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Woods Hole Oceanographic Institution

Advanced Engineering Laboratory Project Summaries – 1990

Edited by

Daniel E. Frye

May 1991

Technical Report

Funding was provided by the Woods Hole Oceanographic Institution.

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Daniel E. Frye

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

May 1991

Technical Report

Funding was provided by the Woods Hole Oceanographic Institution.

Approved for Distribution:

Albert J. Williams 3rd

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

Abstract

The Advanced Engineering Laboratory of the Woods Hole Oceanographic Institution is a development laboratory within the Applied Ocean Physics and Engineering Department. Its function is the 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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ACOUSTIC CURRENT METER

Neil L. Brown

Abstract

Design and breadboarding of the electronics for a low power, low cost acoustic velocity sensor have been completed and initial tests have been performed on a single axis prototype. The electronics are simple and are intended to accommodate a 4 axis sensor head design. The design is a continuous wave type that determines current velocity along each axis by measuring the difference in total phase shift for signals traveling in opposite directions. The essential differences between this and earlier designs are as follows:

1. Transmission takes place in one direction at a time.

2. There is only one receiver which is used to measure the total phase shift in each direction.

3. The phase shift is measured at the 1 mHz carrier frequency. Earlier designs measured the phase shift difference at a low frequency obtained by heterodyning the carrier frequency with a local oscillator.

This approach has a number of advantages. First, only one receiver is required. Secondly, uncertainties in receiver phase shift do not matter since current velocity is a function of the phase difference. The only requirement is that the receiver has a cosine response to the total phase shift including its own. Since phase measurement is performed at the carrier frequency, no heterodyning oscillator is required.

The result is that the prototype current sensor has a zero offset of less than 0.25 cm/s. The power consumption is 2.1 milliwatts which is independent of the number of axes. It is expected that the magnetometer compass and tilt sensor also being developed will consume about 5 milliwatts and the microprocessor will consume 1 to 2 milliwatts on average making a total of less than 10 milliwatts.

Funding was provided by the Office of Naval Research under contract N00014-86-0751.

INDUCTIVE TELEMETRY MODEM

N.L. Brown, E.L. Hobart, A.J. Fougere

Abstract

During the last 12 months, members of AEL have developed a power efficient Inductively Coupled Modem (ICM). A prototype set of modems have been built which allow for 1200 baud data transfer between a number of remote units and a single master. The inductive modem uses standard, plastic-jacketed mooring cable as the data transmission channel. The surrounding sea-water 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. Industry standard modem hardware is used, operating in a half-duplex transmission mode.

Signals are coupled to the mooring wire using a split core transformer which is clamped around the mooring wire. The mooring wire and sea water return are electrically configured as a one turn winding around the split core transformer. Through the use of efficient signal modulation, low noise signal reception, and low power digital electronics, the ICM underwater unit consumes only 350 mW while transmitting or receiving and only 1.5 mW at idle. The underwater water unit continuously cycles "on" and "off" testing the line for carrier signal from the master. If carrier is detected, the underwater unit stays "on" and determines if the data sent from the master is addressed to it. Units not addressed return to power "on/off" cycling while the addressed device passes information to the master. Remotes can also initiate direct data transmission to the master. As a result, the ICM system is configured as a serial data interface between the user and his instrument, requiring little in special protocol to successfully achieve data transmission. Figures 1 and 2 show the ICM system and modem block diagram, respectively.

Dock testing of the ICM has begun which is expected to continue into early 1991. A full sea trial of the ICM is expected to occur during summer 1991. AEL is also working to transfer the ICM technology to industry making it readily available to the scientific community.

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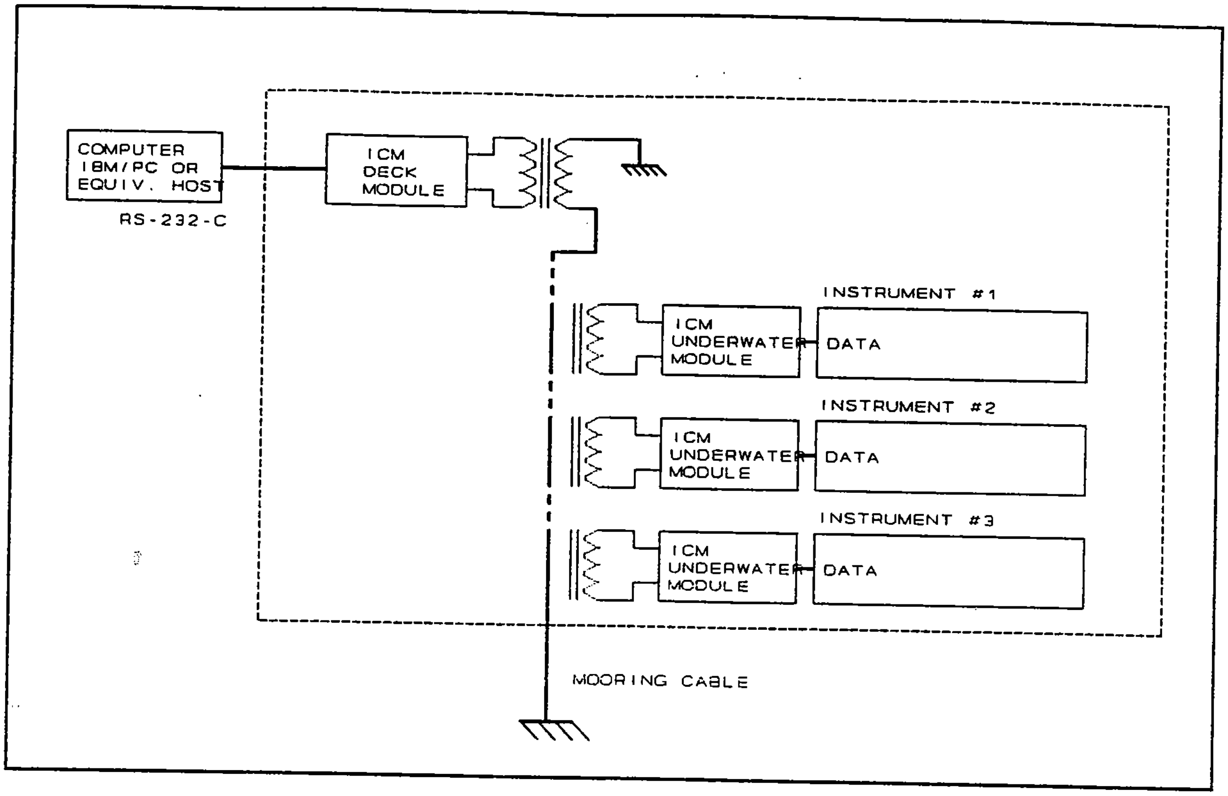

Figure 1: The ICM System

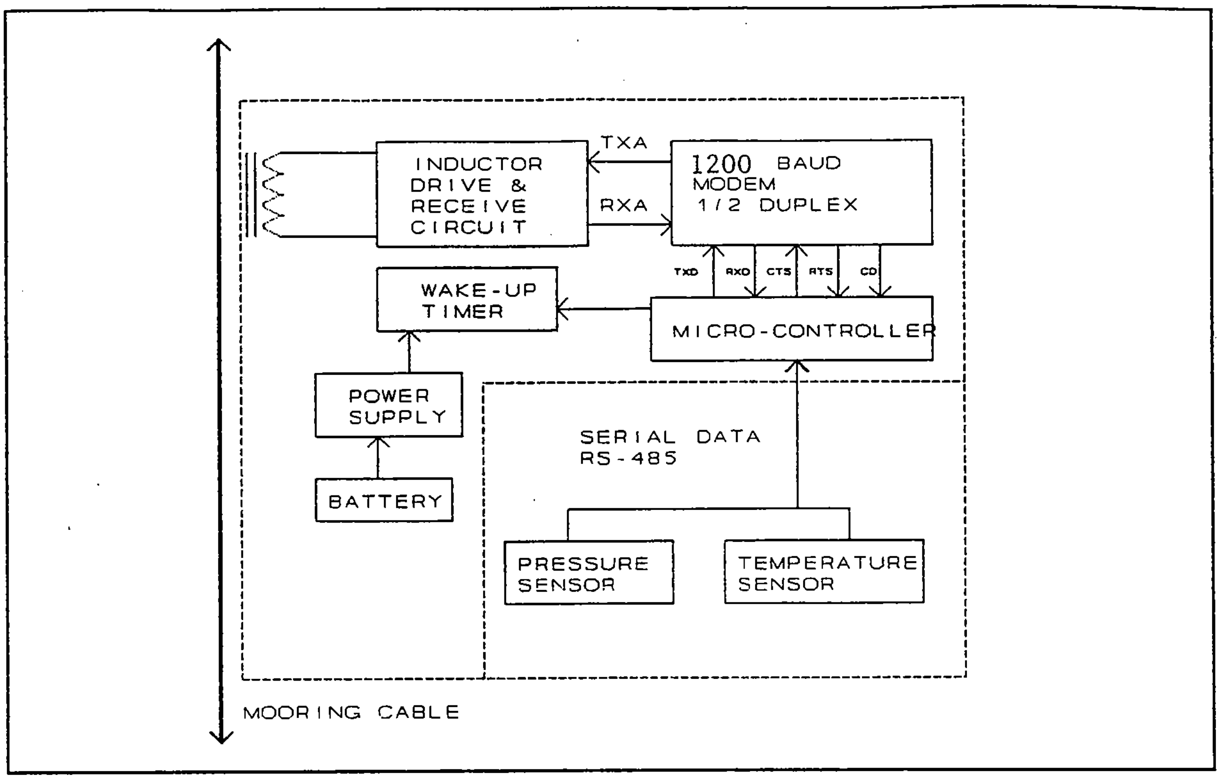

Figure 2a: Inductive Modem Underwater Unit with Temperature and Pressure Sensors

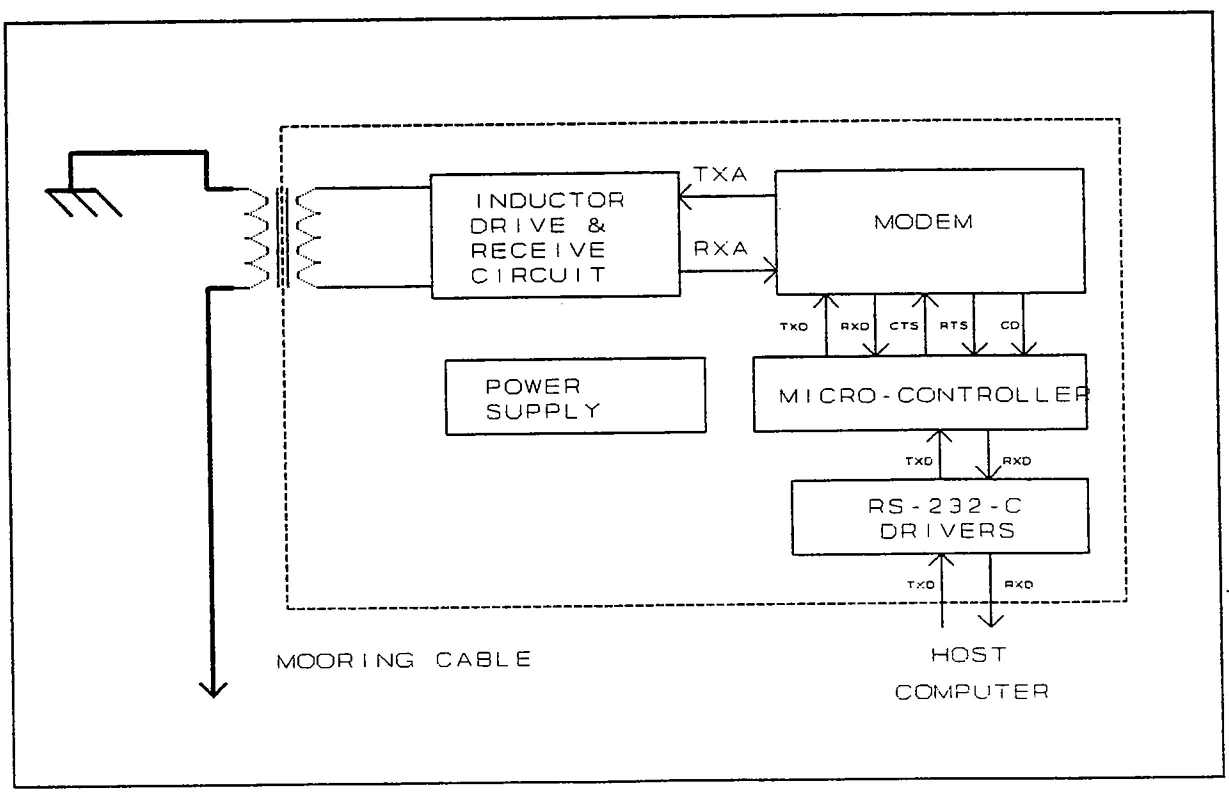

Figure 2b: Inductive Modem Master

BEEP FISH TRACKING AND DATA COLLECTION PROJECT

Frank Carey, Robin Singer and Dick Koehler

Introduction

In the BEEP program, information about fish physiology and behavior has been collected through implantation of sensors and acoustic transmitters in a variety of fish species. In particular, biologists have collected pressure(depth), water temperature, body temperature, swimming speed, and heart rate data from squid, large pelagic fish, and sharks. BEEP data has provided insight on environmentally motivated swimming patterns and the strategies fish use in coping with the large temperature gradients in the ocean.

Hardware

Transmitter

Sensor information is transmitted acoustically by a piezoelectric ceramic transducer at a crystal controlled frequency in the 30 to 50 kHz. range. Multiple channels of pulse rate modulated sensor data are time multiplexed, with periods on the order of a minute. The multiplexer clock is driven by the same crystal which controls the carrier frequency.

Receiver

The receiver consists of 4 broadly directional hydrophones and an electronics package to amplify, modulate, and decode the tones for data acquisition and processing by an IBM PC compatible computer. The hydrophones are arranged in a square pattern under a tow body that is suspended on a conductive cable over the side of a boat. Direction to the strongest signal is determined by switching between hydrophones, and the boat is turned in the direction of the maximum signal in order to follow the transmitting fish. The signals detected by the hydrophone pass through a broadly tuned preamplifier and are amplified, filtered and demodulated by a heterodyne receiver. The audible tones are converted to logic levels by a tone decoder which consists of a phase-locked loop, a phase detector, and a voltage comparator.

Computer Interface

A Metrabyte DASH-8 board, which resides on the PC bus, demodulates the sensor data. It has an 8254 timer/counter, analog and digital I/O channels, and an A/D converter which is used as an additional digital input. The digital circuit associated with the DASH-8 card converts the pulses from the tone decoder to 8254 gate and control signals. The software reads the timer/counters to determine pulse intervals. The DASH-8 digital inputs are used for sensor channel information and counter status signals and a digital output is used for counter control.

Synchronization

The receiver has a clock circuit, identical to the one on the transmitter, to determine which of the multiplexed sensor channels is current. Synchronization is maintained by the researchers who reset the receiver clock manually using the distinct changes in pulse rate which can be heard when the sensor channels change.

Software

The data acquisition program uses the channel information to apply the appropriate calibration factor to the pulse interval data and convert it to engineering units. It presents the data as a time series graph on the PC screen and writes it to disk each hour, with time and date stamps. The screen is dumped to the printer every 10 minutes to provide a paper record that is useful for following the course of an experiment. Analysis programs are used to remove errors and reveal the patterns of fish behavior.

Conclusion

The BEEP system is an inexpensive but effective program for the study of fish in their own habitat. By incorporating a variety of sensors, biologists can examine in great detail the responses of fish to environmental stimuli.

Funding for the project was provided under NSF contract No. OCE-88-11421.

ANALYSIS OF HIGH-FREQUENCY MULTITONE TRANSMISSIONS PROPAGATED IN THE MARGINAL ICE ZONE

Josko A. Catipovic and Arthur B. Baggeroer

Abstract

This work presents estimates of frequency and time coherence functions of acoustic transmissions centered at 50 kHz over a 1-km horizontal under-ice path in the marginal ice zone (MIZ). The data were collected during the MIZEX '84 experiment as part of a feasibility study for an underwater acoustic telemetry link. It is shown that the acoustic fluctuations are dominated by a 10-Hz process conjectured to be due to the turbulent under-ice layer. Significant energy in the 0.1-Hz band was also observed. The two processes differ in frequency coherence characteristics. An underwater telemetry system designed for this channel will be dominated by the high-frequency fluctuations, but the slower process is capable of causing disastrous data losses unless its effects are anticipated.

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BANDWIDTH-EFFICIENT TRELLIS-CODED MODULATION FOR PHASE RANDOM RAYLEIGH FADING CHANNELS

Josko Catipovic

Abstract

A bandwidth efficient modulation method for the incoherently demodulated Rayleigh fading channel is analyzed and implementation results reported. The method is based on partitioning binary expurgated modulation (BEXPERM) codes into subsets with desirable minimum Hamming distance properties. The subsets are comparable to signal constellation subsets used for trellis coded modulation (TCM) over phase coherent channels. A convolutional code is used to generate a subset mapping rule; its free distance is chosen to match the Hamming distance distribution within a subset to produce an overall code with error correcting capabilities comparable to those of a single BEXPERM subset. The resulting modulation method is more bandwidth efficient than MFSK while exhibiting significant coding gain. BEXPERM allows 14 kbit/sec data rates over the 2 - 10 km shallow water fully saturated ocean acoustic channel. This data rate represents a 40% increase over that currently achievable for these conditions.

Funding was provided by the Office of Naval Research under Contract N00014-86-K-0751.

Submitted for publication: IEEE Journal of Oceanic Engineering

COMPACT DIGITAL SIGNAL PROCESSING ENHANCES ACOUSTIC DATA TELEMETRY

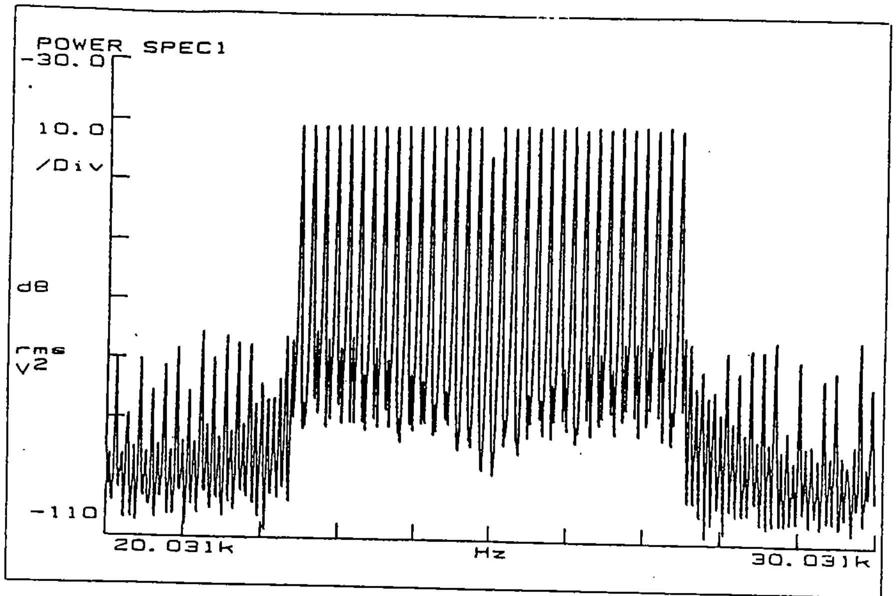
New Power-Efficient Systems Provide Means for Remote Command Control, and Communication Between Two Underwater Locations

Josko A. Catipovic and Daniel E. Frye
Woods Hole Oceanographic Institution
David Porta, Datasonics, Inc.

Acoustic data telemetry has been used ever since it was discovered that the ocean could support signal transmission. Past applications have ranged from low-baud-rate command and control systems for ocean equipment such as sea floor valves and backup acoustic blowout preventer (BOP) control in the offshore industry to acoustic releases for oceanographic moorings. These systems typically operate at tens-of-bits per second. A few higher rate systems have been developed, but these have shown high sensitivity to ocean channel features such as multipath and doppler, and are generally useful only for vertical transmission from sea bottom instruments to surface ships.

Recently, the processing capabilities of compact digital signal processing (DSP) components have encouraged computationally intensive acoustic telemetry implementations capable of overcoming many of the channel-caused problems which limited data rates in the past. The new generation systems are compact, power efficient, and contain most of the essential communication features in software.

One of the more difficult problems in achieving high data rate transmission is channel multipath, encountered particularly when communicating over the horizontal channel. The multipath arises from surface and bottom reverberation; geometric reflections from nearby objects such as piers and ships; and in-water turbulence, thermal gradients, and other environmental effects. The factor dominating system performance is the rate of change of the multipath, rather than the multipath duration or the number of reflections. If the multipath were stationary, classical techniques could track and mitigate the multipath effects. As the multipath becomes more dynamic, tracking becomes difficult and system performance degrades. For this reason, communication over the shallow water horizontal channel, particularly in enclosed bodies such as bays and harbors, is the difficult aspect of acoustic telemetry. Applications in deeper water, or where the data transmission path is more nearly vertical, are easier to address because of the reduced multipath environment. Our strategy has been to design the telemetry system for the most demanding channels of interest, namely shallow water environments, but to design the system hardware to operate over more benign channels with appropriate software modifications.



The ATM-840 transmission spectrum.

Figure 1

Hardware Designs

A general purpose acoustic telemetry system has been designed at Woods Hole Oceanographic Institution and is being manufactured by Datasonics, Inc. under licence. The bulk of the system's complexity is in the software, particularly the channel tracking and adaptation algorithms. The development process began with extensive software simulations on a work-station network. With this technique, a propective algorithm is benchmarked against other techniques with Monte-Carlo system simulations over Rayleigh fading multipath channels. The final step is to migrate the selected algorithms onto space - and power - efficient hardware implementations.

Two hardware designs have been developed:

1. The ATM-840 is a low power acoustic telemetry modem centered around a Motorola 68HC11 microcontroller. The modem consists of a data transmitter capable of coded multiple frequency shift keying(MFSK) transmission at data rates up to 1,200 bits per second, and a data/command receiver with a 300 bit per second capability.

2. The ATM-850 is based on AT&T DSP32C processors. This modem allows transmit and receive functions at rates up to 5,000 bits per second over worst-case acoustic channels. The ATM-850 can use larger signalling alphabets and can implement advanced decoding, adaptive equalization, and synchronization algorithms required to support higher data rates.

The ATM-840 system is envisioned as a modem for subsurface instrumentation. It is compact, and transmit efficiencies approach 1,000 bits/joule/kilometer. The included command receiver and a packet transmission protocol allow implementing a local area network between many subsurface instruments and a central data collection point. It is ideally suited for applications where many subsurface instruments need to be interfaced to a single satellite or fiber-optic link to shore. The system employs MFSK transmission with up to 16 tones which allows representation of two bits with each tone transmission, thus transmitting 32 data bits with each transmission frame. Typically, a synchronization frame is inserted periodically into the data sequence. The data is double sideband (DSB) modulated onto a software-controlled carrier. For this example, 16 tones are transmitted in the 22.5 to 27.5 kHz bandwidth. The actual data rate is 1,200 bits per second exclusive of synchronization overhead. For most applications, the data band utilized is 15 to 20 kHz, although the ATM-840 is designed to accept a variety of acoustic transducers, and the modulation frequency is software controllable from 1 kHz to 100 kHz.

The ATM-840 data receiver uses an incoherent FSK demodulator. Passive filters are used for FSK demodulation, resulting in minimal power drain. The system employs a wakeup receiver which initiates processing of a possible incoming data packet. Packet validity is confirmed by software, and an invalid data sequence (or false alarm) is rejected.

SPECIFICATION SUMMARY

Specifications	ATM-840	ATM-850
Frequency	15-20 kHz (typical) 12-13 kHz (command)	15-20 kHz (typical) 13-14 kHz (command)
Modulation	16 tone MFSK (data) FSK (command)	up to 256 tone MFSK (data) FSK (command)
Data Rate	up to 1200 bps (data) up to 300 bps (command)	up to 5000 bps (data) up to 300 bps (command)
Range	5000 m	5000 m
Acoustic Source Level	186dB	186dB

The Capable Modem

The ATM-850 is a much more capable modem, with a 5,000 bits per second half duplex bidirectional data link. The unit incorporates a DSP-32C digital signal processing system, as well as a 68HC11 microprocessor. The 68HC11 provides simple interfacing to a wide variety of data sources or instruments requiring control and also performs a number of watchdog functions. In long-term operation, the DSP-32C system is powered down; the 68HC11 detects incoming acoustic data packets or an instrument requiring data transmission and wakes up the DSP. This allows long-term remote deployments and reasonable data transfer efficiency. The processing power drain for the DSP is 1 - 3 watts, largely dependent on the amount of fast RAM required by the system.

The ATM-850 is packaged identically to the ATM-840, but because of its increased power requirements and intended application on underwater vehicles and surface buoys, power supplies are external. This results in a compact 4-inch OD by 8-inch cylindrical instrument interfaced to an external transducer. The module consists of an analog input board with an A/D converter, an analog output board with a D/A interface and power amplifier, and DSP processing components. A single DSP-32C is capable of performing up to 25 million floating operations per second at its full rate of 50 MHz. In practice, the slowest clock speed that will allow the desired set of processing algorithms to be implemented is selected. This keeps receiver power consumption at a minimum. Programmable read-only memory contains the software for the receiver, and storage for raw data and intermediate results is provided by fast static RAM. Because long-term deployments usually operate on a low duty cycle, provision was made for powering down the processor when it is not actively receiving or transmitting data. This makes for efficient operation under circumstances where the system is operating intermittently.

The ATM-850 implements a front-end FFT demodulator, aided by a maximum likelihood equalizer and synchronizer. The input data is processed to extract the synchronization data, and this is used by the synchronizer to determine optimal data frame boundaries. This information enables the FFT demodulator to be properly aligned on the incoming frames and to recover the incoming tones representing the digital data. The synchronization sequence also minimizes the resultant equalizer workload. The equalized FFT output is used by a soft-decision Viterbi decoder which greatly reduces data transmission errors.

Operating in a 'Sleep Mode'

Both the ATM-840 and the ATM-850 are equipped with extremely low power command feedback systems which allow the modems to operate in a sleep mode between telemetry operations. One use of this feature is to poll a remote unit which is in sleep mode. The poll includes a system wakeup ID, which, if it is recognized by the modem, powers the microprocessor and initiates a transmission sequence. This allows a number of remote units to be controlled by a single master station and allows each remote to conserve battery power.

The heart of the acoustic modems is the real-time software. The units were designed with future performance and application upgrades in mind. For example, the DSP-32C processors can be connected in a serial pipeline if several processor cards are included in the receiver. This allows augmenting the processing capability for future higher data rate applications or more computationally intensive software components.

On a system level, a local area network (LAN) protocol is under development. The LAN will allow real-time access to and data telemetry from any of a number of instruments deployed within a few kilometers of a hard-wired or satellite link. The central receiver, implemented with an ATM-850 system, has interfaces for a number of satellite systems, such as Argos and Geostar. This software package is targeted at efficient real time data telemetry from large numbers of ocean bottom sensors to the laboratory.

Planned Applications

The ATM-840 acoustic telemetry modem, with 1,200 baud transmitter and 300 bits per second command receiver, should find a wide range of applications for remote recovery of data from subsea instruments where the total data transfer requirements are not too demanding. This would include data acquisition from current meters, tide gauges, and other instruments where periodic samples of several hundred bits per sample need to be reliably transmitted to a surface buoy, platform or other gathering location.

This system is currently under evaluation by the University of New Hampshire for use in a project to monitor an offshore dumping site for the U.S. Army Corps of Engineers. In this case, several subsea modems are to be connected with sea bed monitoring instruments located around a site which is about 3 kilometers x 3 kilometers. A centrally located buoy contains the surface acoustic modem which is interfaced with a packet radio RF telemetry link to a shore laboratory. The subsea instruments can report data on a programmed, or unpolled basis, or can be addressed on command from the shore laboratory. In this application, data will be acoustically transmitted at a 300 baud rate.

Several experiments have been planned utilizing the DSP-based ATM-850. An experiment planned for deployment in the fall of 1990 off the coast of California involves the use of two acoustic telemetry systems to transfer data from bottom current sensors to a pair of surface buoys with line of sight telemetry links. In this experiment, high frequency current fluctuations measured near the bottom are relayed at 1,200 baud to a shore based operator. Because the current fluctuations are of most interest during storms, the sytem is being designed to operate during heavy seas and high winds.

Another planned application will utilize two DSP-based modems to transfer data and downlink commands from a SOFAR moored listening station to a surface buoy 500 meters above it. In this application, data requests will be initiated by the surface buoy controller and the instrument at 500 meters.

An application presently under discussion involves interfacing an internally recording CTD to a 1,200-baud, low power ATM-840 equipped with a highly directional transmit transducer. This system will be designed to collect and transmit CTD data continuously at 1,200 baud. Reception will be at the surface using a directional receive hydrophone and an acoustic receiver interfaced to shipboard computers. The critical design problem in this application is to obtain 6,000-meter range while extracting only 10 watts from the CTD's onboard power supply.

The acoustic telemetry modems undergoing development by engineers at Woods Hole Oceanographic Institution and Datasonics, Inc. represent a significant breakthrough in the art of underwater acoustic data telemetry. Acoustic telemetry has previously been restricted to data rates generally below 100 bits per second, especially in a shallow water high multipath environment. The new telemetry modems allow the use of a transparent medium for transfer of data between underwater locations. The technology will allow periodic acquisition of data from deployed instruments, control and communication with autonomous underwater vehicles, and in general will offer the means for remote command, control and communication between two underwater locations.

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HIGH DATA RATE ACOUSTIC TELEMETRY FOR MOVING ROVS IN A FADING MULTIPATH SHALLOW WATER ENVIRONMENT

Josko A. Catipovic and Lee E. Freitag

Abstract

A compact telemetry system for digital data telemetry at rates up to 10 kbits/sec over 1 to 10 km is presented. The system is designed for worst case ocean acoustic channel conditions, and operates in the presence of source/receiver motion, fading and multipath. In addition, the system incorporates spatial diversity by utilizing multiple hydrophones and data processing subsystems. This allows much more reliable operation under realistic circumstances where noise events and transducer masking are unavoidable. The result is a system specifically geared toward use at sea with an ROV. Preliminary dockside test results are presented to demonstrate the effectiveness of this multichannel system.

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Published in: IEEE Proceedings, Sixth Annual ROV Conference, June 1990.

PERFORMANCE LIMITATIONS IN UNDERWATER ACOUSTIC TELEMETRY

Josko A. Catipovic

Abstract

This work addresses current performance limitations in digital underwater acoustic telemetry. Recent increases in computational capabilities have led to a number of complex but practical solutions aimed at increasing the reliability of acoustic data links. These solutions span the problem from the ocean-basin scale data telemetry to video image transmission at a few hundred yards' range. A common fact is the opportunity to implement highly complex tasks in real time on modest hardware. The data rates range from 1 to 500 kb/s and are much slower than, say, satellite channels, while acceptable system complexity is higher than virtually any other channel with comparable data throughput.

The basic performance bounds are currently the channel phase stability, available bandwidth, and the channel impulse response fluctuation rate. Phase stability is of particular concern for long-range telemetry, channel fluctuation characteristics drive equalizer, and synchronizer design, and the bandwidth limitation is a direct constraint on data rate for a given signaling method.

Funding was provided by the Office of Naval Research under Contract N00014-86-K-0751.

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SPATIAL DIVERSITY PROCESSING FOR UNDERWATER ACOUSTIC TELEMETRY

Josko A. Catipovic and Lee E. Freitag

Abstract

A large increase in the reliability of shipboard or stationary underwater acoustic telemetry systems is achievable by using spatially distributed receivers with aperture sizes from 0.35 to 20m. Output from each receiver is assigned a quality measure based on the estimated error rate, and the data, weighted by the quality measure, is combined and decoded. The quality measure is derived from a Viterbi error-correction decoder operating on each receiver and is shown to perform reliably in a variety of non-Gaussian noise and jamming environments and reduce to the traditional optimal diversity system in a Gaussian environment. The dynamics of the quality estimator allow operation in the presence of high-power impulsive interference by exploiting the signal and noise differential travel times to individual sensors.

The spatial coherence structure of the shallow-water acoustic channel shows relatively low signal coherence at separations as short as 0.35 m. Increasing receiver spacing beyond 5 m offers additional benefits in the presence of impulsive noise and larger scale inhomogeneities in the acoustic field.

A number of data transmission experiments were carried out in Woods Hole Harbor to demonstrate system performance in realistic underwater environments where the acoustic telemetry system is expected to operate. Diversity combining, even with only two receivers, can lower uncoded error rates by up to several orders of magnitude while providing immunity to transducer jamming or failure. The performance improvement is achieved at no increase in bandwidth or transmitted power.

Funding was provided by the Office of Naval Research under Contract N00014-86-K-0751.

Published in IEEE Journal of Oceanic Engineering, Vol. 16, No. 1, January 1991.

SPECIFICATIONS AND APPLICATIONS FOR AN ADVANCED ACOUSTIC TELEMETRY SYSTEM

Josko Catipovic and Daniel E. Frye,
Woods Hole Oceanographic Institution
David Porta, Datasonics, Inc.

Abstract

An acoustic telemetry system capable of reliable operation at data rates up to 5,000 bits per second has been developed at the Woods Hole Oceanographic Institution and is being produced by Datasonics, Inc. of Cataumet, Massachusetts. This paper describes the telemetry system, summarizes results of recent at-sea tests, and discusses several upcoming operational applications of the equipment.

The telemetry technique makes use of MFSK acoustic data transmission where many tones are transmitted simultaneously and modulation and demodulation are done digitally with FFT's. Receiver software has been implemented on a digital signal processing chip, the AT&T DSP-32C.

Tests of prototype hardware have been performed in shallow water over path lengths of 800 to 2500 meters with baud rates up to 5000 bits per second. Vertical transmission tests in depths to 3000 meters have also been performed using low power transmitters operating at 600 to 1200 bits per second. Tests have been performed for both coded and uncoded data and acceptably low error rates have been achieved. Several upcoming deployments of the advanced acoustic telemetry system are described including a deep water moored array application, a bottom to surface link in shallow water, and a profiling application.

Funding was provided by the Office of Naval Research under Contract N00014-86-K-0751.

Published in Oceanology International Proceedings, Brighton, England, March 1990.

ALGORITHMS FOR JOINT CHANNEL ESTIMATION AND DATA RECOVERY - APPLICATION TO EQUALIZATION IN UNDERWATER COMMUNICATIONS

Meir Feder and Josko Catipovic

Abstract

One of the main obstacles to reliable underwater acoustic communications is the relatively complex and unstable behavior of the ocean channel. The channel equalization method, that one can estimate and track this complex and rapidly varying ocean response, may lead to reliable data communications at high rates which utilize fully the available bandwidth. Unfortunately, standardized equalization techniques fail in this environment. In this paper we derive methods for joint ocean-channel estimation and data recovery, using optimal, Maximum Likelihood (ML) estimation criterion. The resulting ML problems may be complex; thus we will use iterative algorithms; e.g., the Expectation - Maximization (EM) algorithm. The different methods correspond to different assumptions about the ocean channel. The theoretical derivation of these methods as well as preliminary results on simulated ocean data experiments are presented.

Funded in part by the Office of Naval Research under contract Number N00014-86-K-0751.

Published in IEEE Journal of Oceanic Engineering, Vol. 16, No. 1, January 1991.

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 twelve 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 bits per second 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 1.45×10^{-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.

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TELEMETRY OF OCEAN CURRENT DATA FROM FIEBERLING GUYOT

Daniel E. Frye

Abstract

A current meter mooring with the capability for real time data telemetry was installed on the summit of a seamount in the North Pacific about 600 miles west of San Diego. This mooring is part of a multi-disciplinary study of the interactions between a large seamount and the surrounding waters. The purpose of the telemetry mooring is to collect information on the current structure at the seamount's summit, particularly to look at the hypothesis that near bottom currents are particularly strong over the summit. These data are then available in real time so that researchers working in waters near the seamount will be able to determine the current structure relative to their sampling patterns.

The telemetry mooring uses a hardwire connection between a surface buoy and three current meters located in the bottom 1/3 of the water column. Data communication on the wire is carried out via FSK modulation with current meters interrogated at 15-minute intervals. Data telemetry is accomplished using the Argos Data Collection System.

Introduction

The Office of Naval Research is funding an Accelerated Research Initiative on Flow Interactions Over Abrupt Topography [1]. This is a multi-disciplinary project involving a number of Principal Investigators in Physical Oceanography, Biology, Chemistry, and Geology. The purpose of the program is to learn more about how rapid changes in bottom topography affect the local physical, biological, and chemical environment in the ocean as well as the near bottom geology.

Dr. Kenneth Brink of WHOI's Physical Oceanography Department is the Principal Investigator for the telemetering current meter mooring. The scientific objectives behind this mooring are both to better understand the general circulation patterns on and around the seamount and to specifically look at the near bottom flows over the top of the seamount. It has been suggested by Dr. Brink that near bottom currents over the seamount summit may be accelerated as a consequence of the abruptly changing topography and the earth's rotation [2]. A Pilot Telemetry Mooring installed by WHOI in August 1989 [3] near the present site confirmed this hypothesis and provided design current data for the overall project.

Fieberling Guyot, an extinct volcano which once rose above the ocean surface, is shown in Figure 1. It rises from the abyssal plain at 4500m depth to a minimum depth of about 440m. The slope angle for much of the rise is about 10 - 30 degrees with a broad flat area at the summit. The telemetry mooring was installed near the seamount summit in 507m of water. Current meters were inserted in the mooring at three depths; 304, 453, and 488m below the surface.

Technical Approach

The telemetry mooring was designed to make measurements at about 20, 50, and 200m above the bottom. Figure 2 shows the mooring design and the current profile it is designed to operate under. Instrumentation on the mooring consists of three Vector Averaging Current Meters (VACMS) and an Acoustic Release. Each VACM is equipped to both record data on magnetic tape and to transmit data to the surface buoy on command. A serial communication board in the VACM acts as a SAIL interface [4] for 300 baud communication. Each VACM is separately addressable by its unique SAIL address.

The instruments are connected electrically to the surface buoy electronics via a three conductor double-armored cable rated for 10,000 lb. breaking strength. Between the subsurface buoy and the surface buoy, this cable is covered with a thick rubber jacket to minimize the chance that hockles or kinks will lead to cable failure. At each end of the rubber- coated cable are bending strain relief boots made of molded polyurethane which limit the bend radius of the cable and minimize stress concentrations due to bending. Since the surface buoy undergoes continuous excitation by surface waves, it is a difficult problem to protect the mechanical strength member and the electrical signal wires from failure due to work hardening and eventual breakage.

The surface buoy provides the platform for the satellite telemetry system, the system controller, and related power supplies. Figure 3 is a block diagram of the main components in the surface buoy. System control and communication with the current meters is performed by an Instrument Bus Computer [5]. This device uses an 80C86 microprocessor, and associated memory, clock, I/O, and power supplies to address the current meters via an FSK modulated signal and to pass processed data to the Argos transmitter via a SAIL loop. The IBC was developed at WHOI as a general purpose controller and is available from a commercial vendor (Seiberco, Inc., of Braintree, Massachusetts). It consists of five PC boards on a backplane which are installed in a 6-inch tube. It draws less than 10 ma at 12v DC on average. Alkaline batteries are used as the IBC power supply.

Satellite telemetry is accomplished with a Synergetics Model 2101A Argos Transmitter modified to respond as a SAIL devise and capable of storing and transmitting up to 32 separate 256 bit Argos messages [6]. For this experiment we are using 16 Argos message buffers and uploading data to them every hour. These data include date and time, east and north current components, temperature, and pressure from each of the three VACMs and engineering data concerning the communication error rate between the IBC and the current meters. A second Argos PTT is used to send instantaneous values of battery voltage, IBC current consumption and surface water temperature. It also acts as a redundant location device if the primary PTT fails.

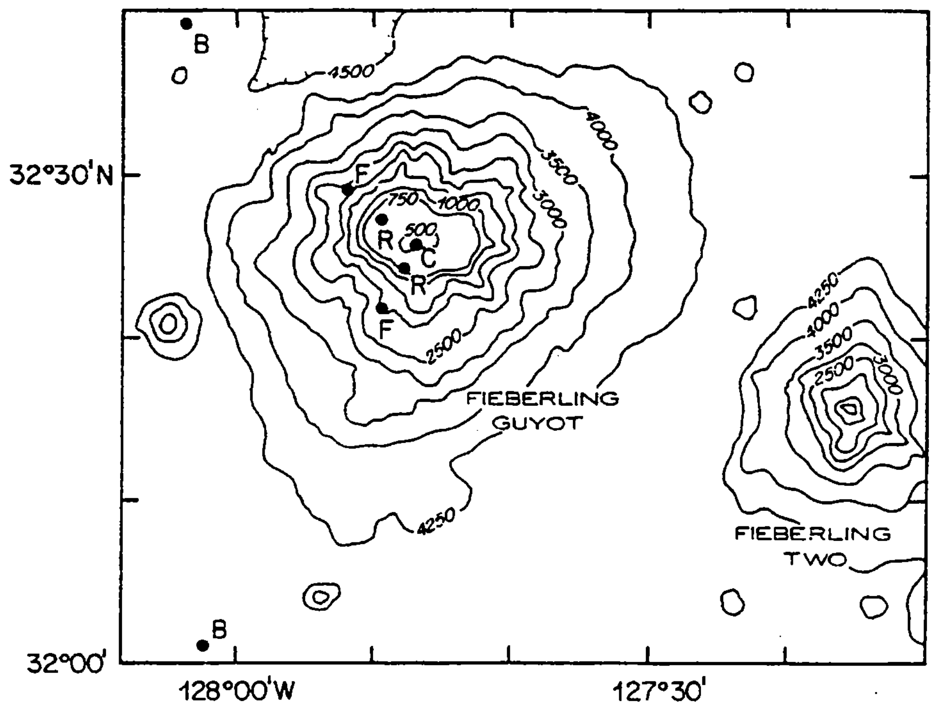
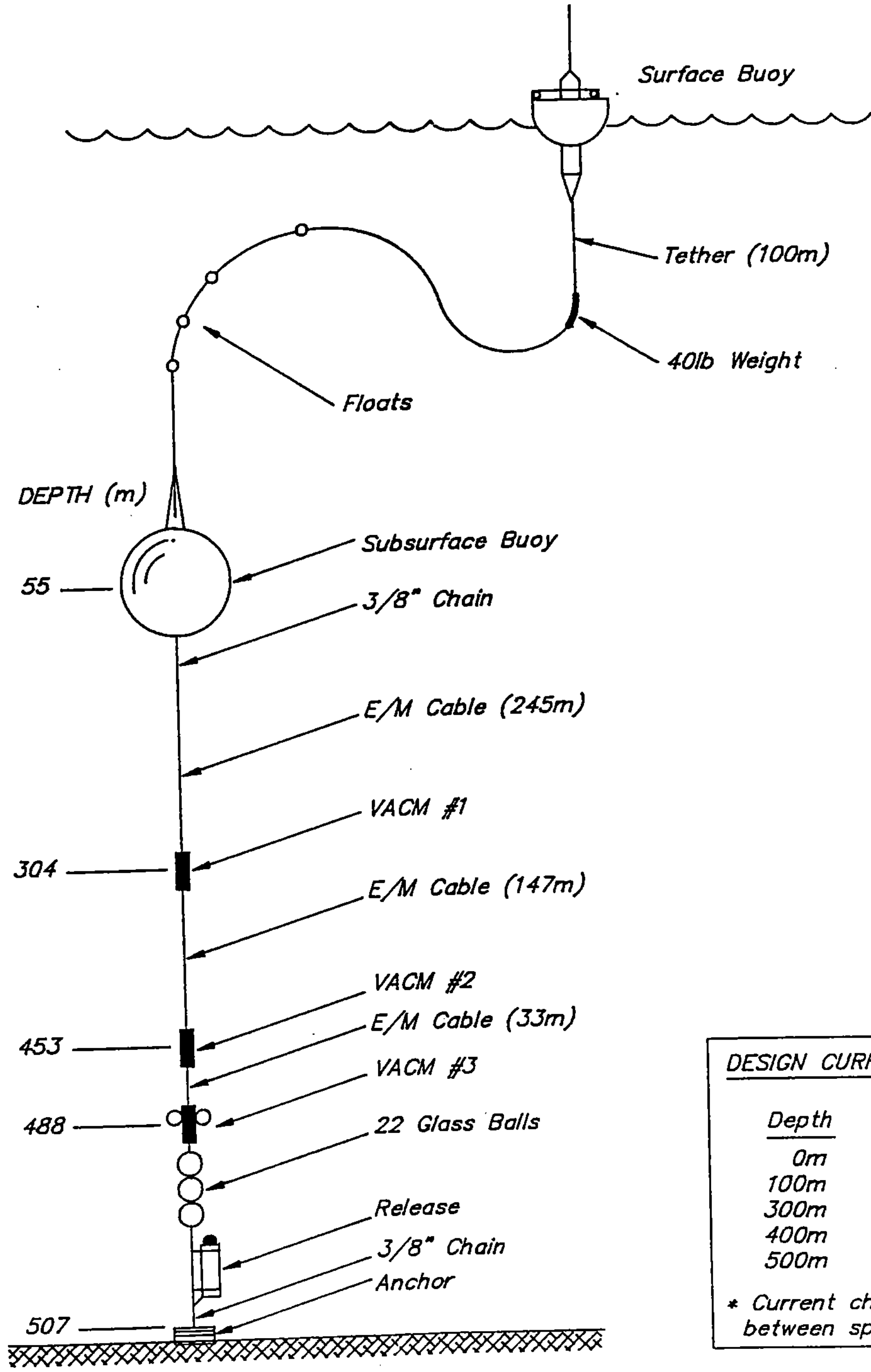


Figure 1: Fieberling Guyot bathymetry



DESIGN CURRENT PROFILE

Depth	Current*
0m	75cm/s
100m	40cm/s
300m	40cm/s
400m	75cm/s
500m	75cm/s

* Current changes linearly between specified values

Figure 2: Mooring deployed on the summit of Fieberling Guyot.

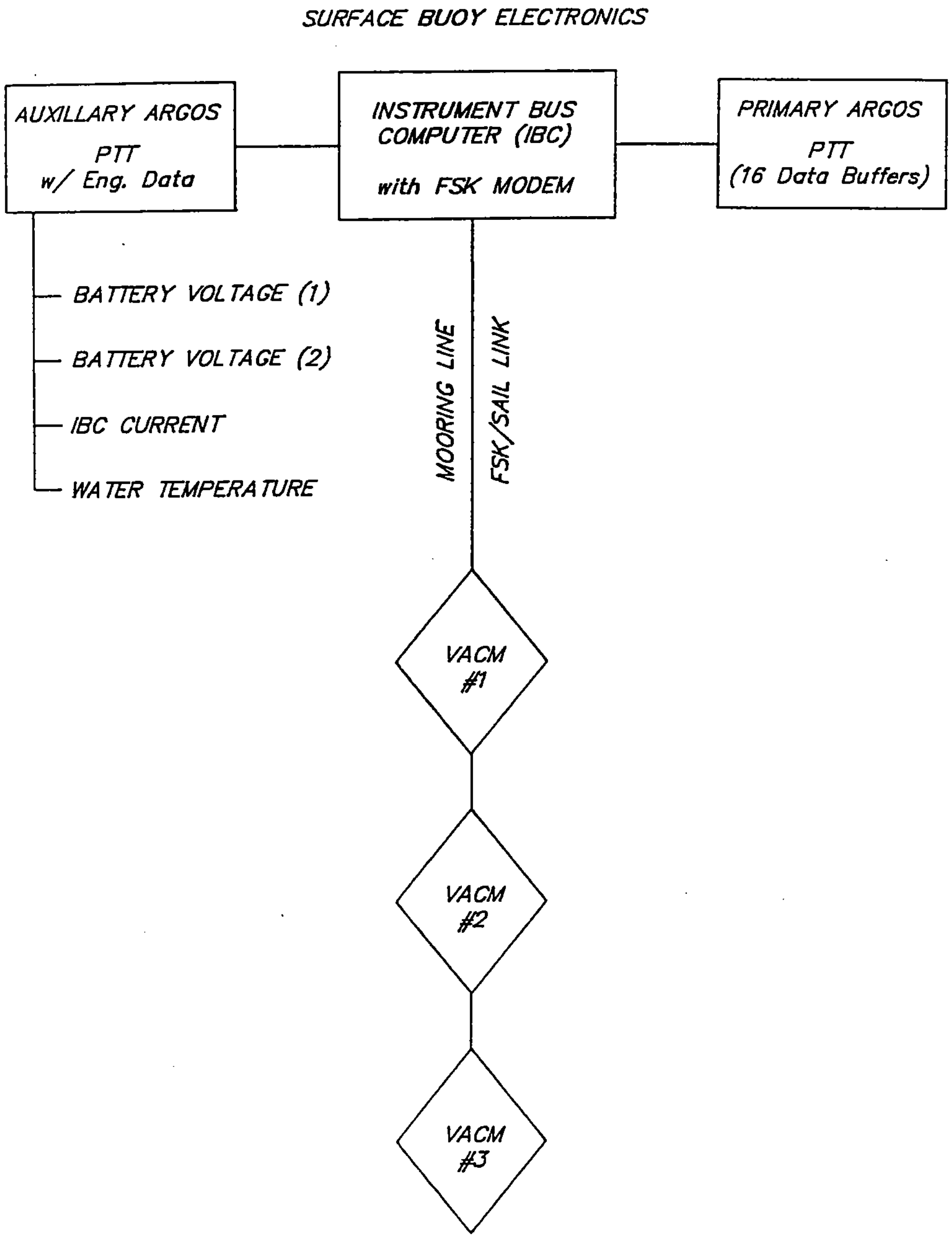


Figure 3: Block diagram of the telemetry system.

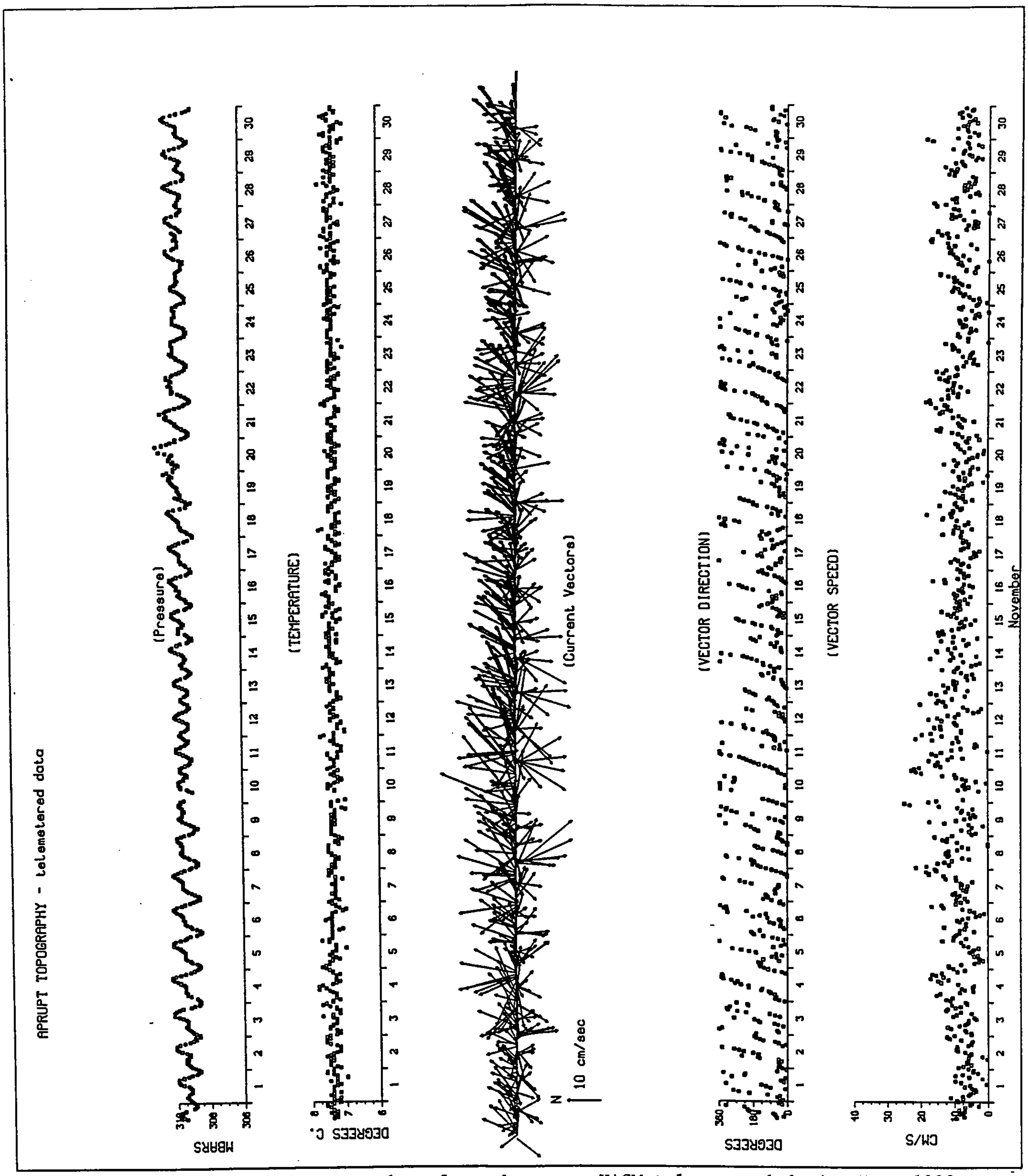


Figure 4: Current meter data from the upper VACM telemetered during Nov. 1990
Note: Depth = 304 m.

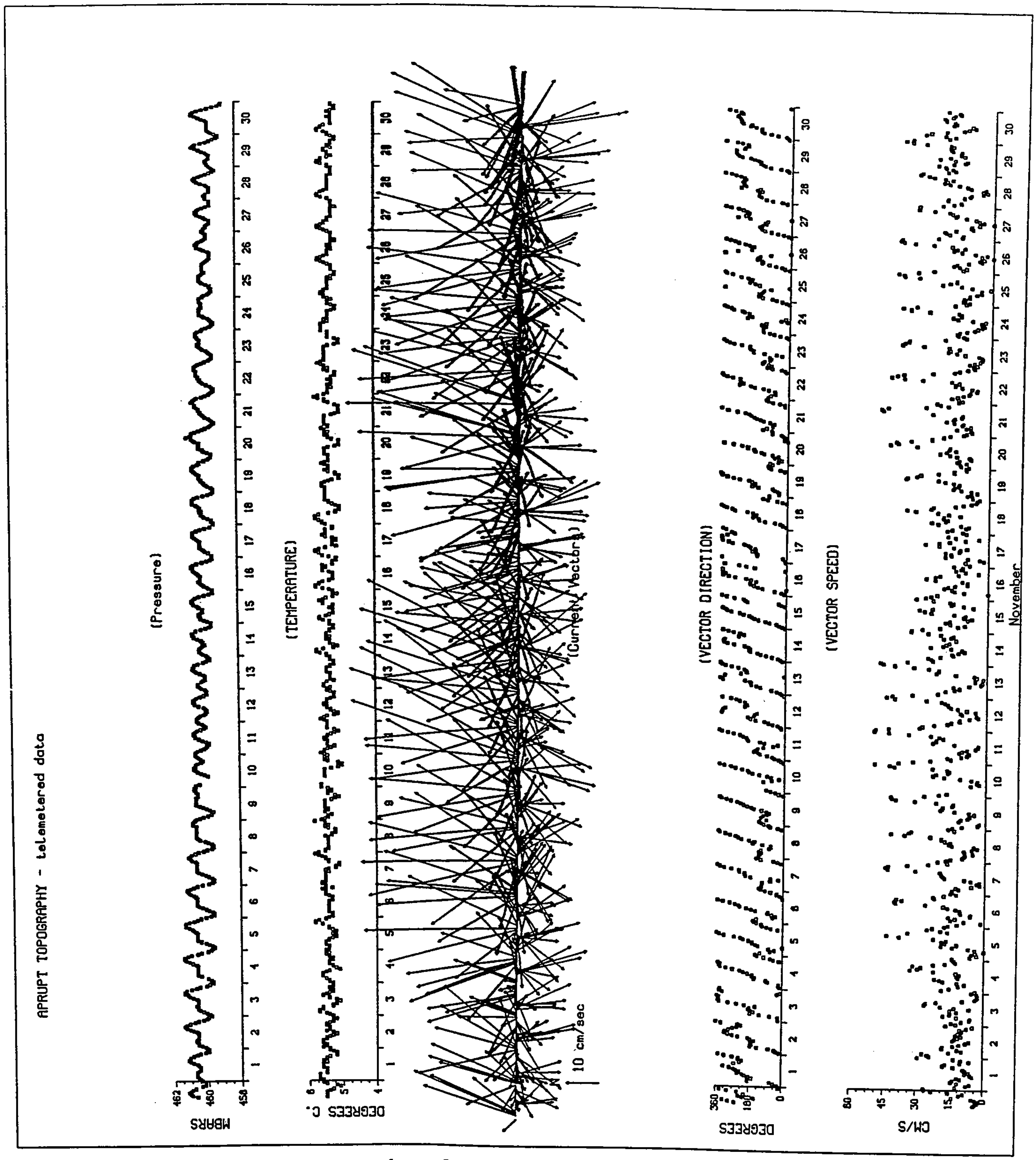


Figure 5: Current meter data from the middle VACM telemetered during Nov. 1990
Note: Depth = 453 m

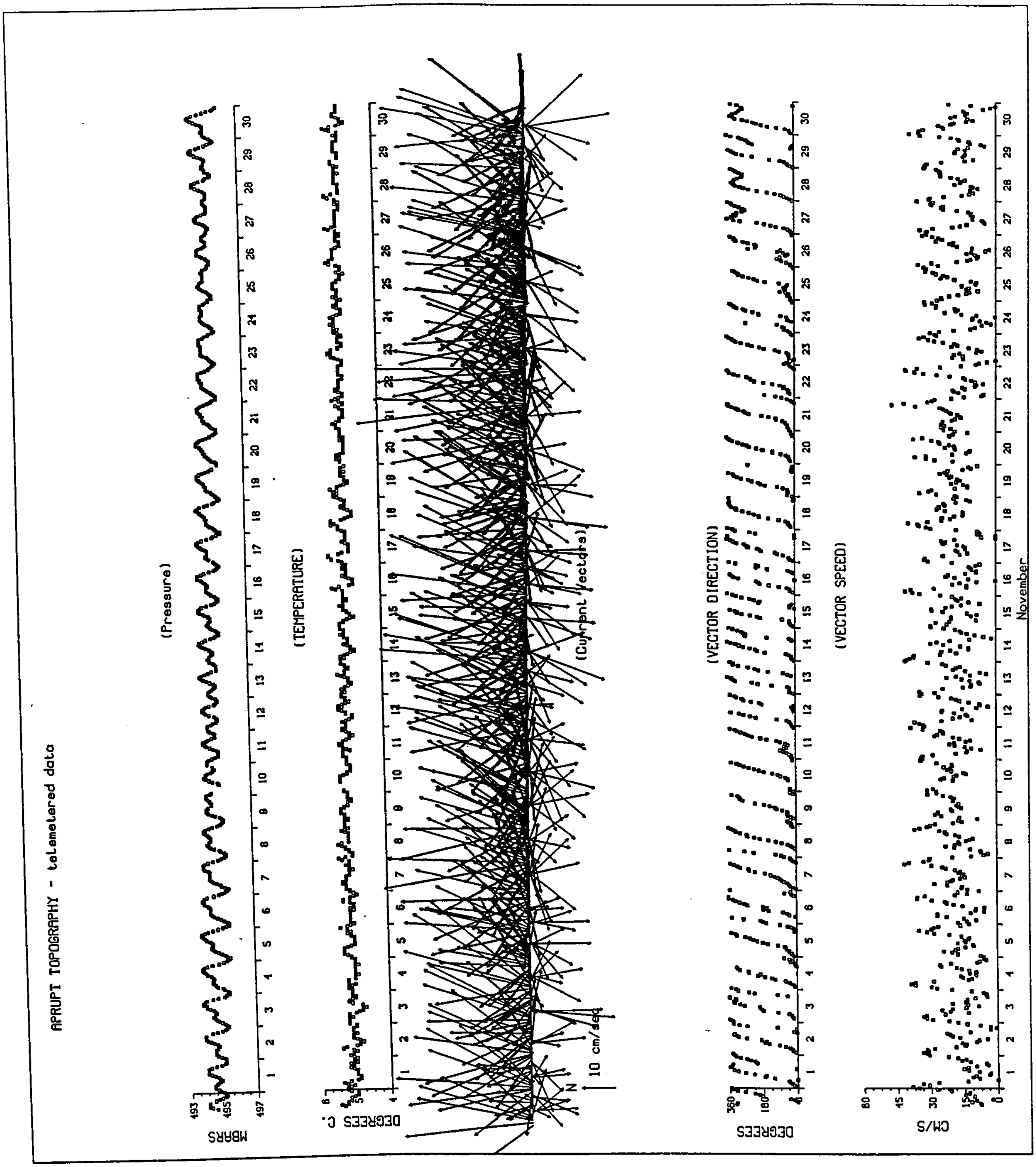


Figure 6: Current meter data from the bottom VACM telemetered during Nov. 1990
Note: Depth = 488 m.

Results and Conclusions

The telemetry mooring was deployed on 14 September 1990. A problem developed shortly after deployment which was traced to the tension cell installed beneath the surface buoy to monitor cable tension. This cell developed a leak which not only caused the cell output to short, but resulted in a ground loop which degraded the performance of the FSK communication link between the IBC and the VACM. The problem was especially bad at night when noise generated by the light (a xenon flasher) was present. We disconnected the tension cell and light by unplugging them at the buoy and the communication problem was solved.

Figures 4, 5 and 6 show data from November for each instrumented level. As anticipated, currents near the bottom were stronger than currents nearer the surface with most of the energy at semi-diurnal tidal frequencies.

Operation of the mooring and telemetry through 20 December was excellent with essentially no data lost since mid-September when the noise problems mentioned earlier were solved. On 20 December the surface buoy broke away from its mooring, probably due to mechanical failure of the termination of the surface buoy. The Pilot Telemetry Mooring which used a similar design failed after 3 1/2 months due to work-hardening of the electromechanical cable at the surface buoy termination. This problem, which was not discovered until after the second telemetry mooring was installed, is the most vulnerable part of the system. The electronics on the surface buoy continue to work well. A more robust surface termination is being designed to improve the chances for a reliable one-year telemetry mooring system.

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Funding was provided by the Office of Naval Research under Contract N00014-89-J-1554.

INCREASED DATA RATE FOR CONTROL OF DEEP OCEAN ROBOTICS

Edward Hobart

Abstract

Hagen Schempf of the Deep Submergence Laboratory has performed a series of experiments to determine the losses in transmissions used in robotics. The results were used in his doctoral thesis. His previous testing method involved commanding SEIBERCO motor control boards in an IBC, via the serial link. Serial communications limited the control update rate to 7-Hz, which is too slow for realistic testing. My task was to provide IBM software and IBC firmware for a parallel communication link that provided a minimum 200-Hz control update rate.

A Metrabyte PIO12 board, its support ribbon cable and terminal box were used to upgrade the control hardware. A 5 foot cable was terminated for the IBC parallel board at one end and wired to the Metrabyte terminal box at the other. The PIO12 is basically an 8255 PIO part interfaced to the IBM bus. The IBC PIO board is also an 8255 interfaced to the IBC bus.

Data transfer is 8 parallel bits in each direction, with 2 wires from each device used to handshake each transfer. Because both ends use the Intel 8255 PIO, the hardware initialization and byte transfer code is nearly identical in both PC and IBC.

The PC support subroutines allow writing commands and write or read of 1, 2, 4 or n number of bytes to/from the IBC. Each routine times out after approximately one second, in the event the IBC does not properly respond. A code byte is returned, indicating the success or failure of each transaction.

The IBC code design is based solely on speed of execution. Each command to the IBC first consists of a command byte. This byte is a binary value used to index into an array of function pointers, each of which is a motor control operation. The executed function transfers a predetermined number of bytes to or from a specific motor controller. When the function completes, it returns to the main line routine that waits for a new command. There are no decisions made in any of the processing. The result is fast, compact code. The trade off with this method is a large number of individual commands. With the IBC supporting control of three motors there are 114 commands, 38 per motor.

All programs were written in Microsoft C 5.1. The PC routines use the large memory model to conform to current code. The IBC code uses the small memory model for speed.

The resulting system was tested by sending a typical series of commands with 48 bytes transferred. This sequence is repeated 65536 times and timed. On the 386 PC with an IBC running at 5- MHz, the command loop was performed at 440-Hz. The equivalent serial transfer would be about 200k baud. With a slower 286 PC and the IBC at 8-Mhz, the command loop was performed at 550-Hz.

Further testing showed errors occurring in the command/data transfers between the IBC and SEIBERCO motor controller. SEIBERCO programs each motor controller to the customer's custom requirements. The original controller code had errors that occur only when operations exceed 50-Hz. Corrections involved revising the IBC code to account for undocumented SEIBERCO timing requirements and SEIBERCO revising their controller code to speed its basic operation. The resulting system provides 250-Hz control.

The package delivered to DSL consisted of an IBC parallel board and cable, IBC eproms, the Metrabyte equipment, a disk with the IBM and IBC source code, listings of the code, a list of the IBC commands and a summary of the IBM subroutines and their use.

Funding was provided by the Office of Naval Research under contract N00014-86-C-0038 and the Naval Research Laboratory under contract N00014-88-K-2022.

DATA DIRECT FROM THE OCEAN BOTTOM TO YOUR DESK

Richard Koehler

Abstract

The STRESS experiment, a group of experiments to measure the movement of sediment along the California coast near Sea Ranch, included two BASS current meter arrays on bottom tripods, spaced five and ten miles from shore in about 100 m of water. 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 user's desk at WHOI, where he 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 his desk. The reverse channel could command the instrument on the bottom to send raw current meter data when desired, e.g., when there were currents strong enough to suspend bottom sediment.

The BASS six 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 was stored on its 20 Mbyte disk every 30 minutes. The processed data was also sent to the acoustic modem, Datasonics model ATM 840, in a burst of 2304 bytes at 9600 bps. The tripod mounted ATM 840 transmitted the data acoustically at 1185 bps to the receiver, an ATM 850, located on the surface buoy. A 3 W VHF transceiver, Kantronics model DRR 2-2, with a quarter wave whip and a PacComm Micropower-2 packet controller (AX.25 protocol), sent the data to shore. The shore station used a yagi antenna connected to the same model transceiver and packet controller. The data packets were 256 byte blocks with error detection, transmitted at 1200 bps. Although error correction using acknowledge and retransmission was available for the radio modem, it was not enabled in order to attain a higher data throughput. There was a separate radio frequency for each of the two buoys, and the shore based computer had a separate input for each channel. The data was recorded as received onto optical disk, with channel identification and time appended.

An Intel 2400B MNP (Hayes compatible) 2400 bps telephone modem, with error detection and correction, connected the shore computer to the telephone network and then to another computer at a remote site, e.g., at WHOI. The shore computer was operated remotely from WHOI using the BLAST data transfer and remote control program. Disk files could be sent in either direction using the BLAST protocol and the shore computer screen display could be seen at WHOI using the BLAST Satellite program.

The system successfully logged data on shore from the offshore tripod and the reverse channel commanding the tripod to send raw data worked well. Communication was achieved from the shore station to WHOI, where many files were downloaded and the shore computer was operated remotely. After three weeks of operation, data from the acoustic modem was interrupted during a storm, when 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 five miles offshore while its electronics were ashore being serviced. The clevis completely unscrewed in this case and the buoy was lost.

Funding was provided by the Office of Naval Research under Contract No. N0014-89-J-1058.

A 5 MHz SONAR FOR DETECTION OF SUSPENDED SEDIMENT

Richard Koehler

Abstract

A 5 MHz acoustic backscatter sonar was built for monitoring the sediment load in the bottom meter of the water column. This was used with a 1 MHz sonar which measured backscatter between 1 and 3m. The instruments were mounted on a tripod in about 100 m of water, and the data was recorded on a 60 Mbyte streaming tape recorder. The 5 MHz sonar used a Panametrics 5 MHz transducer that employed a 1/4 wave matching plate on its surface, which also waterproofed it.

The instrument's amplifier had a 90 dB dynamic range and used a single integrated circuit mixer and IF amplifier. The amplifier was designed for cellular radios, which have a requirement of providing signal amplitude over a 90 dB range with $\pm$ 1.5 dB error. Note that the ac signal is converted to a dc level over the 90 dB range, which cannot be done with a single diode rectifier. It draws only 2 - 3 mA at 5 V. This circuit has a response time constant of about 40 microseconds, corresponding to a sonar range of about 3 cm. The transducer put about 4 W acoustic into the water.

This sonar was used in the 1990-1991 STRESS experiment where data was obtained for two 2-month deployments. The 5 MHz sonar returns were recorded simultaneously with the 1 MHz returns. To date, only the log of the amplitude of the 5 MHz returns have been compared with the linear output of the 1 MHz returns, but they appear to have similar structure.

Funding was provided by the Office of Naval Research under Contract Number N00014-89-J-1049.

MODIFICATIONS TO THE SCHMITT-TOOLE HIGH RESOLUTION PROFILER

Richard Koehler and Ellyn Montgomery

The Schmitt-Toole High Resolution Profiler (HRP) was modified by adding a Datasonics model PSA-900 sonar altimeter so that it could profile within a few meters of the bottom before releasing its weights for return to the surface. This is especially desirable for a bottom that is varying in depth, such as near a seamount. The transducer cable used a shielded version to eliminate false echoes due to noise at the longer ranges. The solid state memory cards in the profiler were redesigned to increase the memory from 4 Mbytes to 16 Mbytes.

The profiler was taken to sea in March, 1990, for the Warm Rings Experiment, where a total of 78 successful profiles were collected. The altimeter was tested on a three-day test cruise in August, 1990.

Funding was provided by National Science Foundation Contract OCE-8911053 for the March Warm Rings cruise and Office of Naval Research Contract N00014-89-J-1073 for the August test cruise.

POWER SUPPLY DESIGN FOR A CABLE BASED ACOUSTIC SOURCE

Stephen P. Liberatore

It has been proposed that an HLF-5 hydraulic acoustic source be deployed approximately 70 miles north of Oahu. This mooring along with existing receivers would be used to implement a basin-scale acoustic tomography observing system. An autonomous mooring powered by a large lithium battery was our first suggestion. Similar moorings have been successfully deployed in the North Pacific, North Atlantic, and the Greenland Sea. This is a technology the Tomography Group at W.H.O.I. is comfortable with. Two problems with this approach are the mooring's one year endurance, and the $30,000 lithium battery. The lithium battery is a primary battery; i.e., it can't be recharged and must be replaced on an annual basis. The funding agency has suggested we consider a cable based mooring instead.

A cable based mooring offers several advantages over an autonomous mooring:

1) While the stringent timing requirements of real-time tomography have not been relaxed, it will be far simpler to implement them since the source will be triggered from shore.

2) A complex signaling scheme is no longer required since navigation data will be telemetered directly to shore.

3) The source's power supply will be augmented by shore power thus increasing the system's endurance.

4) Engineering data will be telemetered to shore, possibly allowing malfunctions to be corrected before they interrupt the experiment.

The cable based approach also poses several interesting questions, all of which must be answered before such a system is implemented. Most of these questions are mechanical in nature; i.e.; how do we deploy the system, how do we recover it for maintenance, how do we mate to an exiting cable? There are also several questions of an electronic nature. One of these, "How do we power the system?" is the subject of this paper.

The source will draw approximately 1.8kW peak when operating. The capacitance of the cable makes it impracticable to transmit this much power using AC. Powering the source directly with DC is also impracticable. I^2R losses in the cable would require the shore based power supply to source over 41kW. By employing a moderately high power switching converter at the mooring end of the cable, the copper losses could be reduced to a few kW. For example, assume the cable has a resistance of 2.5 ohms per mile. A 70 mile cable would then have a resistance of 175 ohms. Allowing 2.5kW for copper loss and assuming 80% efficiency for the switching converter at the source, a 5kW shore supply would be adequate. The shore supply output voltage would be about 1.23kV. The voltage at the mooring end of the cable would rise to 568 volts and the current through the cable would be 3.8 amperes.

The switching supply approach has a few drawbacks. These supplies are relatively complex; i.e., lots of components means decreased reliability. To improve reliability, the shore end power supply should see a constant load. This means that the mooring end power supply must see a constant load and not be power switched. This implies that a technique to switch the supply between a dummy load and the source be devised. Triggering the source must now be accomplished via a MODEM rather than simply interrupting the cable current. Since the cable will also be used to telemeter navigation and engineering data, switching noise injected by the mooring end power supply must be filtered.

The source could also be powered by a local battery which would be maintained at full charge using power from a shore based constant current supply. A supply capable of sourcing about 250mA with a compliance of 200 volts would be adequate since the voltage at the mooring end of the cable would not be allowed to rise above 150 volts. We feel that this approach is inherently more reliable than using switching regulators due simply to the reduced component count.

Two types of secondary batteries were considered:

1) Nickel Cadmium...Although these cells are designed to be charged at constant current and to withstand continuous charging at rates up to C/10, they are not suitable for our application.

Ni-cads exhibit a "memory" effect such that a fully discharged cell may fail to revive with a trickle charge.

30% to 40% of a Ni-cads capacity is unavailable at temperatures below 5 degrees Celsius.

Ni-cads are intolerant of reverse polarity. The first cell in a series string to discharge is badly damaged if the string is totally discharged [1].

2) Lead-Acid...These cells may be recharged employing a current limited constant voltage or a constant current. They have low internal impedance and are well suited to supplying the high surge currents required by the source. Rechargeable lead-acid cells are manufactured using several technologies. At atmospheric pressure either of the two main systems, which employ liquid electrolyte or gelled electrolyte would be suitable. The main problem with these cells is that under normal operation they evolve hydrogen. For this reason the manufacturers strongly recommend against enclosing the cells in any type of pressure vessel.

Liquid electrolyte lead-acid cells are routinely used to power deep sea submersibles. Enclosed in oil pressure balanced cases and allowed to vent freely during recharge at the surface, they have proven to be quite reliable and safe. However, due to electrolyte stratification these batteries are not rechargeable at pressure.

The gelled electrolyte lead-acid seems to be the technology of choice. A design for a rechargeable 140 volt source battery employing Gates gelled electrolyte "X" cells follows [2]:

Power required for a single transmission

14 Amps for 10 seconds = 140 Amp seconds
10 Amps for 81.8 seconds = 818 Amp seconds
Total = 958 Amp seconds

958 Amp seconds * 140 Volts / 3600 = 37.3 Watt hours

Transmission schedule

One transmission every two hours for one day out of four.
Power required for a transmission day

12 * 37.3 = 447.6 Watt hours or 3.2 Amp hours.

Limiting the maximum discharge rate/cell to C/2.5 and selecting the "X" cell de-rated to 4.0 Amp hours

140 volts / 2 volts/cell = 70 cells/level
14 Amps / C/2.5 = 14 / 5/2.5 = 7 levels.

Total battery capacity = 7 * 4.0 * 140 = 3920 Watt hours
and 3920 Watt hours / 447.6 Watt hours per day = 8.75 days.

Battery weight

70 cells/level * 7 levels * 13/16 lb./cell = 398 pounds.

Recharging the above battery at the optimum float rate will produce gas at the rate of 1ml/AH/day/cell [3]. With 490 cells, over the course of one year, the battery will evolve about 894 liters of gas, of which over 90% will be hydrogen. This in itself is a problem; but to make matters worse, since there is only 7.67 liters of gas space in our standard battery case, the internal pressure will rise by about .3 atmospheres/day for as long as the cells continue to evolve gas.

To safely use this battery, a method of venting the case must be found. One solution would be to run an armored pressure proof pipe to a depth equivalent to some pressure less than 8 atmospheres, say 50 meters. This pipe would then vent the battery case through a pressure sensitive one-way valve and a water trap. A battery case thus equipped could then be connected through a differential demand regulator to the nitrogen pressure balance system of the source, thereby insuring an inert atmosphere in the battery case upon recovery. This approach although technically complex is feasible.

Oil Pressure Balanced Batteries

There is another type of gelled electrolyte lead-acid battery on the market. These cells, manufactured by both Panasonic and Yuasa, are reputed to operate while in oil pressure-balanced cases at full ocean depths. Both manufacturers also specify that under normal float service no gas emission will occur. Several Panasonic batteries specially modified for operation in oil were supplied by Deep Sea Power and Light Company, of San Diego, California. The experts at this company were 99% certain that the batteries would accept a charge while at pressure, however, they did not have the facilities to verify this. Their opinion was based on a technical note by W.D. Briggs of the Civil Engineering Laboratory published in 1978. The paper clearly states that oil pressure balanced, gelled electrolyte, lead-acid batteries (manufactured by GE and GLOBE) operating in a cold hyperbaric environment will display a loss in capacity of about 10%. The paper also states that the loss in capacity is due mainly to low temperature and not high pressure. Unfortunately, the evolution of gas while the batteries were cycled is not mentioned [4].

To measure the generation of gas while these batteries were evaluated at atmospheric pressure, a simple gas collecting burette utilizing an inverted funnel and a 10ml graduated cylinder was devised. The batteries obtained from Deep Sea P&L were already modified for pressure compensation and submerged in high grade mineral oil. Prior to being cycled, each battery was vacuum back filled with the oil supplied. The wide end of a funnel was placed over the battery submerged in oil within a two quart container. A 10ml graduated cylinder was inverted and placed over the stem of the funnel in such a way that its open end was beneath the surface of the oil. A small diameter tube was then passed through the funnel's stem to the bottom of the inverted graduated cylinder. A vacuum drawn on this tube allowed atmospheric pressure to force oil into the graduated cylinder completely filling it.

Two Panasonic LCR-12V-2.2-PF batteries equipped with gas collecting burettes as above were placed on charge. The open circuit battery voltage prior to charge was 12.7 volts. The charger was adjusted to 13.7 volts and current limited at 25mA. Within 48 hours, both batteries had generated in excess of 10ml of gas and overflowed their burettes.

Prior to discharging the batteries at a constant 500mA, a 50ml graduated cylinder was substituted for the 10ml cylinder. The batteries were allowed to stand for 24 hours before the discharge test began. The open circuit battery voltage was 12.9 volts. The 10.5 volt cutoff was reached in just under four hours. About .5ml of gas was collected by each burette during this time.

Figure 1:
Oil displacement gas collecting burette used to measure the volume of gas generated at atmospheric pressure during a single charge-discharge cycle.

The graduated cylinders were refilled with oil and the batteries allowed to stand for another 24 hours. A charger adjusted to deliver 13.6 volts, current limited to 200ma, was connected to each battery. Within 24 hours each battery was drawing less than 1mA and had evolved about 18ml of gas.

To measure the volume of any gas generated by the batteries while at pressure, a special gas collecting burette was developed. This burette, machined from lucite, flexible tubing and PVC fit nicely within our smallest pressure test stand. A fully charged battery placed within this device and pressurized to 1200psi was allowed to stand for 24 hours. The battery was then cycled as above; i.e., discharged at a constant 500mA rate to 10.5 volts then recharged at 13.6 volts current limited to 200 ma. Again, within 24 hours, the charge current had dropped to less than 1mA. The internal pressure was then relieved and the chamber opened. At first inspection, no gas was evident within the collecting apparatus; however, as the instrument was being removed from the chamber, a slight jar caused the oil within the burette to "fizz".

Within four hours, a total of 6ml of gas had been collected. The next inspection an hour later revealed no additional gas; however, a seal inadvertently broken at that time terminated the experiment.

Deep Sea Power and Light informs us that their standard case will accommodate twenty of these batteries. In light of the above, the top of each case should be equipped with a pressure sensitive gas vent and a water trap. For use with the HLF-5 source, the batteries in each case would be wired as two series strings of ten batteries each. The series strings would then be connected in parallel via blocking diodes. Five such cases connected in parallel and slowly charged between transmissions would power the source.

The LCR-12V-2.2-PF is rated at 2.2AH (20 hour rate). On average, while the source is running, each battery will be supplying 1.043 amperes. A single transmission will require 958 ampere seconds. The proposed transmission schedule calls for 12 transmissions per day, one day in four. A single transmission cycle therefore requires approximately 3.20AH. Assuming no recharge between the transmissions during a transmission day, the recharge time may be calculated as follows [5]:

$$\text{Tch} = (\text{Cdis}/\text{I}) + 3 \sim 5$$

Tch: time required to charge (hours)

Cdis: AH discharge prior to charge

I: initial charge current

The recharge supply is a constant current source. Regulating the cable voltage to 150 volts, about 240mA at 140 volts will be available to charge the battery.

$$(3.20/.240) + 3 \sim 5 = 16.3 \text{ to } 18.3 \text{ hours}$$

Of course since the 240mA charge current is available continuously, and there are two hours between transmissions, the battery will be at very near full charge prior to each transmission.

How long would the source continue to function if the recharge system were to fail?

The nominal capacity of a single LCR-12V-2.2PF at 25 degrees C is 2.2AH when discharged at the 20 hour rate (C/20). When used on a source mooring the average discharge rate will be C/2.2 at 5 degrees C so each battery must be de-rated to 1.3AH. Since there are 10 strings in parallel the battery will be rated at 13AH. At 3.20AH per transmission day and one transmission day in four, the battery will last about two weeks if the charge system fails.

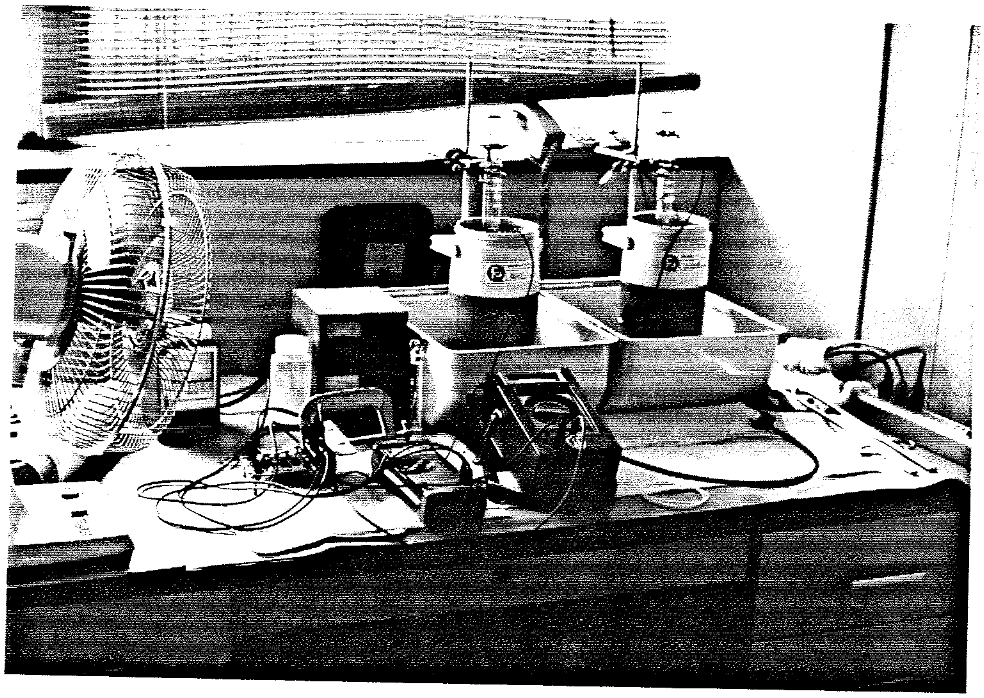

Figure 2: Batteries being cycled at atmospheric pressure.

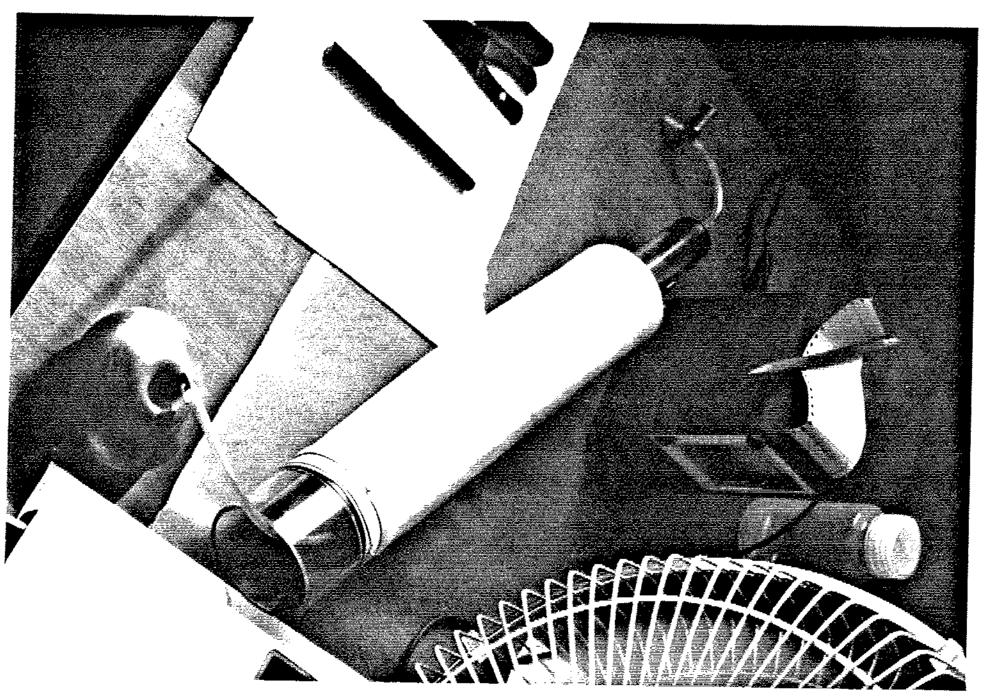

Figure 3: Pressure tolerant gas collecting burette with oil reservoir at one end and graduated cylinder with fill tube at the other end.

How much will the battery weigh?

A single Panasonic LCR-12V-2.2-PF weighs 1.76 pounds. Since we intend using five standard Deep Sea P&L cases a factor of 2 is allowed for the weight of the cases, the oil, and the wiring.

20 * 1.76 * 5 * 2 = 352 pounds.

How much will the battery cost?

Deep Sea P&L offers an estimate of between $2,000 and $2,500 per battery case. Since we need five cases the cost should be between $10,000 and $12,500.

How long will the battery function assuming no charger failures?

Calculating the cyclic life of this battery is difficult since the signaling scheme necessitated by the experiment causes the discharge pattern to be irregular and complicated.

If we assume that the battery is completely recharged between transmissions the calculation is as follows:

De-rated capacity = 13AH
Drain per transmission = .27AH

Depth of discharge = .21% of total capacity

Panasonic specifies between 1000 an 1200 cycles for batteries discharged less than 30% during each cycle at 25 degrees C. Since there are 12 cycles per day, this would yield a life somewhere between 330 and 400 days.

If we assume no recharge between transmissions the calculation is as follows:

De-rated capacity = 13AH
Energy per transmission day = 3.2AH

Depth of discharge = 24.6%

Again this is less than 30% of the total battery capacity so between 1000 and 1200 cycles are to be expected. Now however, there are four days between cycles so the expected life is somewhere between 4000 and 4800 days!

Since during a single transmission less than .5% depth of discharge occurs, and since the duty cycle is so low (less than 2%) the battery may be considered to be in float service. Panasonic specifies the float life of these batteries at 25 degrees C to be eight years, and over ten years at temperatures below 15 degrees C.

The final answer is that with the available data, we can't predict how long this battery will function!

Depending on the calculation technique, life expectancies of less than a year to something over thirteen years have been obtained.

Based on all of the above, a conservative guess of this battery's life would be approximately two years. A more positive way to determine the battery's endurance would be to perform long term cyclic tests under conditions which duplicate those at the mooring site.

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Acknowledgements

Special thanks to Mark Olsen of Deep Sea Power and Light for supplying the test batteries and for his many helpful comments and suggestions, and to Martin Woodward of WHOI who designed and fabricated the pressure tolerant gas collecting burette.

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SAIL COMPATIBLE THREE CHANNEL ACOUSTIC NAVIGATION INTERROGATOR

Stephen P. Liberatore

Abstract

Ocean Acoustic Tomography data are significantly degraded if mooring motion is unknown. An autonomous instrument employing a solid state data logger designed to track and record mooring motion is described.

Navigation is accomplished by simultaneously interrogating each of three bottom mounted transponders positioned in an equilateral triangle around the mooring's anchor at a range approximately equal to the depth of the tracked instrument. The three round-trip travel times thus obtained having a resolution of 250uS and a SNR dependent jitter of less than 1.5mS, define a unique instrument position and are recorded along with the time of day and day of year.

The measurement period, the system clock and the program start time are set via a 20mA SAIL. Since the standby power requirement is negligible compared to the battery capacity, the instrument may be programmed months in advance of the deployment.

System endurance varies with the measurement period, however, typical programs permit navigation for up to 21 months at 12 points per day.

Upon recovery, the navigator data may be down-loaded via SAIL directly to the storage medium of a suitable computer.

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NORTH ATLANTIC TRACER RELEASE EXPERIMENT

Ann Martin

The NATRE project, directed by Dr. James R. Ledwell, is an experiment for the study of cross-isopycnal mixing in the main pycnocline, and uses monitoring of a tracer which has been released near an isopycnal surface. The field phase of the project began in December 1990 with a test cruise on the Oceanus to the edge of the continental shelf, and is expected to continue until summer 1993.

In the initial phase of the test cruise, a Seabird Electronics CTD was mounted inside a metal framework, a "sled", with a dye injector system. The 1100 pound sled, measuring 2.4 m by 1 m by 1 m, was lowered overboard and allowed to sink to the density level where the dye would be released. The sled was then towed at 1 knot at that level, injecting a dye tracer, for 5 hours before being recovered.

Most of the operation is controlled from a 386SX PC in the main lab of the ship. The PC is connected to: a Metrox winch-readout system; the winch controller; the Seabird CTD deck unit; and the SAIL loop providing navigational information. The program used during the sled launch and dye injection phases provides a display of data regarding returned CTD values, winch and tracer injection descriptors, and physical information about the motion of the sled: yaw, roll and pitch. This display also allows the operator to change the target level, to turn the injection pump on and off, to control the tripping of water sample bottles, and to change winch control parameters.

The CTD data are received through a National Instruments GPIB IEEE-488 Instrumentation interface board. The winch control parameters, implemented via a Metrabyte D/A board, order the winch to haul in or to pay out cable when the seawater density is outside the bounds of a preset window. The window size and winch speed are set by the computer user while the program is running. As a safety factor, manual control of the winch by the ship's winch operator can override computer control at any time. Navigation position data are read through the computer's serial port from the ship's SAIL loop. On the test cruise, Loran C positions were used, with the NATRE computer acting as SAIL loop controller in order to acquire position data on demand. For future cruises, the user of the NATRE program will be able to toggle between GPS and Loran C.

Data collected during each deployment of the sled on the test cruise are now being analyzed to evaluate and improve the density-following system. A short test cruise is planned for October 1991. The main experiment consists of an injection cruise in the spring of 1992 and 30-day sampling cruises in May and October of 1992 and in May of 1993 in the eastern subtropical North Atlantic.

Funding was provided by the National Science Foundation Grant No. OCE 90-20492.

WHOI DSP32C Based Acoustic Telemetry Modem

John S. Merriam

Background

An important success of the telemetry research program at WHOI has been the development of a battery powered, high rate acoustic data link suitable for remote ocean deployments. The acoustic link ia composed of a high rate transmitter/receiver and a high rate transmitter/ low rate receiver which can be used in various configurations to make up a multiple node communications system. These components are intended for use anywhere an acoustic telemetry link would provide a robust wireless digital data link. The modulation and processing algorithms used permit data rates up to 5000 kbits per second at ranges of several kilometers. The actual data rate is currently limited by the acoustic transducer bandwidth, not real-time constraints or processing capability. Modulation methods are now being studied which would push the data rates closer to 20k bits per second. A number of test deployments in shallow and deep water have demonstrated the capabilities of the system and enhancements are made on a continuing basis.

1.0 System Components

The high rate receiver/transmitter unit (the model ATM850 Acoustic Modem) employs the latest in signal processing methods and hardware. A digital signal processor, the AT&T DSP32C, is the main processing chip. It is capable of performing frequency domain processing of acoustic wave-forms in real-time which is required at the receiver to process and decode acoustic waveforms.The system hardware is summarized below. Additional details on the hardware can be found in (1).

The hardware consists of analog and digital sections. The analog section utilizes three pc boards. The first of these is the receiver front end board which contains 20dB of fixed and 40dB of variable gain to amplify received acoustic waveforms. The second board employs 12 bit A/D and D/A converters to convert acoustic waveforms for processing by the DSP chip. The third board is a power amplifier which is used during transmission of signals. The digital section consists of one pc board where the AT&T DSP32C is interfaced to a Motorola 68HC11 embedded controller. This board provides appropriate digital interfaces to the A/D D/A board and an RS232 interface to an outside host. The digital board is designed to be a general purpose low power signal processing engine which can be used for a variety of uses other than acoustic telemetry. In fact, data compression and remote sensing applications are currently being considered using the digital board.

The high rate transmitter/ low rate receiver unit (the model ATM840 Acoustic Modem) employs a 68HC11 processor which has a 1200 baud acoustic transmit and 100 baud receive capability. The unit is designed for remote deployment at a data source such as a current meter or other sensor where high rate data transfer in one direction and low rate polling in the other is most useful. The power consumption and cost is much less than the DSP based unit. The 840 consists of one digital/ analog board, a power amplifier and transducer. Again, this unit is described in more detail elsewhere (1).

Both of the telemetry units were designed at WHOI as part of the acoustic telemetry research effort. During 1990, the DSP32C based modem was licensed to Datasonics for production as the ATM850 Acoustic Modem. Also the 68HC11 based unit was re-packaged and is available as the ATM840 Acoustic Modem. Finally, an IBM-PC/DSP32C based development system has been developed which is suitable for use as a shipboard deck unit and may become a Datasonics product in the future. The IBM-PC system uses an off-the-shelf DSP32C PC plug-in board instead of the deployable DSP32C-68HC11 board, but the functionality is the same. Here we shall refer to the PC based system as the 'PC850'.

This document describes the telemetry system signal processing software written for the ATM850 which consists of DSP32C code and 68HC11 code and system control software for an IBM-PC. The DSP32C software as written is not dependent on any particular host controller. The software has been ported to both the ATM850 deployable system as well as an IBM-PC compatible development system where the PC itself serves as the host controller. We have found that utilizing an IBM-PC as a host controller can speed up the development process considerably. In the following discussion, 'host' shall refer simply to a processor which serves as a master controller for the DSP32C modem.

The ATM850 typically is used as a high data rate acoustic telemetry receiver and the ATM840 serves as the transmitter. The ATM840 does not have the signal processing capabilities of the ATM850 and therefore cannot receive high speed data. It does however have a command capability similar to an acoustic release. One would then use the ATM840 at a data source such as a current meter or other deployable device where polling capability is useful but the main data flow is to the surface. The ATM850 can command to and receive data from multiple ATM840s which makes the entire system capable of multiple sensor deployments.

A useful deployment of the system is in a deep water data collection scenario where one would have several sensors deployed on the bottom with a single surface buoy serving as the central collection point. A similar system has been deployed in deep water offshore Bermuda. In this experiment the mooring controller scheduled polling and reception of data from 3 ATM840 units deployed along the mooring cable. The ATM850 and ATM840s were used in this configuration as a transparent communication link between the mooring controller and three remotely deployed sensors.

Work is currently underway to implement high speed data transmission on the ATM850 so that bidirectional communication can be accomplished between two or more ATM850s. This configuration is currently targeted for CTD to shipboard communication using data compression methods. Such as system would also be suitable for ship to UUV communication.

2.0 ATM850/PC850 Theory Of Operation

The ATM850 DSP32C software has evolved into a unified "C" language software package which has the ability to receive and process acoustic transmissions, process and transmit RS232 data streams, and act as a transmitter to command one or more remotely deployed ATM840s. A compact main routine is used as a high level system controller which can select from one of the above modes of operation based on information from the host. A simple data transfer/handshake protocol has been developed to permit communications between the DSP32C and the host controller in use.

A host software package '850cntl0.asm' exists to run on the 68HC11 controller which acts as a master processor to the DSP32C in the ATM850. This software is written in assembly language, but is currently being converted to "C". A "C" code controller program also exists for the PC850 and is functionally similar to the 68HC11 program but has diagnostic features not found in the 68HC11 program. In both the ATM850 and the PC850, a narrowband wakeup detector is used to generate a hardware interrupt when a wakeup pulse is sent (see 2.1). This interrupt is used by the host to signal the start of the data sequence. Since the host is the system master, the DSP is simply powered on and awaits a software flag from the host to begin processing.

Upon startup by the host controller, the DSP32C main routine awaits direction from the host to enter various receive, transmit or ATM840 command modes. Once in one of these modes, the DSP32C will stay in that mode until processing of that mode is complete at which time it returns to main() to report to the host that it has completed. If the host has further activity for the DSP32C then it commands the DSP32C into a new mode. When the 68HC11 is the host, such as in a remote deployment, the DSP32C is usually turned off once the transaction is completed.

2.1 Acoustic Transmission Sequence

The modulation method employed in the ATM840 / ATM850 system is Multiple Frequency Shift Keying (MFSK) where many acoustic tones are transmitted at the same time to represent a number of data bits. The method of representing data bits by sending a number of frequencies at once can be thought of as a parallel transfer of data. Currently we send 8 to 16 data bits per 12.8 ms frame resulting in a data throughput rate of up to 1200 baud. As is explained further, a matched field data pattern, the Barker code, is used to acquire and track the transmitted data frames.

A typical acoustic sequence transmitted by an ATM840 or ATM850 begins with a 15 ms 12.5kHz wakeup tone which, when detected by external analog hardware, is used by the host controller to start the DSP32C. A Barker code, which consists of four 1.0 ms tones is received next and is used to obtain a reference upon which to start tracking incoming data frames. A pause is then followed by the first of nineteen 12.8 ms data frames (256 sample points). A Barker code is then sent for data tracking purposes. The data frames followed by a Barker code are then repeated until the message is complete. A set up parameter change allows the number of data frames between Barker codes to be changed easily to meet the needs of various link conditions.

2.2 DSP32C Receiver Mode Operation

The ATM850 analog hardware samples received data at 20.144kHz and the data is transferred to the DSP32C via dma input. A flip-flop buffer is implemented in the receiver software. Data can be dma'd into memory in one half of this buffer while signal processing algorithms are processing data out of the other half of the buffer. This permits real-time data processing without placing stringent synchronization requirements on the acoustic source and receiver.

When an incoming frame is expected to be a Barker code frame, the DSP32C software switches into Barker processing mode. A Barker code frame is used to obtain a reference point in time relative to the start of the next data frame. Depending on whether the Barker code is early or late in time, the start of the next frame can be adjusted during the dma transfer. Initial testing has shown that use of the Barker code can correct up to 40% uncertainty in the time synchronization. A 4 chip Barker code is used for initial data lock and data tracking.

When an incoming frame is expected to be a data frame, the data is passed to an FFT routine. The resultant frequency spectrum is searched for high energy in specific bins which represent encoded data bits. If a convolutional encoder was used at the ATM840, the input samples are FFT'd and are sent to a viterbi decoding algorithm. The resulting data bytes are transferred to the host using a host-DSP32C flip-flop buffer arrangement which, like the input dma data, allows the DSP32C to enter data into one buffer while the host is obtaining data from the other buffer.

2.3 DSP32C Transmitter Mode Operation

In transmitter mode, the DSP32C software encodes serial input data into the same MFSK data transmission used by the ATM840. The software can be easily changed to invoke single or double sideband modulation.

As in receiver mode, the transmitter software also uses a two dma buffer flip-flop arrangement so that while an encoded waveform is being clocked out of one buffer, an inverse FFT can be performed in the other buffer. The processing requirements of the transmitter software are minimal. A digital data stream is transferred to the DSP32C from the host in another dma flip-flop arrangement. Once a host-DSP32C data buffer is full, the DSP32C starts encoding the data from it and sending the data to the output D/A converter via another dma buffer. Meanwhile, the host can send data to the other host-DSP32C buffer. This arrangement allows all processes to continue uninterrupted operation and provides for maximum data throughput. Once the DSP32C has exhausted all of the data downloaded from the host, it informs the host that it is complete and waits in idle mode in main() for further direction from the host.

2.4 ATM840 Command Mode Operation

An 8 bit ID/command can be issued to an ATM850 (or PC850) by the host to deliver to the ATM840. The ATM850 sends the information to the ATM840 by way of an 8 bit FSK transmission. This information is typically used to poll the ATM840 for sensor data or simply to send the 4 bits of information to an externally connected instrument. Future code updates are expected to increase the number of data bits to more than 4.

In the ATM850, a routine is used to obtain one byte from the host which contains an 8 bit command/ID sequence. The routine then generates an acoustic wakeup, sync and 8 tone sequence which is detected by an ATM840. The tones are generated by using a previously calculated sine lookup buffer and performing serial dma output to the D/A converter of the appropriate sine values necessary to generate a given tone. Each tone is of fixed duration and is separated from other tones by a known delay. This FSK sequence is similar to those used on acoustic releases. Once the ATM840 command sequence has been transmitted, the DSP32C informs the host that it is complete and waits in idle mode in main() for further direction from the host

3.0 ATM850/PC850 Software Structure

The software is presently divided into three main sets of code, one of which runs on a PC compatible such as a 386, one which runs on the 68HC11 and the other which is runs on the DSP32C.

3.1 DSP32C Code and Module Names

This code consists of a main program module main() which is an idle loop that awaits direction from the host controller via a variable called 'mode_flg'. Once a given mode has been sent to the DSP32C by the host, main() then calls on one of the following routines: receive(), transmit(), or carey_trans().

receive() controls acquisition and processing of dma data that is received from an external A/D converter via memory mapped dma. receive() uses a library of routines named 'DSP_RLB.C' which contains barker code, decoding and test specific software modules and a library of routines named 'URIP_VIT.C' which contains viterbi decoding specific software modules.

transmit() controls acquisition and processing of digital data received from the host for transmission acoustically. transmit() uses a library of routines named 'DSP_TLB.C' which contains encoding and data handling code as well as all of the ATM840 command mode code.

Two assembly routines '_FFTFI.S' and '_RFFTA.S' are adaptations of AT&T supplied FFT algorithms for accomplishing forward or inverse FFTs and real FFTs respectively. These routines are to be replaced in the future with faster AT&T supplied routines.

One unified header file 'DSP_GEN.H' contains predefined constants and variable declarations and is used by all of the software modules.

Memory map files 'ACOUROM.MAP' and 'ACOURAM.MAP' are used to specify the memory layout of code at link time.

The major code segments: main() and global data, receiver code, transmitter code, and assembly code each have their own directories which are compiled using batch files. The receiver and transmitter libraries, the assembly routines as well as global data are placed in a common .lib file after compilation.

All of the above DSP32C code is compiled/assembled and linked by the AT&T D3CC compiler which conforms to the ANSI "C" standard but generates highly optimized code for the DSP32C chip. Signal processing and math libraries are provided as well as support tools.

3.2 PC850 Code

This code consists of a main program module 'PC_850.C' which controls handshaking and communication with the DSP32C board as well as processing and disk file output. 'PLOT.C' is a fast interactive plot routine used to display uploaded DSP32C arrays in close to real time. These two programs use 'DSP_GEN.H' to obtain common information about array sizes and variable definitions. A batch file is used to compile and link these modules using Microsoft C Version 5.0 or higher compiler.

3.3 68HC11 Code

This code consists of a host program '850cntl0.asm' which initializes the DSP32C, determines whether it was brought out of sleep mode due to an acoustic wakeup or external RS232 input and commands the DSP32C into an appropriate mode. Once in this mode, the 68HC11 transfers data to and from the DSP32C to an external RS232 port via a software circular fifo buffer. Once the DSP32C processing is complete, the 68HC11 code turns off the DSP32C and returns to sleep mode.

4.0 DSP32C Detailed Module Descriptions

The following descriptions are provided to give a detailed explanation of the software operation. One should be able to follow the code operation if these descriptions are referred to while viewing the software itself.

4.1 FILE URIPMAIN.C

4.1.1 main() - calls a system initialization routine init_sys() and init_vit() is called to initialize the viterbi state metrics. Main() enters a loop waiting for the host to issue a mode command via mode_flg. Once a mode has been downloaded, main() calls receive() or transmit() or carey_trans() whichever is applicable. When a return from one of these modes occurs, main clears mode_flg to tell the host that it has completed processing.

4.2 FILE DSP_RLB.C

This file is a library of routines used to support the processing of received data and barker codes in conjunction with main().

4.2.1 sample() - is used to read integer values out of dma_buf, float them and put them into fft_bufs for fft'ing by decode(). Since all 16 bit samples are replicated twice during the dma process, the code skips every other dma value.

4.2.2 barker_proc() - is used to process dma'd barker frames of 256 or 512 samples in length. The float buffer fft_bufl is used for accomplishing in place FFT's and convolution. Many integer registers are used as pointers to values in fft_bufl and two float registers are used to speed up manipulation of floating point values during convolution.

At the start of barker_proc(), mode_flg is checked to determine whether the code is to be used in acquisition mode (512 point barker frames) or tracking mode (256 point frames) and sets the length of FFT buffer to use. This in turn determines whether all of fft_bufl is used or only half. The log of the FFT length is also established for later use.

Once initial parameters have been established, 256 or 512 values are taken from dma buf and are put into fft_bufl. This data is all of the raw dma data used by this routine. After sampling the data, _rffta() is called to accomplish a real in-place FFT.

The resulting spectrum is only half of the total symmetric spectrum, so in order to multiply it by the asymmetric barker code-filter spectrum reference (bar_vec) the real complex conjugate of the spectrum is folded over in fft_bufl in order to produce the desired symmetric spectrum.

The barker code/filter reference spectrum bar_vecs or bar_vecl is chosen based on mode flag and is then multiplied by fft_bufl to produce a convolution. The result (in fft_bufl) is then inverse FFT'd by _fftfi().

The resultant time-domain waveform is checked for its highest value. If this value is greater than a pre-defined constant BARK_THRESH, then the return value for bark_proc is one otherwise it is zero. The array index of the highest value is used to determine a 'dither' value from the center of the buffer where the highest value was actually found. This returned 'dither' value is used by resync() to track data frames.

4.2.3 decode() - is used to obtain data bits from a data frame's post FFT spectrum. Since the frequency bins are symmetric about a center bin due to double sidebanding, two bins are added together to produce one bin. The highest energy bin is compared against the nearest M bins wehere M = 4 or 2 depending on whether 1 of 2 or 1 of 4 modulation was used. Depending on which of the M bins is the highest determines which data bit(s) were encoded at the transmitter. The energy values are stored in the array v_frame for later use by the Viterbi decoder if the decoder is used. Running sums of the highest and lowest energy bins are maintained for later calculation of signal to noise level. This information is only of use when the transmitted sequence matches the prestored reference buffer syst_bytes which is usually the sine look up table found in the ATM840.

4.2.4 data_proc() - is used to call sample() and _rffta(), and in the uncoded case to call decode(). data_proc() has a return value of one only if a data byte is returned.

4.2.5 This routine deleted.

4.2.6 data_trans() - is used to set a flag for the host processor that indicates that the 386_dat buffer is ready for upload. The routine does not exit until the flag has been cleared by the host.

4.2.7 delay_dma_samples() - can be used to delay dsp processing a known number of dma samples.

4.2.8 resync() - is used to resynchronize the dma pointer based on a non zero value of dither. If dither is positive, this implies that the data frames are advanced in time and need to be retarded in time. To accomplish this, dither is converted into a pointer value and is added to a user supplied dma start location dma_add. When pin advances to this new address, it is sent back to the dma start, effectively throwing away dither dma samples. This results in the first dma sample of the data frame being aligned at dma_add.

If dither is negative, this implies that the data frames are retarded in time and need to be advanced. This is accomplished by subtracting dither from dma_add (remember dither is < 0) and assigning the result to pin. This advances the start of the second data frame after the present one to its appropriate start address in dma_buf.

4.2.9 this routine deleted

4.2.10 receive() - This module is the main control module for receive mode and is used to start and control the dma transfers from an external A/D converter and call on processing algorithms to obtain data bytes out of the received data stream.

Startup - Register variables are heavily used throughout all of the receiver software, and in this module, 4 integer pointer registers are utilized for manipulation of the dma transfers. In this module, some assembly language instructions are used to manipulate the 'pin' register which is used by the DSP32C as a dma pointer. The assembly instructions require that the register variables be defined by the 'C' code in a certain order so that the correct register numbers created by the 'C' code match those used by the in-line assembly instructions. The registers are r13,r12,r11, and r10. r13 points to the start of dma_buf, r12 points to the middle of dma_buf and r11 points to the end of dma_buf. r10 is used only during initial data aquisition to collect dma samples until the start of the data frames is acquired.

receive() then collects 512 samples of dma data in dma_buf and allows the dma transfer to continue into the rest of dma_buf while the barker processing is occurring. barker_proc is called to determine how far off in time the incoming samples are and returns the number of samples the dma input needs to be adjusted in order to lock on the first data frame. bark_proc is designed to determine whether the highest barker peak found has exceeded a preset threshold. If the threshold is not exceeded, then presumably no barker was found, and the wakeup which enabled the system to startup initially must have been false. If this is the case, then the DSP32 would return an error flag and terminate processing.

Once barker_proc returns a good dma adjustment in dither1, the code continues collecting dma samples until the beginning of the first data frame and then resets pin to the start of dma_buf. data_start is initially set to the beginning of dma_buf plus the expected number of samples from the start of the 512 point sync barker frame to start of the first data frame (BARK_TO_DATA_DELTA). data_start is adjusted after the call to barker_proc based on dither1 to account for any barker peak shift. receive() then collects dma samples until pin reaches the address pointed to by data_start. At this point, the next dma sample is expected to be the first sample of the first data frame, and pin is sent to the beginning of dma_buf.

Data Processing and Tracking - Once the start of the data is found, receive() enters a loop for data processing and continued barker tracking. At the start of the loop, a dma collection loop is used to acquire 512 dma samples into the start of dma_buf. Once pin reaches dma_mid which points to the middle of dma_buf, pin is resynchronized to adjust for any jitter found during barker processing of the second half of dma_buf which is stored in dither2. Of course, dither2 will equal zero immediately after initial data acquisition and for several more frames during data processing, since barker processing is only done every 19 data frames in tracking mode.

After resync is called (if dither is not 0), num_data_frames is tested against D_TIL_B to determine if the appropriate number of data frames have been processed prior to processing a barker tracking frame, or if 2 more data frames should be processed. If a 256 point barker frame is expected to exist in the second half of the first half of dma_buf, then one 256 point data frame is processed by data_proc and then one 256 point barker frame is processed by barker_proc. Otherwise, the 512 points in the first half of dma_buf are expected to be two 256 point data frames and they are both processed by calls to data_proc.

Once processing on the first half of dma_buf is complete, pin should not yet have reached the end of dma_buf, so a dma loop collects values into dma_buf until pin reaches the address pointed to by dma_end. Once pin reaches dma_end, it is sent back to the start of dma_buf to begin collecting another 512 dma points.

Processing of the second half of dma_buf is identical to that done on the first half, except that any calls to resync are done based on dither1 which may contain a jitter value from processing of the first half of dma_buf.

When data_proc is called, it sends a data byte to host_handlr which handles transmission of data bytes to the host and increases a data byte counter d_cnt. If viterbi decoding is done, two calls of data_proc are necessary to produce one byte. During calls of data_proc which do not produce a data byte, d_cnt is not incremented because data_proc will have a return value of 0.

4.3 FILE DSP_TLB.C

This file is a library of routines used to support the processing of transmitted data and Carey Modem commands in conjunction with main().

4.3.1 get_host_dat() - This routine flip flops between the two host to DSP32C transfer buffers host_dat1 and host_dat2 and returns the number of bytes transferred in a given buffer and a pointer to the start of the data in the buffer chosen.

4.3.2 trans_frame() - calls the routines fft_buf_prep(), _fftfi(), and fft_to_dma() to process a frame of bits for output to the output dma buffer dma_buf.

4.3.3 fft_buf_prep() - analyzes a data byte sequence and places zeros and ones into appropriate fft bins in fft_buf prior to an inverse fft. If double sideband modulation is chosen, then the bins are mirrored about the modulation frequency bin. Since the fft spectrum is of a non-complex waveform, the first half of fft_buf is mirrored into the second half so that after the inverse fft is done, the result will be real.

4.3.4 fft_to_dma() - this routine copies the floating point post inverse fft waveform into the integer output dma buffer dma_buf.

4.3.5 carey_trans() - calls play_tone() for the appropriate tones and tone durations for a 1 byte carey modem id/command. The following sequence is transmitted :

wakeup....sync....bit....bit....bit....bit....bit....bit....bit....bit

where: "wakeup" is a 30 ms 12.978 kHz tone, "...." is a 90 ms quiet period, "synch" is a 10 ms 13.513 kHz tone, and "bit" is a 10 ms data tone where one=14.084 kHz and zero=14.706 KHz.

4.3.6 play_tone() - Given a frequency and time period, this routine calculates an appropriate delta time increment into the sine buffer tone_buf and plays the tone for the length of time given. The sine values are transferred out to the external D/A converter by using the DSP32C serial I/O capability.

4.3.7 tone_gen() - Generates a prestored sine table tone_buf when the software is initialized.

4.3.8 transmit() - This is the main transmitter control routine when in transmit mode. Similar to receive(), transmit() uses a flip-flop dma buffer dma_buf to transfer output waveforms (via trans_frame) to the external D/A converter for acoustic transmission. transmit() calls get_host_ dat() to obtain a buffer of data bytes from the host and then enters the dma flip_flop routine until no more data is returned from get_host_dat(). Once all of the data has been transmitted, transmit() returns to main().

4.4 FILES RAMDATA.C and ROMDATA.C

These files contain initializations for ram and rom data respectively. The two files are the only global data declarations used in the DSP32C code.

4.5 FILES RFFTA.S and _FFTFI.S

These two assembly modules are adapted from AT&T supplied routines to accomplish real and complex fft's. _FFTFI also performs inverse fft's.

4.6 FILE BAR_VEC.C

This file contains two prestored barker reference buffers bar_vecs and bar_vecl which are 256 and 512 points in length respectively. This file is generated by running the PC program BARK_MAK.C.

4.7 FILE DSP_VLB.C

This file contains modules which perform the Viterbi algorithm

4.7.1 init_vit.c - initializes the viterbi state metrics and clears the traceback array traceb().

4.7.2 numbits() - returns the number of 1's found in a 16 bit word.

4.7.3 getdata() - obtains raw fft output from v_frame and places it in the appropriate elements of rawdata.

4.7.4 vit3() - is a k=3 viterbi decoding algorithm which is used to obtain data from the traceback array once it has established an appropriate traceback path based on the viterbi state metrics.

5.0 ATM850 68HC11 Code Detailed Description

Reserved for future versions

6.0 PC850 Code Detailed Description

PC_850.C and PLOT.C are two "C" code files which are the source code for PC_850.EXE. PC_850.C is the control program which emulates the host functions of the 68HC11 processor on the deployable ATM850. PC_850.C was written to have the same interface with the DSP software that 850cntl.asm (the 68HC11 control code) uses. There are additional diagnostic and data logging capabilities written into PC_850.c which are not possible in the embedded system. Regardless of these extra capabilities, the DSP software used in PC850 and the ATM850 is the same.

PC_850.C utilizes the PC hardware IRQ5 to obtain acoustic wakeups just as XIRQ is used in the 68HC11. An interrupt vector routine rec_int() alters the PC's 8253 programmable real time clock to obtain and accurate time base once an ATM840 acoustic wakeup is received. This gives PC_850 the ability to accurately start the DSP just prior to the transmitted acquisition barker code. This is functionally the same as 850_cntl.asm on the 68HC11.

The DSP development plug in board from Communications Automation and Control is used along with a library of routines to communicate with the board. These routines are used by PC_850.C to download the DSP code, obtain addresses of DSP parameters, start the DSP and handshake data between the PC and the DSP memory.

PC_850 contains an initialization section where the DSP code is downloaded, addresses of dsp parameters are obtained, local variables are initialized and the interrupt vector table is configured to use rec_int() as the IRQ5 interrupt routine. Two data logging files are opened. The first defaults to 'PC_850.log' and is a general ASCII log file where data and diagnostic information is stored during the program's execution. The second 'w:raw_dat.log' is intended to be a file in a PC RAM- DRIVE where raw sampled dma data is stored while transmissions are being received. If, during reception, the user wishes to have a copy of the raw data for further evaluation, the user may select a menu option to copy the ramdrive file to a hard disk file.

The body of PC_850.C consists of an infinite while(1) loop within which all other processing occurs. Within the loop there exists a menu section, a data reception section, and a timed polling section. The menu provides a number of options to the user for data logging capabilities as well as the ability to poll a remote ATM850. Anytime PC_850 is not receiving data or polling a remote unit, the user can hit a key and obtain the menu to make selections.

When an acoustic wakeup is received by the analog front end hardware, rec_int() is vectored to a routine which changes the PC clock divider to a high divider so that a high resolution timer is available. PC_850 uses this fast clock to time when to start the DSP processing relative to the acquistion barker code. rec_int() sets a flag which causes PC_850.C to enter the data reception section of the while(1) loop. Within the data reception section, decoded or diagnostic data is uploaded from the DSP and is logged in the two log files. When decoded data is selected earlier in the menu, PC_850 displays and logs either an ASCII coded hex version or a straight ASCII version of the data. When a diagnostic mode has been selected, bit error rates and signal to noise ratio data is logged and displayed. One only expects to obtain useful bit error rate and signal to noise ratio information when the ATM840 command number 8 has been sent to obtain the transmission of sine table information from the ATM840. The DSP code is written to calculate SNR and bit error information when the data transmitted is the ATM840 sine table.

The timed polling section of PC_850.C uses the PC clock to poll a remote ATM840 on a timed basis. The user can select the polling cycle time via the menu. Currently, PC_850 only polls the remote ATM850 for diagnostic data, however newer versions will permit the user to enter any ATM840 command. This capability will permit one to obtain specific information from a remote instrument or other data source.

7.0 EMBEDDED APPLICATIONS CONSIDERATIONS

All of the DSP32C code has been structured to avoid using initialized global variables in RAM. This is done to avoid having to copy the initialized data from ROM into RAM which adds needless complexity to the code. None of the prestored data used in this code changes during normal operation, so it can reside in ROM. init_sys() is responsible for initializing global RAM variables and buffers to zero at processor startup and set any variables which are non-zero to preset values. Structuring the code in this manner also avoids wasting memory space for buffers which reside in both ROM and RAM. Future code expansion will follow this model closely. Note that all DSP32C routines are compiled and assembled into specific text and data segments which are allocated to certain areas of ROM and RAM by URIPMAIN.MAP.

8.0 REFERENCES

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PIEZOELECTRIC RAIN SENSOR

Robin Singer and Robert Weller

A piezoelectric rain sensor is under development in AEL for use in global climate studies. The measurement of fresh water flux in the oceans will help scientists understand the transfer of heat and momentum between atmosphere and ocean. The development goals for the sensor include low power consumption, inexpensive fabrication, and the ability to accurately measure wind driven rain.

Piezoelectric material converts mechanical stress or strain to electrical signals. Piezoelectric film, manufactured by Atochem North America, Inc. (formerly Pennwalt Corporation) is produced when beta phase PVDF (Polyvanilidenefluoride) is subjected to a high electric field at an elevated temperature. The film is anisotropic and has an open circuit voltage which is ten times that of piezoelectric ceramics for a given force input. It can be modelled as a charge generator and a parallel capacitor (see Figure 1).

A series of experiments has been performed to determine the suitability of piezoelectric film for use as a rain sensor. Two early prototypes have been built and have undergone preliminary tests. The earliest development work has focused on waterproofing methods and electronics. More recent work has focused on characterizing the waterproofed film and the signals generated by rainfall.

The sensor consists of a 15 cm by 15 cm piece of 28 micron piezoelectric film, sandwiched between two sputtered NiAl electrodes with leads attached by conductive epoxy, covered by sheets of polyurethane and sealed with Scotch Cote and silicon putty. It is adhered with GE-RTV to a 30 cm by 20 cm piece of 60 durometer .48cm (3/16") neoprene and mounted on the hinged lid of a plastic box. The neoprene backing translates the impact of the drop into a spring-like stretching and compressing of the piezo film. Thus, the force is applied in the longitudinal axis of the film, the axis which produces the largest signal. The lid of the box can be held at a variety of angles. The electronics consist of an amplifier and bandpass filters. They are powered by four 9 volt batteries with which they are housed in a waterproof box.

An early test of the sensor used a PC with a Metrabyte data acquisition board to digitize and process the signals, and a lawn sprinkler to produce rain. The RMS values of the signals and the area under the rectified signal curves were calculated and averaged over two minute periods and compared to the volume of water collected in a bucket beside the sensor. The results are shown in Figure 2. They demonstrated that the sensor can successfully track rainfall although they were not precise enough to permit a determination of the sensor's accuracy.

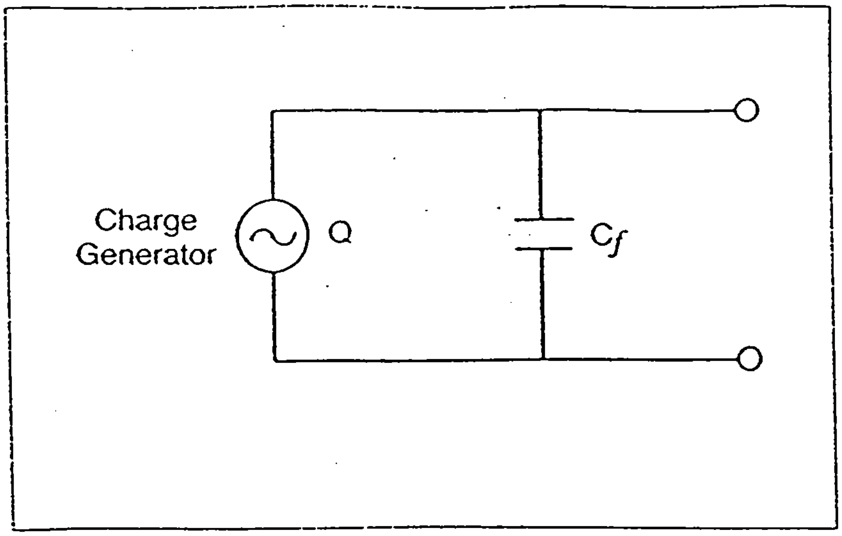

Figure 1: Simplified charge mode
equivalent circuit

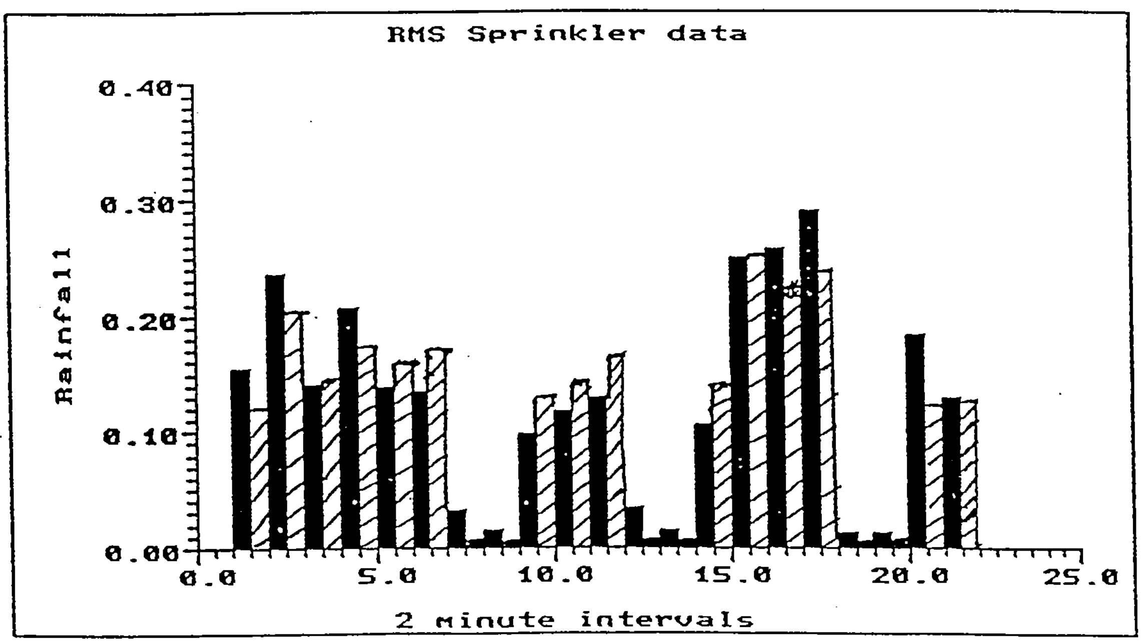

Figure 2: Rain sensor results (solid bar) compared to
bucket data (hatched).

The sensor is currently being tested in a stand-alone configuration with a charge amplifier, filters, a hardware RMS circuit, and a peak detector. A Tattletale Model VI with a 12 bit A/D converter takes 2 minute averages of the RMS and peak outputs and stores the values on disk. An R.M. Young self-siphoning precipitation gauge and an S.T.I. optical precipitation gauge are also interfaced to the Tattletale for comparison.

Experiments performed to characterize the sensor included investigations of the signals produced by different size drops, the effect of sensor angle relative to drop trajectory, and the effect of drop location on sensor output. The experiments were performed by releasing drops of known volume from a pipette onto the sensor through a 50 foot pipe, in order to achieve terminal velocity and remove the effects of wind. A digital storage scope with a GPIB port, sampled the signals at 20 kHz, stored them and transmitted them on command to a NEC 386 PC. Figure 3 shows the signals in the time and frequency domains. In the laboratory lead shot and ball bearings were released from a height of 2 feet onto the sensor and they produced the signals shown in Figure 4. Since the use of lead shot and ball bearings closely approximates the use of actual drops, future experiments can be done with ease in the laboratory.

Both drops and bearings were used to investigate the relationship between signal power and drop (or bearing) size. The sensor transfer function, shown as Figure 4, is a plot of 'momentum in' versus 'power out' for the drops, as reflected in the mean RMS values of the signals and also by the values achieved by rectifying and integrating the signals.

Space and angle experiments were also done with both drops and bearings and the results are shown in Figures 5 and 6. It is clear that the sensor is currently not space invariant but the signals are linear with respect to the cosine of the angle of inclination at angles of 45° and below. Continuing work will focus on ways to improve the spatial homogeneity of the sensor which may be varying as a result of the waterproofing method, uneven application of the epoxy when mounting to the neoprene, non-homogeneity of the film itself, or may even be an artifact of experimental technique. The angle data will be useful in designing a sensor that will measure wind driven rain.

In order to predict the effect of the current space invariance on the accuracy of the sensor, eight typical drop size distributions for 2 cc samples of rain were created and the range of values which would be reported by the sensor, prior to any optimizations, was calculated (using mean plus and minus one standard deviation). Using RMS values, a 2 cc volume of rain would have a maximum potential error range of approximately 12% (see Table 1).

In addition, a library of signals produced by actual rainfall has been collected and examined. Most of the signal energy is contained in frequencies below 1 kilohertz. Figure 8 shows the signals in the time domain and the frequency domain.

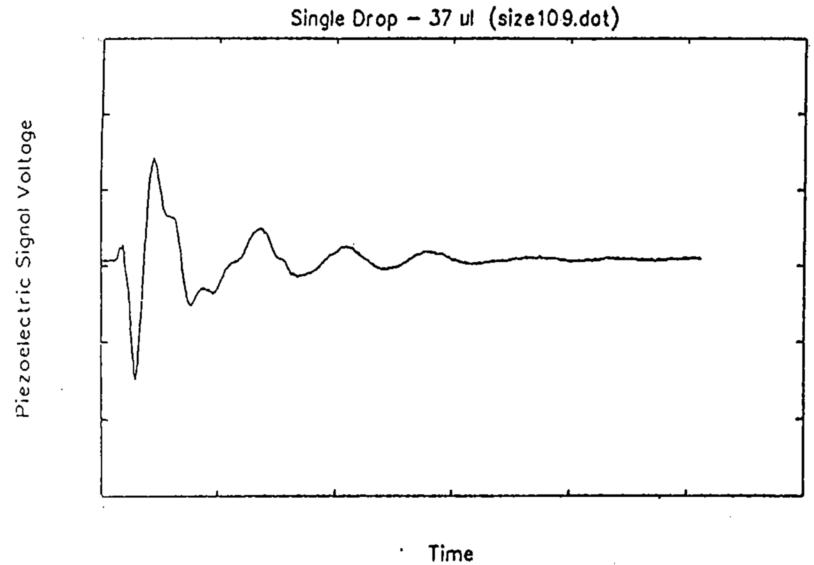

Figure 3A: Time domain signal generated by 37 microliter drop: duration = 200 milliseconds.

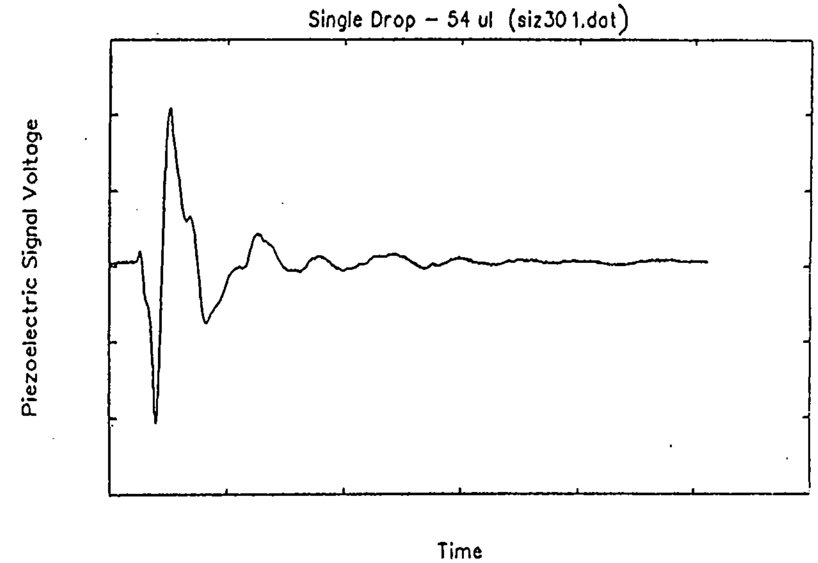

Figure 3B: Time domain signal generated by 54 microliter drop: duration = 25 milliseconds.

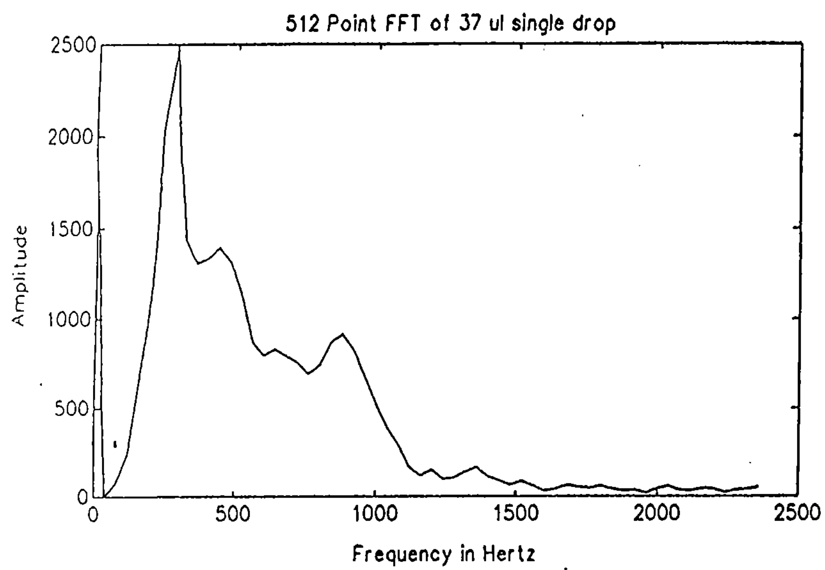

Figure 3C: Frequency domain representations of signal shown in A.

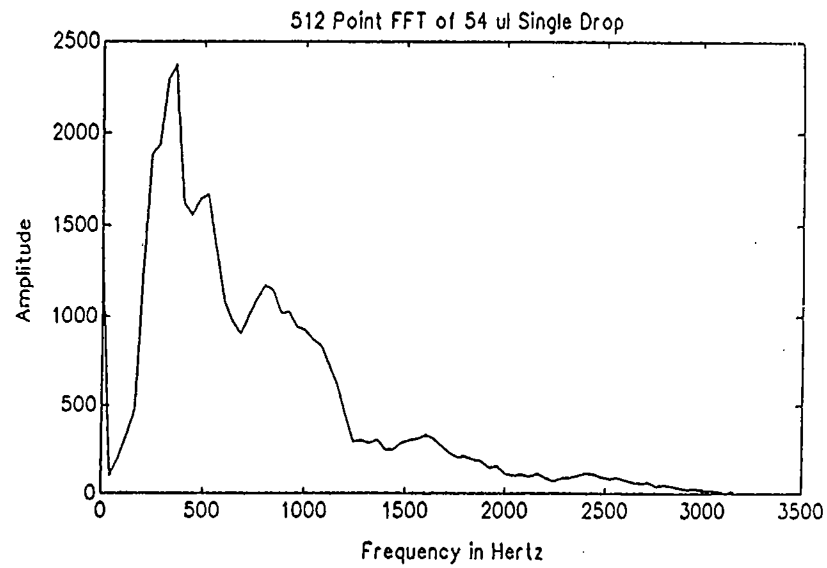

Figure 3D: Frequency domain representations of signal shown in B.

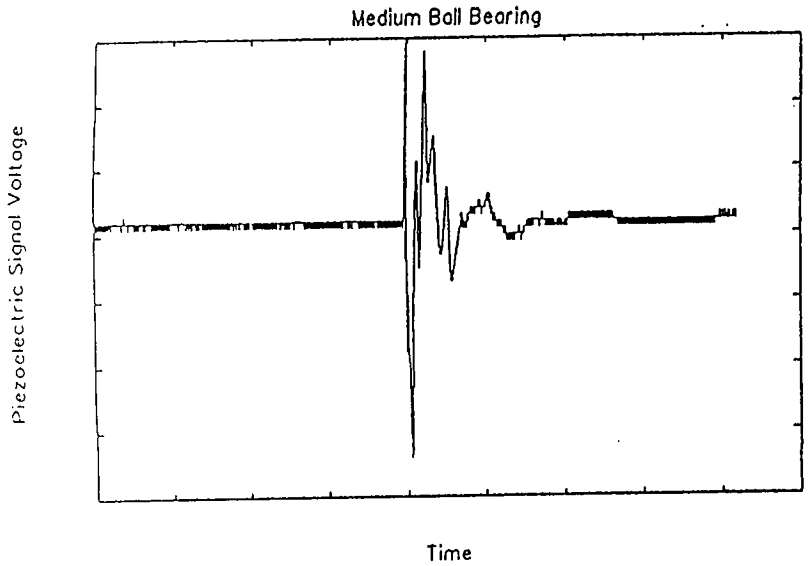

Figure 4A: Time domain signal generated by medium ballbearing: duration= 200 milliseconds

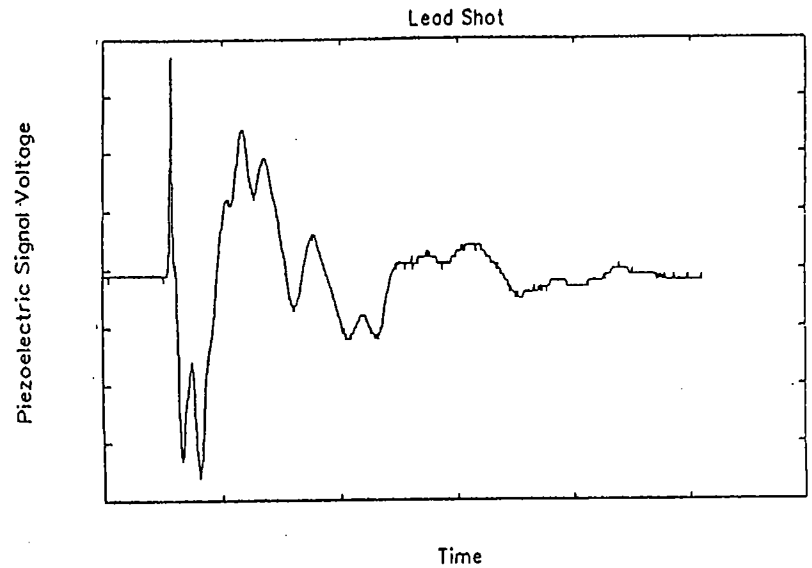

Figure 4B: Time domain signal generated by lead shot: duration = 50 milliseconds

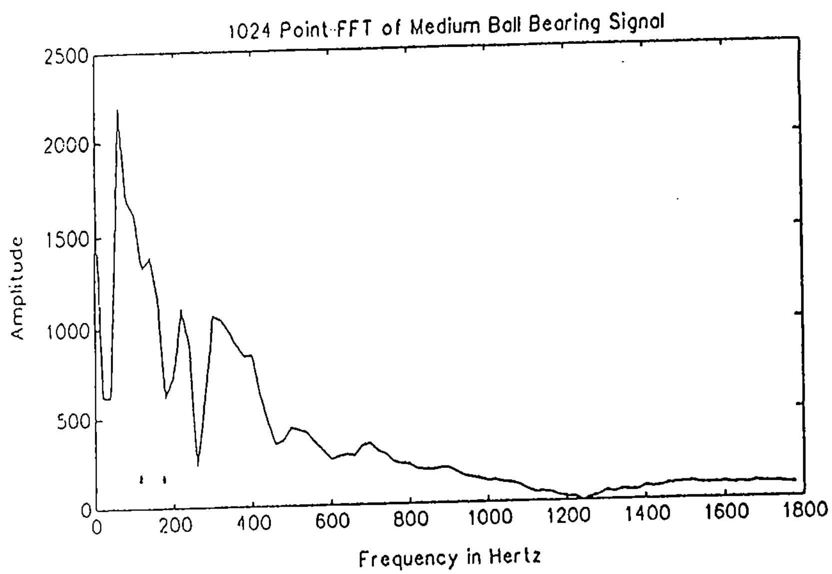

Figure 4C: Frequency domain representation of signal shown in A.

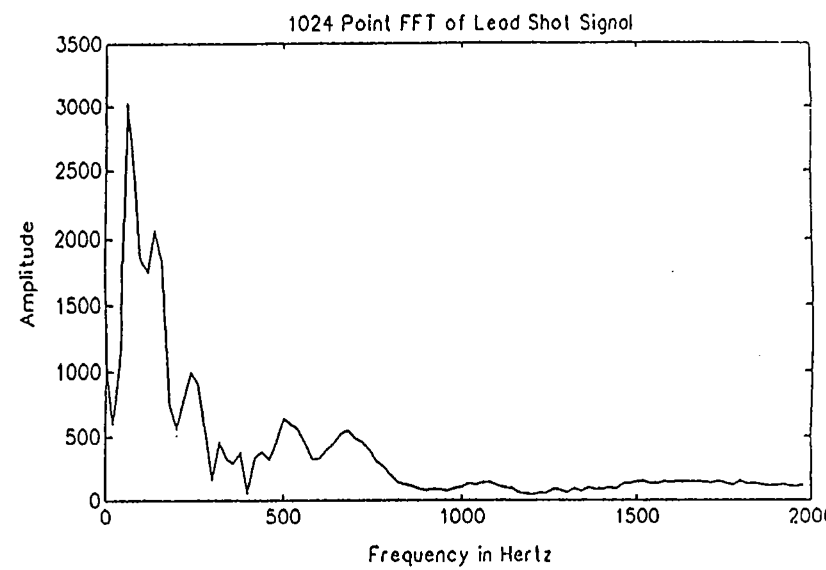

Figure 4D: Frequency domain representation of signal shown in B.

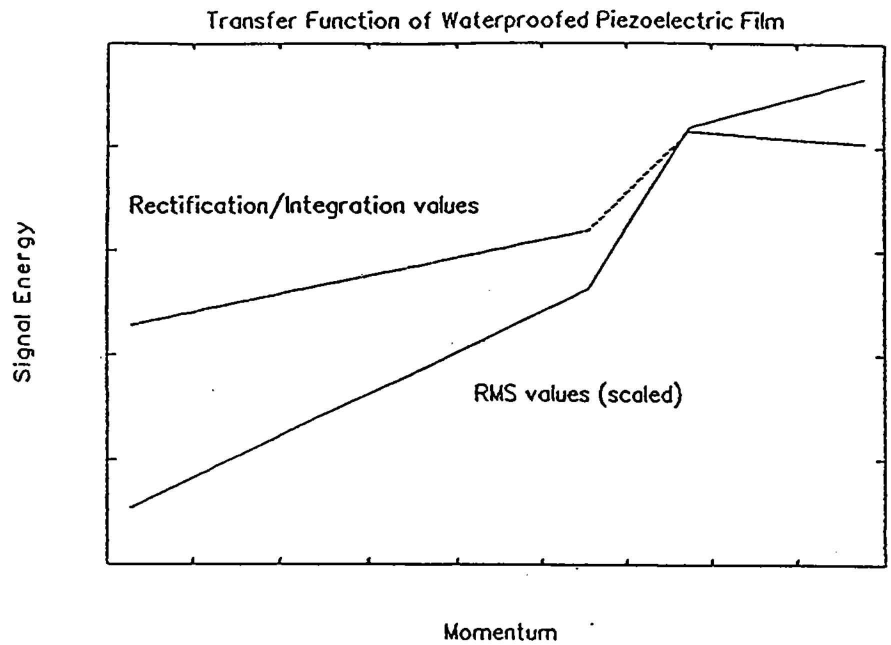

Figure 5: Mass times velocity for four drop sizes are plotted versus signal energy, as reflected in the mean RMS signal values and the mean area under the rectified signal curves.

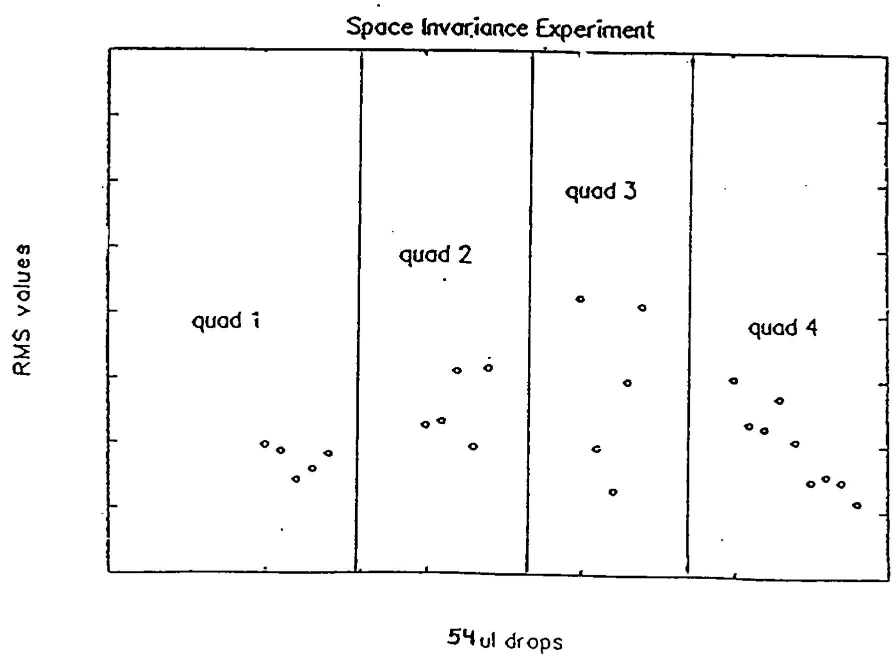

Figure 6: RMS values of the signals were calculated in repeated trials in all four quadrants of the sensor. There was significant spatial variability for both lead shot and calibrated drop trials.

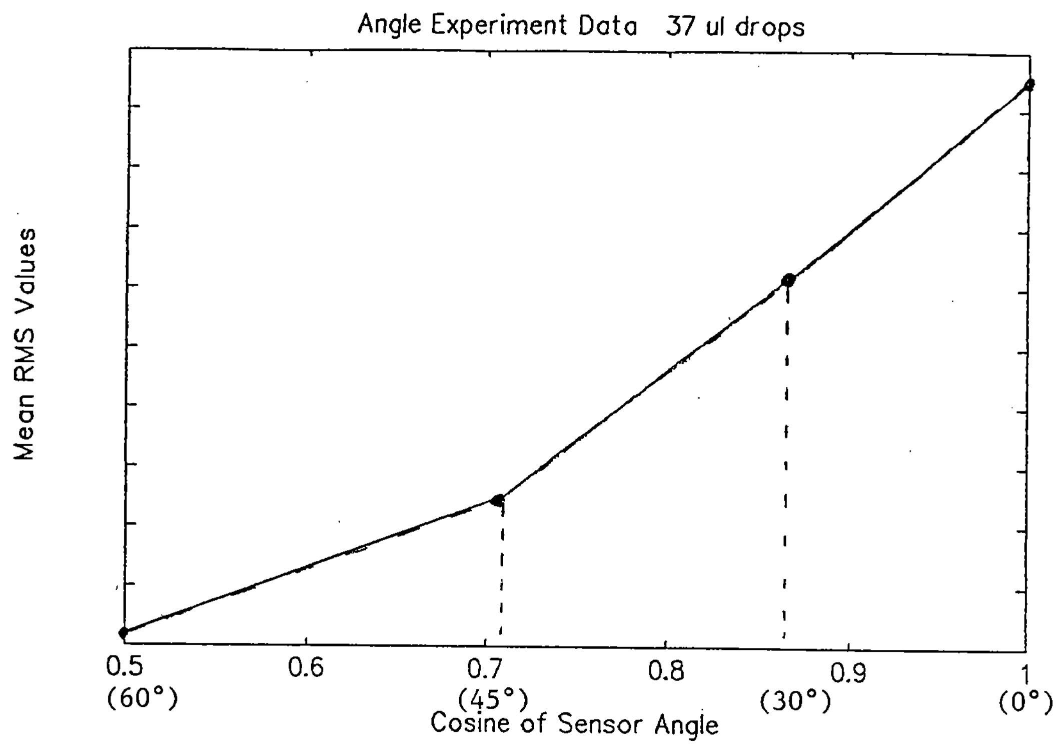

Figure 7: Angle data from 37 microliter drop experiment. The sensor was propped at 30°, 45°, and 60° angles respectively and the RMS values of the signals are plotted against the cosines of the angles.

8 ul	37ul	54ul	RMS range	Rect/Int range
90	20	10	163 < 186 < 208	142 < 156 < 169
106	18	9	164 < 184 < 204	155 < 169 < 182
149	16	4	163 < 178 < 192	190 < 204 < 218
154	12	6	165 < 179 < 194	194 < 208 < 221
170	10	5	166 < 178 < 190	207 < 221 < 234
186	8	4	166 < 176 < 187	220 < 234 < 247
202	6	3	167 < 175 < 183	233 < 247 < 260
218	4	2	167 < 173 < 179	246 < 260 < 273

Table 2: Hypothetical drop size distribution and resulting signal output ranges (for 2cc of rain).

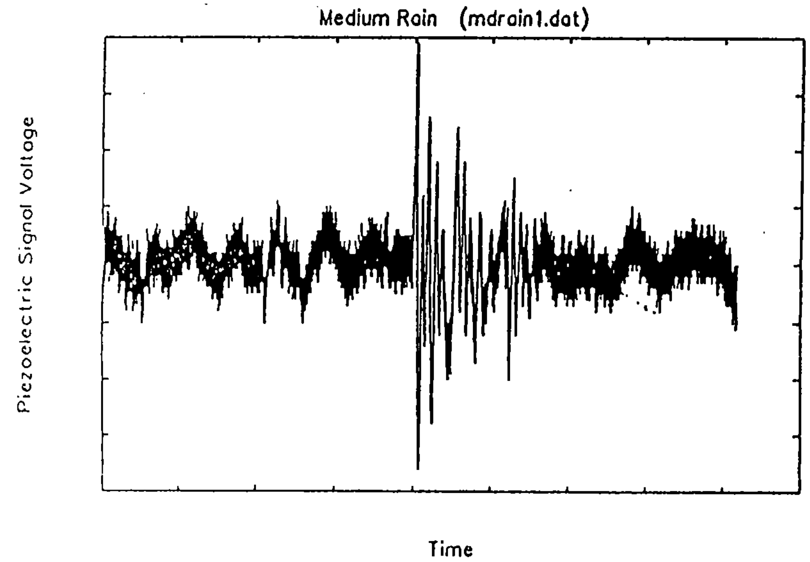

Figure 8A: Time domain signals produced by moderate rainfall: duration = 200 milliseconds.

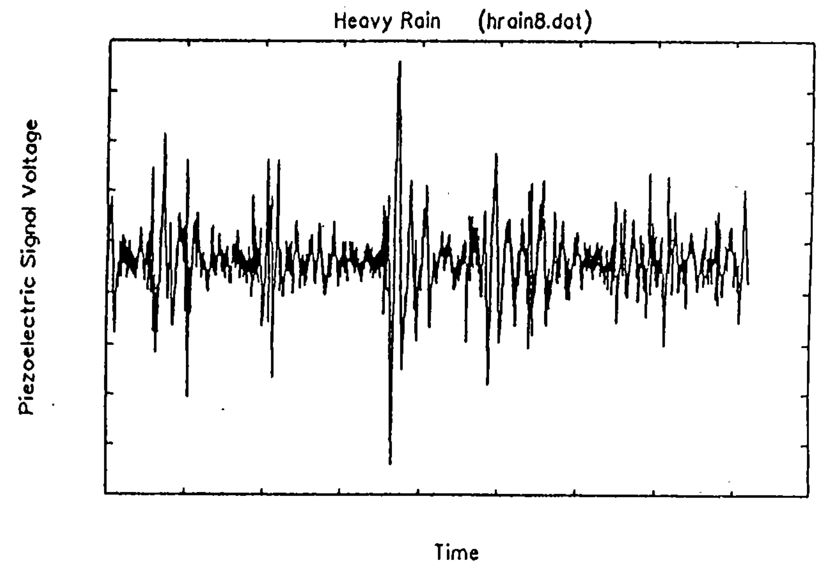

Figure 8B: Time domain signals produced by heavy rainfall: duration = 200 milliseconds.

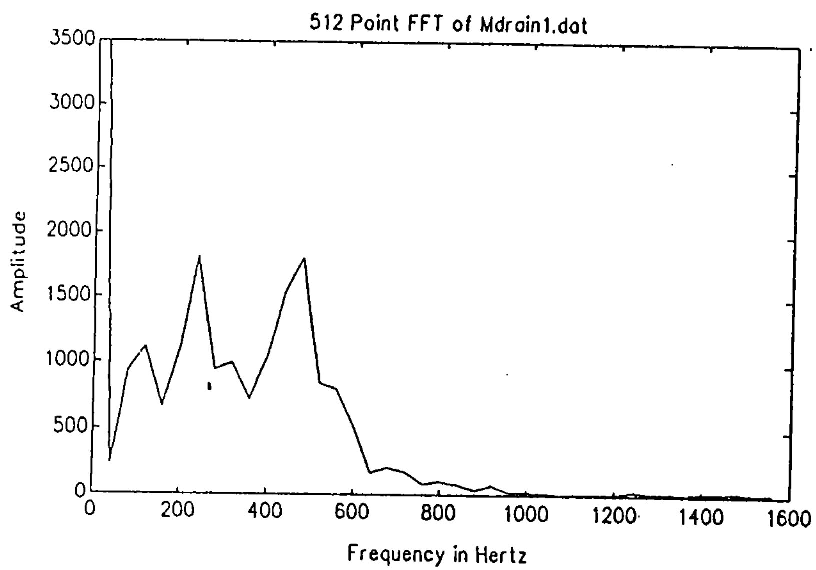

Figure 8C . Frequency domain representaions of 8A.

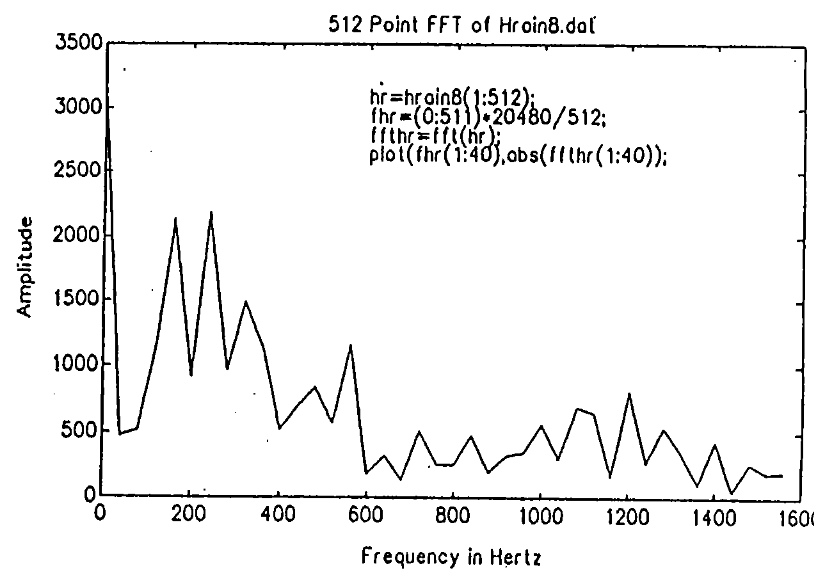

Figure 8D: Frequency domain representations of 8B.

In conclusion, a rain sensor made of piezoelectric film shows promise and could be of great use in global climate studies. The goals of the next stage of development include improvement of sensor accuracy through better fabrication techniques and incorporation of the relationship between mass and terminal velocity into the sensor algorithm, investigation of temperature effects, and an examination of the geometry necessary to measure wind driven rain and to avoid sea spray.

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THE AUTONOMOUS BENTHIC EXPLORER (ABE): A DEEP OCEAN AUV FOR SCIENTIFIC SEAFLOOR SURVEY

Dana R. Yoerger, Albert M. Bradley, and Barrie B. Walden

Abstract

The Autonomous Benthic Explorer (ABE) is a vehicle that will perform scientific surveys of the seafloor over an extended period of time without a support vessel. The vehicle is being designed to complement the existing manned submersible and remotely operated vehicle systems available to the scientific community. A primary application of ABE will be repeated surveys of hydrothermal vent areas at depths of 4000 meters. Specifically, ABE will be able to provide data concerning the long term variability of hydrothermal vents, a task that existing assets cannot accomplish. This paper discusses the motivation for ABE, outlines the specifications and basic design approach, and describes critical technical problems. Initial and future ABE mission scenarios are also discussed.

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ACOUSTIC FISH TAG

Jia Qin Zhang, Albert Bradley, Josko Catipovic, Stephen Liberatore, Neil Brown, Alan Duester, Lee Freitag and Frank Carey

A miniature version of the acoustic modem developed by the Acoustic Telemetry Group [1] has been designed and fabricated for use as a fish tag. This fish tag, which measures and telemeters pressure and four temperature channels, is also used to trace the movement of fish. A 68HC811E2 microcontroller is used for system control, timing, counting, data sampling, encoding and communication management. The remaining low-power CMOS circuitry includes pressure interface and multiplexer, multiplexer for temperature channels, capacitor charge/discharge and comparator circuit, communication interface, pulse width modulator, carrier-suppressed amplitude modulator, power supply, amplifier, and a wake-up clock generator.

The software is loaded into the 2Kbyte EEPROM within the 68HC811 through its SDI line (PD0) using the bootstrap mode. Software modules which allow for circuit testing and trimming can be loaded in at appropriate periods during the construction and testing process. Final operational parameters can be loaded prior to deployment.

Pressure

The pressure measuring circuit was originally designed by Albert Bradley and Stephen Liberatore [2]. The pressure sensor is a KELLER PA-7 series with full scale selected for the experiment (50-100 bar standard). The signal is multiplexed (CD4052) and is applied to a DC biased differential amplifier whose output is the integral of the pressure signal. The circuit's single-ended supply is balanced around 2.5 volts.

A pulse output from the microcomputer is used to balance the current from the amplifier to keep the output integrating within its linear limits. The 68HC811 A/D is used to measure the output voltage of the integrator at the beginning of the measurement cycle. Current pulses of 120 microseconds duration are then applied each 150 microseconds, discharging the integrator in discrete amounts. The 68HC811 A/D is used as a comparator to sense the output of the integrator, and when enough pulses have been applied to bring the output below the 2.5 volt reference (MSB changes from 1 to 0), the process halts. The pulse count represents the most significant 8 bits. The ending output voltage is then measured. The difference in the internal A-D readings between the start and end of conversion then give the least significant 6 bits, known as the residual. The 6 bit residual obtained from the A/D is multiplied by four (shifted left two bits) and stored in the least significant byte.

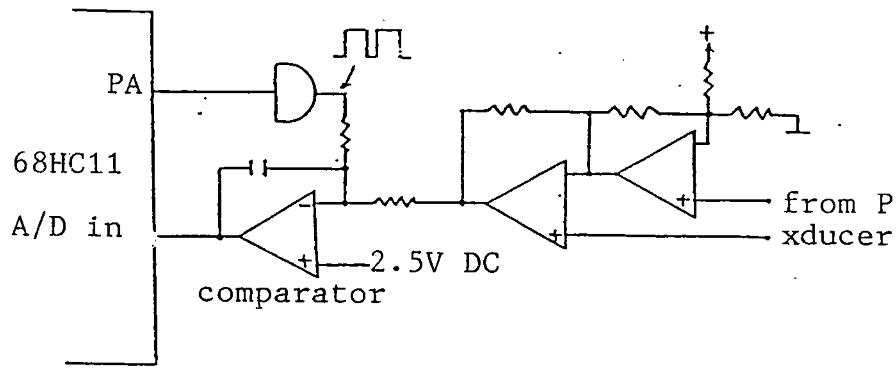

Figure 1A: Fish tag pressure interface

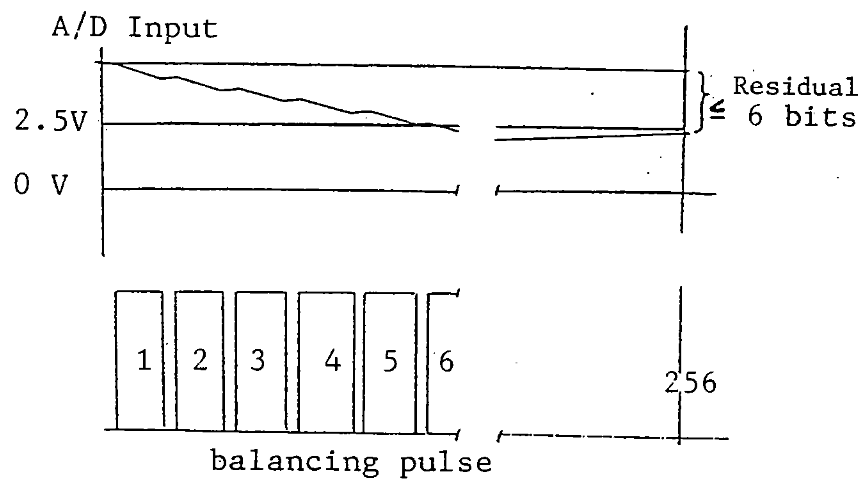

Figure 1B: Pressure measurement technique used in the fish tag

The circuit is designed so that when there is no pressure applied, the integrator has the highest input, and the number of balancing pulses required is the largest, 255 (8-bits). When full scale pressure is applied, the integrator has the lowest input and the number of balancing pulses is 1. The circuit must be trimmed so that slope and endpoints of the residual and pulse-count sections match. Software which assists in this is loaded into the 68HC811 in the trimming stage of circuit construction.

Temperature

The temperature measuring circuit was designed by Albert Bradley [3]. The circuit charges a capacitor through a multiplexer with enough time (3 ms, 26 times as long as its time constant) so that it is fully charged to 5v. The capacitor is then discharged through a thermistor. The 68HC811 monitors the output of a comparator, which compares this voltage with a 2.5v reference and records the time of this discharge procedure until the comparator output changes. This time is proportional to the resistance of the thermistor. A reference resistance is provided for real-time calibration operations. The software routine measures all channels twice, then stores the data in a buffer. The data resolution is 14-bits (stored as 2 bytes, data shifted to full left).

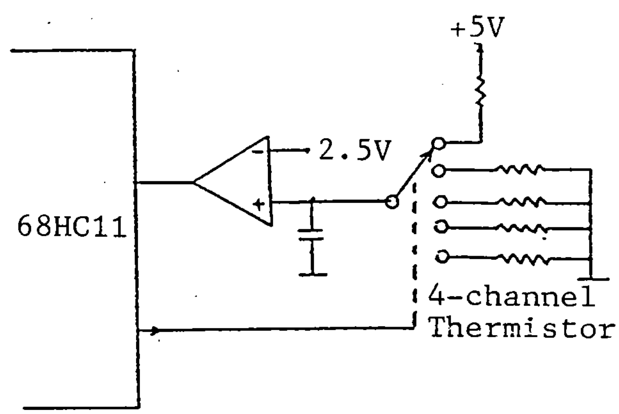

Figure 2: Fish tag temperature interface

Data Transfer

The data stored in the buffer is transmitted acoustically. The data encoding and transmitting software is similar to that used in the ATM 840 Acoustic Modem. To improve reliability of data communication, the 10-byte data stream (one pressure value and four temperature values in each data scan) is convolutionally encoded. A total of 22 bytes of data results from the convolutional encoding. This data is then encoded into the MFSK format, and each data byte is represented by an acoustic tone which is composed of 8 frequencies. The data tone is modulated by the carrier suppressed amplitude modulator and is transmitted through an acoustic transducer. The carrier frequency of 31.25 khz, is directly generated from the system clock. Each data tone is 12.8 ms long; the bin width equals 149.52 hz.

System Timing and Power Consumption

To conserve power, the system spends much of its time in a low power "sleep" mode. A dedicated clock generator (32.768 khz) and divider is used in the wake-up system. A pulse wakes up the 68HC811 every 0.5 seconds through the IRQ interrupt. The system operates on a 2-second cycle (4 wake-up interrupts). During the first interrupt it samples and formats data (136 ms) then returns to sleep. It transmits data on the next interrupt for 563 ms, then sleeps. The interrupt occurring during the transmission is ignored. The system immediately returns to sleep during the fourth interrupt.

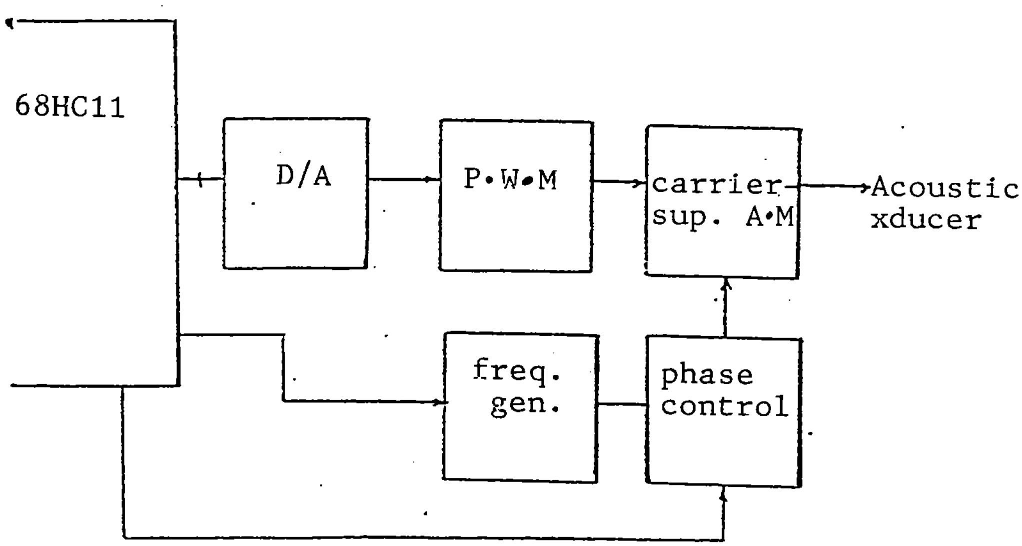

Figure 3: Fish tag block diagram

Each 12.8 ms tone burst contains one byte of information. During transmission, 12.8 ms tone bursts alternate with 12.8 ms pauses. The transmitter draws 3.68 W of electrical power during transmission. The integrated power consumption is 0.21 AH per day from the +7v supply, and 0.26 AH per day from the -7 v supply. With four 3.5v lithium CSC-3B24 cells, (1.8 AH capacity each), the system can operate for 6.9 days before battery voltage drops to 6v.

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[1] Catipovic, Josko, Daniel E. Frye and David Porta, "Compact Digital Signal Processing Enhances Acoustic Data Telemetry," Sea Technology, pp. 10-15, May 1990.

[2] Bradley, Albert and Stephen P. Liberatore,' Simple 14-Bit A-D Converter, patent disclosure, January 1989.

[3] Bradley, Albert and Baoren Wu, "A New Temperature Recorder," Journal of Ocean, University of Quindao, Vol. 19, no. 1, 1989.

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