location, and sufficient data framing information to allow resynchronization of short portions of the data.

There are additional improvements that should be incorporated as this communication system evolves to become more robust and easier to use.

Improvements to the Overall System

There are several groups of improvements. The first group are the repairs and discoveries that have been made to get the system working. These are listed so they will not have to be rediscovered. Second are the improvements made in the acoustic modems since this experiment, which are mentioned so you can be aware of the improvements. The third group are the several deficiencies that prevented the communication system from being a total success. These are mentioned so they can be repaired before trying again and so the other parts of the system that worked are identified. The fourth and largest group are the many refinements that would make the system work better and be easier to use and service.

Some of the items which were repaired.

The 1/2 inch chain in a nearby pickup mooring rang at 12.5 kHz, the wakeup frequency for the ATM-850 acoustic modem. This chain had to be dropped to the bottom to keep it from continuously waking up the acoustic modem. The wakeup signal has been increased to three frequencies in the acoustic modem. However, determine that the chain used does not ring at any frequencies used by the acoustic modems.

The PacComm Micropower-2 TNC has battery backup for stored parameters. This system sometimes forgets when the main power is turned off. We turned off the TNC power in the buoy after every use, so sometimes it forgot. The manufacturer recommends that you use a ROM with the parameter default values set to the desired values. The manufacturer sell EPROMS with your default parameters for $50 for the first one and $30 for additional copies. However, the manufacturer should fix the battery backup logic so it works.

The Kantronics model drr 2-2 transceiver uses a BNC RF connector. The center conductor of this BNC is made of dead soft copper, so it deforms out of place and stays there. This connector must be replaced with one with a spring metal center contact.

Sharply bending the cable at the base of the quarter-wave antenna breaks the center cable conductor at the connector. This connector needs a good strain relief, and should not be doubled back sharply during handling and shipping. Also, it was not a waterproof connection.

The frequency modulation level in the transceivers was set too low. The frequency modulation level was increased until the received signal became distorted. Then the level was reduced about a third. This technique for setting the frequency modulation level was used in the field with little test equipment. The correct frequency modulation level should be determined.

I adjusted the carrier signal level detector slightly above the level with no signal present. We need a better method for setting the signal level detector for the receiver in the transceivers. The Kantronics transceiver has a 90 dB range signal level detector, stable to 2 dB, and the Radiocom handie-talkie uses the in-phase phase detector output for an amplitude. Both are stable signal level detectors.

Improvements already made to the acoustic modems by the manufacturer.

The wakeup signal that starts the ATM-850 receiving has been changed from a single frequency to three frequencies. Thus a single frequency (such as chain ringing) will not start the reception.

Phase steps in the transmitted signal occurred when the transmitted signal changed frequency. The sharp edge of the phase step generated high frequency interference. Now the output signal phase is continuous when the signal changes frequency and the self generated noise caused by the phase step is gone.

The ATM-840 started transmitting as soon as its input buffer was full. If the ATM-840 received any more data before its input was empty, the contents of the buffer would be discarded, the transmission would be terminated, and the new input would be accepted. The input buffer has been changed to a circular buffer, so it can receive new input before it is empty, and the current transmission is not terminated.

Data is encoded for error detection and correction in the updated acoustic modem. This new feature uses half the data transmission capability, so the bit rate is lowered from about 1200 to 600 b/s.

Another modification to the digital-to-analog converter output makes the transmitter output more closely resemble the intended signal, which lowers the transmitter generated noise.

Changes that could be made to the acoustic modem.

The ATM-850 uses a 24 volt power source; transmitters use a 12 volt source. If solar cells were being used to recharge the batteries in the buoy, it would be convenient to have only one set of batteries. The ATM-850 does not need high power output when working with an ATM-840, so its supply voltage could be lowered to 12 volts.

Data format improvements to aid data recovery and determine transmission errors.

In this experiment the condensed data was sent three times, spaced in time. Each transmission sent the most recent data, the data for the previous interval, and the data for the time before that. We had planned to compare the data from three transmissions and use majority vote to determine the correct data. The data header, which denoted the beginning of each of the three data segments, was missing two-thirds of the time. This meant the data could not be compared without a lot of guessing about where it started. Data containing errors that have to be removed manually is seldom used. Do not assume that you can distinguish the good data from the errors. Maybe you can, but you probably won't.

Here are some recommendations for error detection and recovering from errors. Add error detection code frequently in the data stream. Add data delimiters frequently in the data stream. Use a delimiter that cannot occur as part of the data. Some sequence determination scheme should be included as part of the delimiter, so you know which parts are left if some of the data is missing. If part of the received data is corrupted, use the delimiters to know where to start each part of the data sequence and the error detection codes to tell if the data in each part is correct.

One should find out what others do about this problem. Jet Propulsion Labs send pictures a long way without feedback error correction; compact discs perform error correction without feedback.

More replaceable acoustic modem components on the buoy.

The acoustic transducer and cable under the buoy should have an underwater plugable connector, so that the hydrophone can be changed underwater by a diver. The acoustic transducer cable should be shielded to reduce noise pickup.

The acoustic transducer housing includes a preamp, which requires 12 volts DC. If the transducer is removed underwater, the 12 volts would corrode the contacts of the open connector. Currently, the connector has to be unplugged from the buoy well to temporarily remove the 12 volts. Move the preamp out of the acoustic transducer to get rid of the 12 volt supply on the cable.

The acoustic transducer is held in its acoustic shield with bungy cord, threaded rod, washers, and nuts. It is a force fit into the foam filled bucket. This acoustic shield should be redesigned so the transducer is more securely held and easily changed by a diver. For example, the bolts could use captive nuts.

The acoustic transducer cable is molded into the snake under the buoy to protect the cable. It is impossible to remove this cable on the mooring. A path for a replaceable cable should be built into the snake and a more protected cable path found through the buoy.

Better remote control program.

The BLAST data transfer program often requires multiple attempts to connect, and the remote control part of the program is slow. One should find out why BLAST balks at connecting. There is a script code used for the connection process that could be explored and improved. We could try the new version of the BLAST program. Also, other data transfer and remote control programs exist which update the screen faster.

Solar battery charging system as standard on buoys.

A 250-pound battery made of alkaline D cells was used because it was the cheapest option and there was no charging system to deal with. However, solar cells would permit more radio transmissions, and you would not have to save the battery for possible later transmissions. If you had some disaster which discharged the batteries, you would not need spares or get replacements, which takes about a month. The solar panels could be used for future projects. The buoy with solar panels and rechargeable batteries should become a standard device.

Higher efficiency radio transmission.

Three of the five sections of the 250 pound battery were for the radio transceiver alone. This shows that the radio transceiver is the place to increase efficiency.

A linear regulator was used to provide power from the 20 volt alkaline battery stack. A DC-DC converter could be used for more efficient power conversion to the 12 volts needed by the transmitter. The converter would be turned on only when the transmitter is running. It would turn off when the receiver is running, so the DC-DC converter noise would not interfere with radio reception.

We used a 1/4 wavelength antenna. A higher gain 5/8 wavelength antenna could be used. We could use a lower loss antenna cable. At 148 MHz, even 15-foot antenna cables have significant loss. We used RG-58, and we should use the lower loss RG-8 cable.

The transmitter power could be reduced, commensurate with the power saved with the higher gain antenna and lower loss cable.

We could use a higher data rate than 1200 b/s to transmit the data in less time, and thereby save energy.

We used one transceiver that required only 6 mA for the receiver. The Kantronics used about 40 mA for the receiver, which is a lot more power. The lower power transceiver costs $600 compared with $250 for the Kantronics, but it could be worth it. The lower power receiver is a section of a handie-talkie, and is more difficult to connect up.

We would like to be able to transmit and receive on two different frequency radio channels at the same time at the shore station. Both the antenna and the frequencies would have to be separated by an unknown amount to keep one transmission from interfering with the other receiver.

Terminal node controller (TNC) improvements.

When receiving blind transmissions, you have two choices for the data block containing an error: (1) throw away the block with the error in it, or (2) let the block pass through. If you throw the data block away, it is nice to mark the spot where it was thrown away so spaces can be left in the data. If you do not throw the data block away, it should be able to be marked so you know it contains an error.

The TNC manufacturer should solve the memory forgetting problem when the TNC is turned off. Using custom defaults in the EPROM gets around this problem, but it should be fixed.

One of the many (approximately 60) commands for the TNC is to ignore further commands. This command should be removed for the TNCs on the buoys since it could cause a fatal latchup on the buoy.

An alternative to turning the TNC off is to have it go to sleep. The TNC manufacturer would have to engineer this change.

Interface circuit between the acoustic modem, TNC, and radio transceiver.

The power in the interface between the acoustic modem and the TNC is turned on and off. An output enable on the interface should be switched instead of the whole circuit.

Other improvements.

Sometimes the buoy electronics has to be changed while the buoy is moored. A splash cover for the buoy electronics would protect the electronics from drops of sea water.

The snake under the buoy was covered with a two-foot thick marine growth after four months in the ocean. This large area adds to the thrashing the buoy takes in the waves. The snake should be painted with antifouling paint. If paint will not stick to the rubber snake, the rubber could be impregnated with tributal tin.

Do not peen nuts to keep them from coming off. They will come off anyhow unless severely deformed. Use some retaining nut or bolt such as Nylok, or use Loktite or a cotterpin. In the case of the tie rod, weld the clevis to the tie rod instead of pinning it with a bolt.

Consider the NOAA Data Buoy Office version of the size buoy used in this experiment. It has solar cells and a single post for the tower.

Tests to Assure Correct Operation

Radio tests

The buoy was deployed with a broken antenna wire, which went undetected because enough signal leaked out to communicate with a receiver that was nearby. A field strength meter should be used to measure the power output from the buoy antenna. To test the transceiver in the receive direction, a much reduced radio signal should be transmitted to the buoy. This technique would measure the margins available.

An FM deviation meter should be employed to set the frequency modulation levels. One should find out what the approved maximum modulation levels are for this class of transceiver.

System tests

The whole system was plugged together in the laboratory before it was deployed. Many times there would be a problem, but we could not isolate which part of the many pieces that were connected in series was causing the problem. A means for monitoring data anywhere along the data path needs to be developed. Using the TNC monitor command with an auxillary TNC and receiver is an excellent example of this type of monitoring.

Conclusion

The acoustic modem and the radio packet communication system work. The error detection, small changes in the mooring design, and correction of the format of the data source would have made the experiment a success. Implementing the long list of improvements would make the system easier to operate and deliver more complete and error free data to the user. This communication system should evolve, and this report forms the basis for that evolution.

Acknowledgments

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TRANSFER FUNCTION OF ONR/OBS

Don Koelsch and John Hallinan

By applying analytical techniques to the circuits, the following conclusions have been attained.

Figure 1 is the simplified block diagram of the Office of Naval Research/Ocean Bottom Seismometer (ONR/OBS). It indicates signal flow through the instrument. The following is the transfer function of each stage. These functions are stated in the Laplace variable S where jw can be substituted for S and the equation solved.

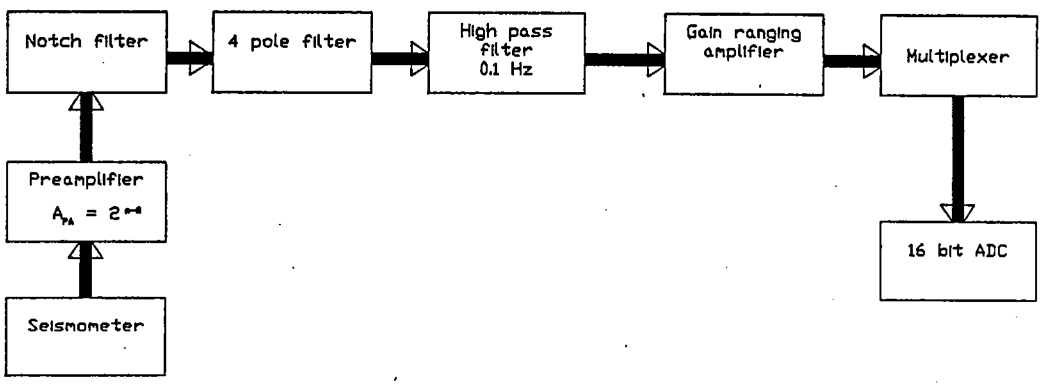

Fig. 1. Signal path for the ONR/OBS from the seismometer to the input of the ADC.

The preamplifier has no reactive components, therefore, its transfer equation has only gain components.

$$A_{P.A} = 2^{(n-2)}$$

where 'n' = gain step number and ranges from 0 to 10.

Notch filter:

The notch filter has three active filter stages connected in a series.

Stage N_1

$$A_{N1}(s) = .254\left[\frac{\dfrac{S}{2\pi(.504)}+1}{\dfrac{S}{2\pi(0.1)}+1}\right]$$

Stage N_2

$$A_{N2} = \frac{\left[\dfrac{S}{2\pi(1.51)}+1\right]}{\left[\dfrac{S}{2\pi(32)}+1\right]\left[\dfrac{S}{2\pi(5.05)}+1\right]}$$

Stage N_3

$$A_{N3}(s) = 2\,\frac{\left[\dfrac{S}{2\pi(1.51)}+1\right]\left[\dfrac{S}{2\pi(1.51)}+1\right]}{\left[\dfrac{S}{2\pi(5.03)}+1\right]\left[\dfrac{S}{2\pi(5.08)}+1\right]}$$

$$=2\left(\frac{\left[\dfrac{S}{2\pi(1.51)}+1\right]^2}{\left[\dfrac{S}{2\pi(5.03)}+1\right]^2}\right)$$

$A_N(S) = A_{N1}(S)\cdot A_{N2}(S)\cdot A_{N3}(S)$

$$= .508\left(\frac{\left[\dfrac{S}{2\pi(.504)}+1\right]\left[\dfrac{S}{2\pi(1.51)}+1\right]^3}{\left[\dfrac{S}{2\pi(0.1)}+1\right]\left[\dfrac{S}{2\pi(5.05)}+1\right]^3\left[\dfrac{S}{2\pi(32)}+1\right]}\right)$$

Four Pole filter Tuned to 30 Hz

This filter is a four pole Chebeshev with a one dB ripple in the pass band. The first stage is tuned to 15.1 Hz with a damping factor $\alpha_1 = 1.26$*. The second stage is tuned to 28 Hz with a damping factor $\alpha_2 = .28$. The expression for the four pole filter is:

$$A_{4P}S = \left(\frac{S^2}{\left[2\pi(15.1)\right]^2} + \frac{S(1.26)}{\left[2\pi(15.1)\right]} + 1 \right)^{-1} \left(\frac{S^2}{\left[2\pi(28)\right]^2} + \frac{S\,(.28)}{\left[2\pi(28)\right]} + 1 \right)^{-1}$$

* Some text use the term ζ where $\alpha = 2\,\zeta$.

High pass section of the 4 pole filters

$$A_{HP}(S) = \left(\frac{\frac{S}{2\pi(0.1)}}{\frac{S}{2\pi(0.1)} + 1} \right) = 1.59 \left(\frac{S}{\frac{S}{2\pi(0.1)} + 1} \right)$$

The gain ranging amplifier has no reactive components. Therefore like the preamp, contributes a gain term.

$A_{GRA} = 2^{nGRA}$ where n = gain step of the GRA.

The total transfer function is:

$$A_{TOTAL}(S) = A_{PA}\ A_N(S)\ A_{4P}(S)\ A_{HP}(S)$$

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WHOI Technical Memorandum, Dept. of Geology & Geophysics, October 29, 1991.

DYNAMOOR Subsurface Mooring Experiment

Ann Martin

DYNAMOOR, a field experiment designed as the initial step in a program to monitor the modes and frequency ranges of a subsurface moored buoy and its anchoring line in strong currents, was conducted in June 1991 at a site off Nonamesset Island. Data acquired from this experiment are expected to provide a better understanding of cable vibration (strumming), which can lead to the destruction of instruments, and of the mooring line, in oceanographic experiments conducted in strong currents such as the Gulf Stream, the Agulhas, and off Gibralter. The experiment was also designed to determine the effect of strong and varying currents on the motion and stability of a subsurface sphere.

The principal investigator was H.O. Berteaux; the initial experiment was conducted by C.F. Eck.

An anchor and junction box were lowered to the seafloor at a 100-foot depth in a current of about 3 knots. This was the link between a subsurface buoy and a fiber-optic cable feeding in to a PC data logger at the surface. The design specified the following data collection instruments: Acoustic Doppler Current Meter, SHARPS transponders, and a directional wave and tide recorder.

Data were collected for 3 days and stored by the logging PC aboard RV Asterias. For this initial phase, the stored data included the battery voltage from the subsurface sphere, and measurements of the anchor tension from a tension cell attached to the anchor line at the base of the sphere. Current profiles from the Acoustic Doppler Current profiler and positional data from the SHARPS transceiver net were recorded on separate PCs, providing the data on the input forcing functions.

The logging computer is a 386 25MHz PC with a 40MB hard disk. It is anticipated that in future experiments up to 8 lines in the fiberoptic cable will deliver signals to the PC, so the PC has been equipped with a DigiCHANNEL PC/8 multichannel serial communications board which accepts 8 DB-25 serial connectors in the form of a fanout cable. The full complement of serial devices was enabled for the experiment, but only two lines were used. The communications software controlling data input through multiple ports was the Greenleaf Software CommLib, a library of interrupt-driven asynchronous communications functions. Each port has its own buffer for which size can be defined; the baud rate for each port is defined separately, so that data can be accepted at a variety of rates.

It was also necessary to equip the PC with a mass storage system, since future experiments will require logging of far more data than can be stored on the 40MB hard disk. (In the event, for this experiment a copy of the data was stored on the hard disk since the volume was small.) We chose a Bi-Tech Exabyte tape system, with SCSI interface. It was designed for use as a backup system, but with the driver provided by APtek, Inc., and access functions written by engineers in W.H.O.I.'s Deep

Submergence Lab, it can be used for sequential storage. The tape has a capacity of 2.3 Gigabytes.

Data were acquired through the serial ports at 9600 baud, and the buffers were set to 4096 bytes each. The buffers were polled, and when it was found that a buffer contained a specified number of bytes (2032), these were offloaded into a data array variable, following a header. The header contains sufficient information so that the data could be retrieved at a later time for several specifications:

all data from a specific channel
all data from a single Julian day
synchronous data

Data and header added up to 2048 bytes; when each array variable was completed, it was written to tape.

The experiment yielded useful information, both in observations of cable behavior in currents, and in software design and hardware configuration for the logging of data. The collected data suggest that the higher the tension of the cable, the higher the frequency of vibrations. The design of the logging system has been changed for the next iteration of the experiment, in which all eight serial ports are to be used, with data arriving through four of them at 19.2K baud.

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PERFORMANCE OF AN MFSK ACOUSTIC TELEMETRY SYSTEM

Steve Merriam, Daniel Frye and Josko Catipovic

ABSTRACT

A low power, medium data rate acoustic telemetry system has been developed at Woods Hole Oceanographic Institution to address a broad range of underwater communication needs. The system utilizes advanced digital signal processing techniques to implement an MFSK telemetry scheme capable of data rates up to 5000 b/s. A series of shallow and deep water tests of this system have been performed over ranges from a few hundred meters to 2500m which allow system performance to be characterized. Operation over the vertical and horizontal channel has been investigated. The paper will provide a system description, summarize the results of the in-water tests and compare the results to the expected theoretical performance of the system in a realistic ocean channel.

Typical bit error rates for the acoustic telemetry link over the vertical channel are 10^{-4} to 10^{-6} over ranges of 500 to 2500m using directional transmit and receive transducers with the receiver hydrophone suspended a short distance below the surface. Performance over the shallow-water horizontal path is about an order of magnitude worse. Recent improvements in link performance using more sophisticated error correction coding will also be reported.

The MFSK acoustic telemetry system technology has been transferred to industry, and acoustic modems are now available from a commercial vendor.

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IN SITU PROCESSING OF ADCM DATA FOR REAL TIME TELEMETRY

Robin Singer and Steve Smith

A Data Processing Module (DPM) has been developed to provide data reduction through real time, in situ processing of Acoustic Doppler Current Meter (ADCM) data. This enables the transmission of ADCM data from remote locations via satellite, despite the low throughput of such telemetry systems and the high data volume of ADCM's. AEL engineers, working in a team lead by W.H.O.I. physical oceanographer Al Plueddemann, designed the DPM for maximum reliability and low power. DPM-enhanced ADCM's can be easily interfaced to buoy systems or instrument packages over an EIA-485 serial link.

The DPM was developed for use in the Ice-Ocean Environmental Buoy (IOEB), a second generation Arctic drifting buoy, put together by engineers working for W.H.O.I. geologist, Susumu Honjo. It consists of a large suite of subsurface instruments, a meteorological package, two buoy controllers, and a pair of ARGOS satellite transmitters housed in the surface floatation element. The IOEB was designed for extended deployments in the pack ice. The long deployment duration and limited buoy recovery opportunities dictated the use of satellite telemetry to ensure timely data acquisition. The limited ARGOS system throughput necessitated reduction of the ADCM data by a factor of about 170:1.

The DPM processing includes manipulation of velocity and echo amplitude data, received in beam coordinates from the ADCM, to produce depth-time averaged arrays in earth coordinates. Before averaging, tilt data is used to interpolate the slant velocity and echo amplitude for each beam onto standard depths, the four slant velocity beams are combined into two horizontal and two vertical velocity estimates, and heading data is used to rotate the horizontal velocities into earth coordinates. Eight fifteen minute data sets are time averaged for the IOEB application, and data from 30 eight meter depth bins are averaged into four 10-bin arrays. (2 horizontal velocities, 1 vertical velocity, and 1 echo amplitude). In addition, unnecessary ADCM data is eliminated and status/error values are combined into summary parameters to achieve the desired data reduction.

The DPM can be easily interfaced to buoy systems because it communicates over a standard EIA-485 link and its intelligence is derived from firmware written in "C" and therefore easily modified. The hardware is based on a low power CMOS Intel 80C51FC microcontroller with on-chip UART, RAM, EPROM, interrupts, and timers. An additional UART and communication circuitry allow the DPM to receive data over an EIA-423 serial link from the ADCM while simultaneously providing for two way communication over the EIA-485 link with a buoy controller. The EIA-485 communication is implemented with the SAIL (IEEE-997) software protocol which allows a variety of instruments, responding to different SAIL addresses, to communicate on a common link.

There are a variety of features that increase the DPM reliability under adverse conditions and reduce its power consumption to enable long deployments. These include a watchdog timer to prevent firmware glitches, comprehensive error checking, optical isolation from the ADCM to prevent corrosion, a dual address scheme to enable redundant data telemetry, and shut down modes to save power between tasks. Self-powered and housed in its own pressure case, the DPM provides a robust tool which can bring ADCM data from remote locations in real time, to scientists in their laboratories.

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COHERENT COMMUNICATIONS OVER LONG RANGE UNDERWATER ACOUSTIC TELEMETRY CHANNELS

Milica Stojanovic, Josko Catipovic, and John Proakis

ABSTRACT

This work is focused on the possibilities of achieving reliable coherent communications over long range underwater acoustic (UWA) channels. The UWA channel is characterized as a time dispersive, rapidly fading channel, which in addition exhibits Doppler effects. In high speed communication systems, frequency selective fading results in performance degradation of coherent reception. In conventional systems, which employ phase and delay locked loop structures, a major obstacle for satisfactory performance is the intersymbol interference (ISI). In order to achieve both power efficiency of coherent detection and diversity improvement from multipath propagation, we address the problem of joint optimization of synchronization and equalization methods.

Our work consists of two major parts. The first part treats the problem of channel estimation, which is of primary importance for gaining insight into multipath characteristics and fluctuation dynamics of the UWA channel prior to the design of detection algorithm. The second part presents an algorithm for jointly adaptive equalization, carrier phase and symbol timing recovery.

The analysis was performed using data collected during an experiment conducted by the Woods Hole Oceanographic Institution off the coast of California in January 1990. The modulation format used in the experiment is QPSK, with data rates ranging from 10 to 1000 symbols per second. Bandwidth efficiency is achieved by cosine roll-off pulse shaping of the signal at the transmitter. The data were transmitted over ranges of approximately 70, 140, 200 and 250km.

For purposes of channel estimation, PN probing sequences were used. Two types of analysis were done: correlation analysis and adaptive channel identification. Correlation analysis provides insight into general channel characteristics such as multipath intensity profile. We applied the least mean squares (LMS) and the recursive least squares (RLS) algorithms to adaptive channel estimation. Both algorithms proved effective in channel estimation and tracking of individual channel path fluctuations.

The second part of our work involved the design of algorithms suitable for data detection in a given fading environment with additive white Gaussian noise. The receiver features joint, decision-directed adaption of synchronization and equalization parameters. We adopted the maximum likelihood (ML) estimation approach for the optimization of receiver parameters. Such an approach is well suited for burst type communications when the parameters to be estimated can be considered relatively constant over a burst. The optimum receiver in such a case is a joint ML estimator of

symbol delay, carrier phase and the data sequence. This receiver, however, requires complete knowledge of the channel impulse response. In order to circumvent this problem, we use a decision feedback equalizer, whose performance in the absence of decision errors is expected to be close to that of a ML sequence estimator. The equalizer tap coefficients are estimated jointly with the carrier phase and symbol timing. Since the parameters to be estimated are not constant in practice, it is desired that the receiver operate in an adaptive mode. The proposed algorithm requires the existence of initial estimates within a convergence region. The initial estimates of Doppler frequency, carrier phase and symbol timing are obtained from a signal preamble in the nonrecursive manner based on ML estimation principles.

After the initialization period, the receiver is switched to operate in a decision-directed mode. The recursive algorithm is derived based on joint minimization of the mean squared error of the detector output with respect to all the relevant parameters. Application of a one shot stochastic gradient method results in an algorithm which corresponds to the LMS adaptation of equalizer tap coefficients and the first order digital phase and delay locked loops for carrier phase and symbol delay tracking. Such an algorithm, however, is not powerful enough to track all the fluctuations present in the UWA channel. A more powerful algorithm is obtained through the use of an RLS-type update for the equalizer coefficients, which provides faster convergence during a relatively short preamble, and the second order stochastic gradient updates the estimates of carrier phase and symbol timing, whose equivalents, in the absence of intersymbol interference and decision errors, are second order digital phase and delay locked loops. The algorithm is currently being tested on the real data, and is giving satisfactory results.

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16. Abstract (Limit: 200 words)

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 oceanography, and to enhance current research projects in other disciplines within the community. This report summarizes recent and ongoing projects performed by members of this laboratory.

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