Design of a Low-cost Acoustic Modem for Moored Oceanographic Applications

Bridget Benson Grace Chang Derek Manov Brian Graham† Ryan Kastner

ABSTRACT

This paper discusses the current state of the art systems of real time telemetry on oceanographic moorings and describes the design requirements for making acoustic modem data telemetry a more widely used form of data telemetry for moored oceanographic applications. We present the design of a low cost 'mooring modem' and the results of an initial pool test for its prototype. Based on these results, we describe how the mooring modem meets the design requirements for moored oceanographic applications by looking at how it meets the requirements for a specific mooring example – the SB CHARM. We conclude by presenting the future work required to create a prototype mooring modem, which will be tested on the CHARM mooring. The end goal is the production of a cheap, low power acoustic modem for real-time data collection in moored oceanographic applications.

Categories and Subject Descriptors

C.3 [**Computer Systems Organization**] Special-Purpose and Application-Based Systems. – *signal processing systems* C.2 Computer-Communication Networks – *data communication, wireless communication*

1. INTRODUCTION

Moorings provide an effective way to monitor ocean life and processes by providing a platform for sensors to collect data throughout the entire water column over large temporal scales. The high temporal resolution, long-term data collected from moorings capture a broad dynamic range of oceanic variability and provide important information concerning episodic and periodic processes ranging in scale from minutes to years [1-6]. Such data greatly enhances our understanding of the earth's oceans and contributes to solving world problems such as natural disaster prediction and global warming.

Moorings provide important data sets; however, many moorings, particularly those in the deep sea, do not provide comprehensive data sets in real time. Open ocean moorings are typically deployed and retrieved at six to nine month intervals for data download and analysis, and mooring servicing. Real time data is crucial for scientists and managers to detect important events (e.g., tsunamis, hurricanes and storms, eddies, harmful algal blooms) when they occur in order to respond appropriately, e.g. interrogating the moored instruments to increase their sampling rates.

Scientists, managers, educators, and engineers have recognized the need to provide real time oceanographic data and have developed, or are developing, several different real time telemetry options: shore to mooring cables (cabled observatories); surface to bottom cables (cabled moorings) or acoustic technology in conjunction with satellite [8-9], radio frequency (RF), or cell phone technology.

Because acoustic technology in conjunction with satellite or cell phone technology provides a convenient means to collect real time data from oceanographic moorings, this paper presents the design of a low cost 'Mooring Modem' that could be widely used by the oceanographic community.

This paper is divided into six sections. Advantages and disadvantages of various real time data telemetry systems are discussed Section 2. Section 3 discusses the design requirements of underwater acoustic modems for moored oceanographic applications ('mooring modems'). Section 4 presents a specific oceanographic mooring, - Santa Barbara (SB) CHARM. Section 5 presents the preliminary design of our Mooring Modem, and describes how the modem meets each requirement presented in Section 3 for the SB CHARM. We conclude the paper with a section on future work to discuss what further steps are necessary to test the modem on the SB CHARM.

2. BACKGROUND

This section presents examples of and describes the advantages and disadvantages of existing real-time oceanographic data telemetry systems including cabled observatories, satellite, radio frequency, and cell phone telemetry, cabled moorings, and acoustic modem data telemetry.

2.1 Cabled Observatories

The most recent technological development in the field of oceanographic real time data telemetry is cabled ocean observatories for high power and virtually unlimited data bandwidth, e.g., Monterey Accelerated Research System (MARS [10]), North-East Pacific Time-series Undersea Networked Experiments (NEPTUNE [11-12]), Martha's Vineyard Coastal Observatory (MVCO [13]), Victoria Experimental Network Under the Sea (VENUS [14]), Long-term Ecosystem Observatory (LEO [15]). These observatories provide a means to send real time data from moorings to shore via bundled seafloor electrical and fiber optic cables [7]. Currently deployed cabled systems (e.g., LEO, MVCO, VENUS) have proven to be relatively robust and reliable in terms of low data dropout rates and sustained observations. However, laying cables through the surf zone and along the ocean floor is time intensive (extensive environmental permitting required), expensive, and oftentimes impractical, especially in the deep-ocean and remote regions (e.g., Arctic Circle, Southern Ocean).

2.2 Satellite, Radio Frequency (RF), and Cell Phone Telemetry

To eliminate the need for seafloor cables, scientists and engineers have taken advantage of developments in satellite, radio frequency (RF), and cell phone data telemetry to transmit data to shore in real time. Some of these real time data systems utilize surface buoy to bottom cabled moorings for full water column data transmission, whereas others telemeter only the surface or near-surface portion of the mooring's data.

One example of a highly successful real time surface system is the U.S. National Oceanic and Atmospheric Administration National Data Buoy Center (NDBC [16]). NDBC supports a global network of surface buoys for marine monitoring and forecasting purposes. The surface buoys are equipped with marine batteries charged with solar cells for power generation and commercial sensors for meteorological and physical (e.g., waves, currents, hydrography) observations. Collected data are transmitted in real time to the NDBC data center via satellite. Satellite systems are very robust and reliable. However, data rates are more limited (1200 bytes per three hours with Argos and 2400 baud rate for Iridium) and satellite communication costs can be quite expensive ($5.50 per I.D. day for Argos plus $560 per month charge and $1 per minute for Iridium).

Several coastal moorings (e.g., Monterey Bay Aquarium Research Institute (MBARI) OASIS system [17], Univ. of California,. Santa Barbara Ocean Physics Laboratory (UCSB OPL) CHAnnel Relocatable Mooring (CHARM [18]) currently utilize RF telemetry for oceanographic data transmission. RF telemetry can support large amounts of data and is relatively inexpensive; however, line-of-sight between the mooring and the shore-based data receiving station is required, which is nearly impossible for deep-sea open ocean applications. Cell phone technology is currently under development for moored oceanographic purposes; it is also restricted to coastal regions.

2.3 Cabled Moorings

A major limiting factor associated with satellite, RF, and cell phone data telemetry systems is that data must be transmitted from various depths in the water column to the surface buoy in order to be telemetered. Surface to bottom cabled moorings are currently under development for high power and data bandwidth from buoy to anchor. MBARI, together with Woods Hole Oceanographic Institution (WHOI), tested the design and mechanical loading of a surface to bottom cabled mooring system as part of the MBARI Ocean Observing System (MOOS) [19]. These types of cabled systems have the capability to harvest and store solar and wind power in batteries mounted in the surface buoy. Electricity is then conducted down to water column sensors via an electro-optical mechanical (EOM) cable. The EOM cable also transmits data from the sensors to the surface buoy in real time. The data are then telemetered to shore using satellite, RF, and/or cell phone technology, depending on feasibility.

EOM cables provide the power and data bandwidth necessary for sustained ocean observations. However, these cables can be subjected to high mechanical loading from buoy movement due to winds, waves, tides, and currents, resulting in tension and cable breakage [19]. EOM cables are very expensive (on the order of $50-100K per deep water system) and time consuming to replace, in terms of finding emergency ship time and personnel. In addition, should a mooring cable break, researchers could lose valuable equipment and sensors and more importantly, data. Researchers and engineers are developing stronger and more robust EOM cables that can withstand mechanical loading by oceanic processes [20]. However, these cables may still remain too costly to be widely used by the oceanographic community.

2.4 Acoustic Modem Data Telemetry

Underwater acoustic modems attached to individual sensors or sensor packages on a mooring provide cost-effective and robust alternatives to surface to bottom cables. Acoustic modems can wirelessly transfer data up the mooring line to a surface buoy where data can be telemetered to shore via satellite, RF, and/or cell phone technology. Several acoustic modems currently exist [21-25] and some are being used for oceanographic applications [26]. For example, the NOAA Deep Ocean Assessment and Reporting of Tsunamis (DART) Project currently utilizes acoustic modems and satellite telemetry in an effort to improve the capability for early detection and real time reporting of tsunamis in the open ocean. The DART Project employs deep ocean moorings that are equipped with a bottom pressure on the ocean floor and an acoustic modem operating at 15-18 kHz to transmit data to a surface buoy, which then relays the information to shore through satellite telecommunications [27].

3. ACOUSTIC MODEM DESIGN REQUIREMENTS

Despite the success of the DART project, much development is necessary for acoustic telemetry systems to be widely adopted by the oceanographic community. In this section, we highlight the major requirements for designing an acoustic modem for moored applications.

(1) **Sensor-to-Modem Interfacing:** At present, sensor-to-modem interfacing is quite difficult. Though many commercial oceanographic sensors use RS-232, there currently is no standard data protocol for oceanographic instruments. *It is necessary to develop a standard protocol and design off-the-shelf, plug-and-play underwater acoustic modem data telemetry systems for use with commercial oceanographic sensors.*

(2) **Packaging:** *Just as oceanographic sensors must be waterproof and resistant to biofowling, so too must acoustic modems.* Barnacles or algae building up on a transducer could block the modem's signal and corrupt data.

(3) **Power:** In the absence of cables, the operation of underwater oceanographic equipment is dependent on battery power. Moorings are typically serviced at 6-12 month intervals for sensor battery replacement, instrument cleaning and calibration, and data download. With acoustic modems, the need for data download is eliminated; however, instrument servicing is still required. Therefore, the acoustic modems must use low enough power so that the length of deployment is limited solely by the need to service the instruments, not the modems. Currently, acoustic modems are quite power hungry and thus, not suitable for long-term deployment on moorings. *Acoustic modem power requirements need to be reduced.*

(4) **Low Cost:** At present, acoustic modems cost $1000+. Mooring platforms typically carry several oceanographic sensors at multiple depths (see Section 4). In order to telemeter complete mooring datasets, it would be necessary to deploy many modems along the mooring, severely increasing the costs associated with this system. *The design of either cheaper systems or systems that can be used with bundled sensors to reduce the number of individual modems is needed.*

(5) **Data Transmission Range:** Individual sensors or sensor packages on moorings are generally mounted at irregular depth intervals, anywhere from less than a meter to hundreds of meters apart from one another, creating difficulties in gauging acoustic transmission distance requirements**.** *Network strategies must be developed that focus on energy efficiency*. These strategies should balance the number of wireless links, power requirements, and cost.

(6) **Data Transmission Rates:** Sampling rates for subsurface instruments on moorings are highly variable, from high frequency (one sample per second) to low frequency (as infrequently as one sample every day). Depending on sensor type and sampling rate, some simple sensors can produce as little as 10 kBytes/day whereas more advanced sensors can produce more than 100 kBytes/day. A typical deep-sea mooring as a whole produces roughly 1Mbyte of data per day. Therefore**,** *acoustic modems on moorings should operate at least at 12 baud (bytes per second) or 96 bps (bits per second).*

(7) **Oceanic Motion Resistance:** Mooring motion is dependent on winds, currents, waves, and tides. The surface buoy can (a) swing back and forth in all directions, (b) rotate 360°, and/or (c) heave up and down relative to the mooring anchor. "Watch circle" (distance of buoy movement over 360° relative to the anchor) size is dependent on mooring water depth. Typical watch circles for deep-sea open ocean moorings are several km whereas watch circles are several meters for shallow coastal moorings. The average heave for deep-sea (coastal) moorings is 1-2 meters (tens of centimeters). The maximum mooring heave is over 10 meters during hurricanes and tropical storms. Average horizontal and vertical speeds of motion are < 10 cm/s, but can be much higher during heavy sea states and high current velocities. *The acoustic modem design for oceanographic moorings must be resistant to oceanic motions*; acoustic receivers must be resistant to the Doppler shift caused by mooring motion.

(8) **Acoustic Interference:** *The use of acoustic modems for moored data transmission must not interfere with oceanographic sensors that are acoustic in nature.* For example, the commonly moored acoustic Doppler current profiler (ADCP) sends out precise acoustic pulses from four beams and then receives backscattered acoustic signals reflected off of acoustic scatterers in the water column (e.g., suspended sediment). The Doppler shift principle is then used to measure velocities along the four projected acoustic beams (the Doppler shift of the backscattered signal is proportional to the velocity of the scattering particle). The ADCP, as well as other acoustic sensors, could potentially interfere with modem transmission along a mooring.

4. THE SANTA BARBARA CHARM

In this section, we describe the Santa Barbara CHAnnel Relocatable Mooring[1] (CHARM) [18] and discuss possible networking schemes for real time telemetry. CHARM is a key observatory testbed facility for the development and testing of sensors, sampling systems, power generation systems, and long-term sampling capabilities using advanced data telemetry systems.

CHARM is located in 24 m water depth off the town of La Conchita, CA. CHARM has been deployed since May 2003 with the purpose of: (1) developing and testing relatively small, lightweight optical and chemical sensors and real time data telemetry for autonomous deployment, (2) investigating particulate dynamics through optics, (3) optical and chemical detection and characterization of harmful algal blooms, and (4) determining effects of physical processes on chemical and bio-optical properties.

CHARM is equipped with physical, hydrographic, bio-optical, and chemical sensors (see Figure 1). Current velocities and wave information (significant wave height and period) are measured with an ADCP mounted on a nearby (within tens of meters) bottom tripod. Hydrographic properties are collected using temperature sensors and temperature with conductivity sensors. Bio-optical instrumentation includes: radiometric quantities at 123 wavelengths in the visible, downwelling irradiance and upwelling radiance; absorption and attenuation coefficients at 90 wavelengths in the visible; backscattering coefficient at one (three) wavelength(s); chlorophyll, colored dissolved organic matter, and phycoerythrin fluorescence; and bioluminescence potential. Chemical processes are monitored with the dissolved oxygen sensor. Briefly, bio-optical and chemical data are useful for myriad applications not limited to: (1) assessing water clarity for environmental or military purposes, (2) characterizing particulates and pollutants (size, type, etc.) in terms of erosion, resuspension, and transport, (3) monitoring blooms and busts of phytoplankton including harmful algae, and (4) evaluating heat

[1] Funded by the National Oceanographic Partnership Program

transfer across the air-sea interface (e.g., see Special Issue: “Coastal Ocean Optics and Dynamics,” 2004; Chang et al., 2006).

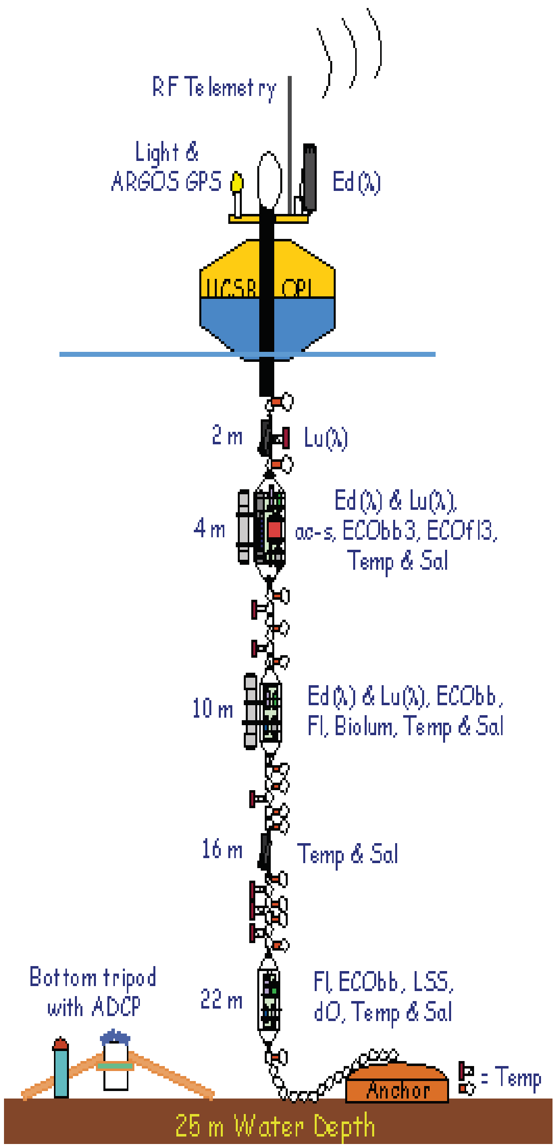

Figure 1. Schematic diagram of the CHARM. Abbreviations: GPS = global positioning system, RF = radio frequency, $E_d(\lambda)$ and $L_u(\lambda)$ = downwelling irradiance and upwelling radiance, ac-s = absorption-attenuation meter, ECObb(3) = backscattering sensor, ECOfl3 = spectral fluorometer; Fl = chlorophyll fluorometer; Biolum = bioluminescence sensor, Temp = temperature sensor, Sal = conductivity sensor, dO = dissolved oxygen sensor, ADCP = acoustic Doppler current profiler, DH-4 = data handler

Data sampling rates for instrumentation on CHARM are highly variable (see Table 1). A nearby bottom-mounted ADCP allows assessment of acoustic interference issues. Importantly, the CHARM buoy supports RF telemetry from its location, ~2 km from shore, to a shore-based data receiving station within line-of-sight. The 4 m instrument package is currently hard-wired to the surface buoy (i.e. partial cabled mooring) and all data from 4 m are transmitted to shore every 20 minutes. Therefore, a design-cost-benefit analysis between cables and acoustic technology for shallow water real time moored systems can easily be accomplished using the CHARM.

Table 1. Data amounts for major sensors and sensor packages on the CHARM.

Depth and Sensor or Sensor Package	Approx. Data Amount (per day)
1 m SBE 39 Temperature Sensor	**40 kB**
2 m Hyperspectral L_u Sensor	**130 kB**
4 m Sensor Package	**450 kB**
7 m SBE 39 Temperature Sensor	**40 kB**
10 m Sensor Package	**325 kB**
19 m SBE 39 Temperature Sensor	**40 kB**
22 m Sensor Package	**65 kB**
24 m ADCP	**100 kB** or **1 MB** w/ waves

The CHARM is an ideal platform for testing acoustic modems for underwater data transmission. Data transmission distances are relatively short (buoy to anchor distance is only 24 m). Most sensors are bundled and mounted on instrument cages and placed at three depths: 4, 10, and 22 m, thereby reducing the required number of modems for data transmission.

The bundled sensors also allows for networking the acoustic modems on the buoy. The modems should cooperate to save energy. For instance, rather than having each modem send data directly to the surface, a simple scheme like passing data up the mooring will save energy. When a modem passes data up the mooring it will have to be sure to transmit when another nearby modem is not transmitting. Coordinating multiple modems that potentially transmit concurrently poses a difficult research challenge and is not addressed in this paper.

The first step in building a moored network is developing acoustic modem technology that meets the design requirements outlined in Section 3. The next section describes our first attempts at designing a low cost, low power acoustic modem for moored applications.

5. MOORING MODEM

Our underwater acoustic modem for moored operations (hereafter referred to as “Mooring Modem”) uses binary Frequency Shift Keying (FSK) - a simple modulation scheme used for transmitting digital signals over an analog channel. We selected FSK for the Mooring Modem because of its design simplicity, low cost implementation, and its proven ability to work in underwater acoustic communications [23].

The transmitter represents a digital ‘1’ with an analog waveform of a specific frequency (the mark frequency) for a bit duration T_b and represents a digital ‘0’ with an analog waveform of a different specific frequency (the space frequency) for the same bit duration T_b. Digital data are transmitted over the analog channel by shifting the frequency of a continuous carrier to the mark or space frequencies depending on whether a digital '1' or '0' is present. The bit duration, T_b is equal to the inverse of the data rate in bits per second (bps).

$$T_b = \frac{1}{bps}$$

For coherent transmission, the transitions from mark to space and vice versa must be continuous. To insure continuity the mark and space frequencies are integer multiples of the bit rate.

$$f_{mark} = n \cdot bps$$
$$f_{space} = m \cdot bps$$

The receiver converts the analog waveform it receives back into the digital signal that was transmitted. In other words, the receiver detects the mark and space frequencies in the received signal and converts them back to digital '1's and '0's respectively.

The detection is done by sending a bit duration of the received signal through two bandpass filters (one filter that is centered around the mark frequency and the other that is centered around the space frequency) and comparing the output of the two filters. If the output of the mark filter is greater than the output of the space filter a '1' was sent whereas if the output of the space filter is greater than the output of the mark filter a '0' was sent.

Before the received signal can be sent through the mark and space filters, the bit duration of the signal that goes through the filters must be synchronized with the beginning of a mark or space. If the received data is not synchronized with the beginning of a mark or space the filters would not be able to correctly detect whether a '1' or '0' was sent. To synchronize the data, the transmitter sends a training sequence of alternating ones and zeros followed by an end sequence to the receiver before sending the actual data. The receiver sends successive bit durations of the training sequence through the mark filter looking for where along the received signal the output of the mark filter is greatest. When the output of the mark filter is greatest, the receiver has found the beginning of a mark and is thus synchronized.

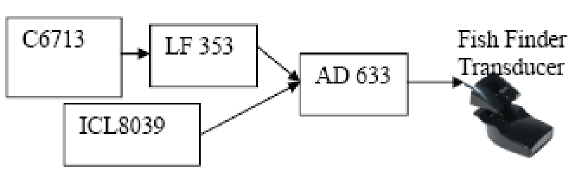

Figure 2. Implementation of prototype Mooring Modem transmitter

A block diagram for the implementation of a prototype Mooring Modem transmitter is shown in Figure 2. We used Texas Instrument's C6713 digital signal processing board [29] to generate the appropriate mark and space frequencies based on the digital data we wished to transfer. The LF353, a duel JFET operational amplifier [30], amplifies the signal. The ICL8038 [31] is a voltage control oscillator that produces a continuous carrier frequency of 50 KHz. The AD633 [32] is an analog multiplier that mixes the mark and space frequencies with the carrier frequency to send to the fish finder transducer (with resonant frequency 50KHz) to transmit the signal through the water.

A block diagram for the implementation of a prototype Mooring Modem receiver is shown in Figure 3. The fish finder transducer receives the signal sent by the transmitter. The LF353 amplifies the received signal and the AD633 mixes the signal with the 50 KHz carrier produced by the ICL8038. The mixed signal is then sent through a second order low pass filter and finally sent to the C6713 for synchronization and detection.

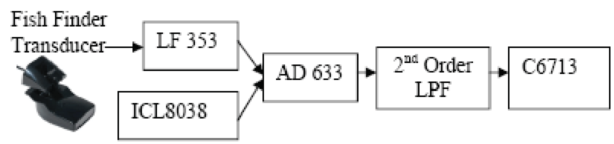

Figure 3. Implementation of prototype Mooring Modem receiver

Figure 4 shows the implementation of the Mooring Modem receiver and transmitter. The transmitter and receiver laptops connect to the C6713 DSP boards allowing us to view and process the data. The DSP boards are connected to the bread board (shown in the middle of the photo) containing the analog circuitry for both the receiver and transmitter. The fish finder transducers (not shown in the figure because they are underwater) connect to the bread board. The power supply supplies the circuit with 12V and the scope allows us to view the transmitted and received signals.

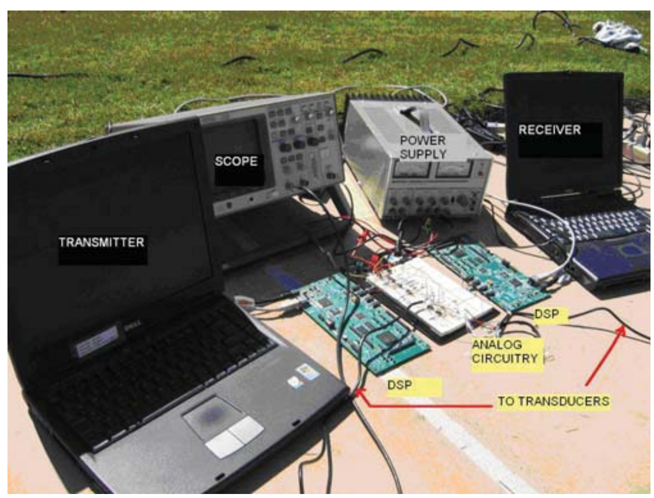

Figure 4. Mooring Modem prototype implementation

We tested the prototype Mooring Modem in a 40 ft swimming pool with f_{mark} = 1040Hz, f_{space}=1360Hz, and bps = 80. Our pool test consisted of 6 trials, each with a different distance and direction between the transmitter and receiver. The 'horizontal' direction means the transducers were placed facing each other at the same depth. The 'vertical' direction means the transducers were placed facing each at different depths. The '20 degrees' direction means the transducers were placed on a diagonal offset 20 degrees from the vertical at two different depths. For each trial we sent 30 bytes of time and temperature data produced by the SBE39 found at 1m depth on the CHARM at a transmit voltage of 2.36 Vpp. (http://www.opl.ucsb.edu/mosean/dep5/dep5data.html). Table 2 reports the number of bit errors, number of data errors, bit error rate (BitER), and byte error rate (ByteER) for each trial. . Bit error rate is the number of bit errors divided by the total number of bits sent (240) while byte error rate is the number of byte errors divided by the number of bytes sent (30).

Table 2. Pool test results for Mooring Modem prototype using 30 bytes of time and temperature CHARM data

Distance (ft	Direction	Bit errors	Byte errors	BitER	ByteER
4	Vertical	2	1	0.002	0.033
9	Vertical	10	10	0.010	0.333
10	Horizontal	0	0	0.000	0.000
17	Horizontal	4	4	0.004	0.133
19	20 deg	10	4	0.010	0.133
25	Horizontal	17	6	0.018	0.200

The sub sections below address the Mooring Modem's ability to meet the various design requirements (see Section 3) for the SB CHARM.

5.1 Sensor-to-Modem Interfacing

We have not made enough progress on the Mooring Modem to make it 'plug and play' with a wide variety of oceanographic sensors. However, all of the sensors on the CHARM listed in Table 1 use the RS-232 data protocol. If the Mooring Modem also adopts the RS-232 data protocol, sensor-to-modem interfacing can be accomplished for this oceanographic application.

5.2 Packaging

As shown in Figure 4, the Mooring Modem prototype is not waterproof. In fact, the only components of the prototype that are waterproof are the transmit and receive transducers. We must compact the Mooring Modem design to fit in a small waterproof biofowl resistant package before it can be used on the SB CHARM.

5.3 Power

For a given transmit power, transmit distance is set by acoustic propagation factors including spreading loss and absorption.

Spreading loss is related to the transmit distance. Since the energy emitted gets expressed over a larger and larger spherical (assuming sound radiates uniformly in all directions) surface area as distance from the transmitter is increased, the power per unit area decreases by R^2. Figure 5 illustrates this approximate R^2 decrease experienced by the Mooring Modem transducers for two different transmit voltages. The fit to the data is not very good as the transducers are not omnidirectional and therefore do not exhibit an exactly spherical distribution.

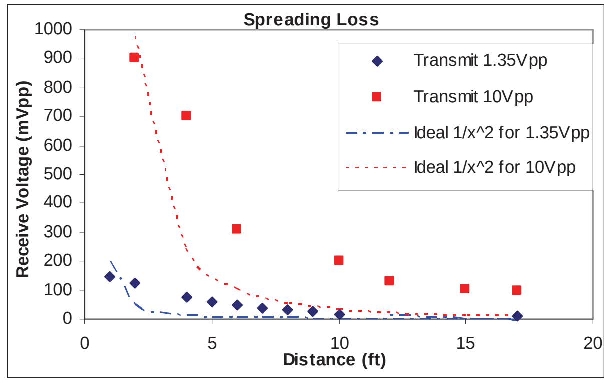

Figure 5. Spreading loss of Mooring Modem transducers

Because power decreases rapidly with distance, power issues become more of a problem for long range transmissions. Because the Mooring Modem only needs to be able to transmit at most 9 ft on the CHARM (between the 10 ft and 19 ft sensor packages), we can operate at low power.

Acoustic absorption is the attenuation of a sound ray due to frictional losses in the water. It is strongly frequency dependent (higher frequencies suffer the most). In sea water the 'absorption coefficient' ranges from 0.05 dB/km to 20 dB/km for frequencies of 1kHz to 100kHz [28]. Because our Mooring Modem operates close to 1kHz, the absorption coefficient of close to 0.05 dB/km does not cause significant signal attenuation once again allowing us to operate at low power.

We have not yet computed the actual battery life of the Mooring Modem to see if it will last 6 months before servicing is needed on the CHARM.

5.4 Cost

A major cost of existing underwater acoustic modems is the custom made and highly proprietary transducers used with the modems that cost $1000+. Replacing these $1000+ transducers with $50 Fish Finder Transducers (commercial-off-the-shelf transducers already mass produced for anglers and industry fishers) greatly reduces the overall cost of the modem.

All the components of the prototype mooring modem implementation are inexpensive except for the C6713 DSP boards. We used the C6713 boards for development because they were readily available for our use. However, because the transmit and receive functions performed by the C6713 for our FSK modem are relatively simple, the board can be replaced with an inexpensive micro-controller. We anticipate the cost of one Mooring Modem to be as follows

$50 Fish Finder Transducer
$30 Packaging (waterproof casing and underwater connectors)
$20 12 V batteries and electronics
$100 Total

Eight Mooring Modems are needed for the CHARM, one at each of the 7 depths listed in Table 1 and one at the surface, bringing the total cost to $800 (which is less expensive than one existing commercial acoustic modem!).

5.5 Data Transmission Range

The results of the pool test shown in Table 2 illustrate fairly accurate transmission (Bit Error Rate < 2%) for a distance of under 25 ft and a direction 20 degrees or less. This data transmission range is sufficient for the CHARM because the farthest distance the data has to transmit is 9ft (between the modem at 10ft and the modem at 19ft depth) in the vertical direction. These small bit errors can be corrected with error correcting codes.

5.6 Data Transmission Rates

The data rate used in the pool test, 80 bps, is too slow for the minimum data rate required by the CHARM (200 bps), but is sufficient for moorings that transmit less than 900 Kbytes per day. The 80 bps data rate is also sufficient for a subset of the sensors on the CHARM (i.e. it is sufficient for transmitting the data for the 4, 10, and 22 ft sensor packages).

5.7 Oceanic Motion Resistance

The parts of the Mooring Modem design that must be resistant to mooring motion are the mark and space bandpass filters used in the receiver. The bandpass filters need to have a wide enough bandwidth to compensate for the Doppler shifts in the mark and space frequencies caused by the motion of the mooring line and need to be spaced far enough apart to ensure the two bandpass filters do not overlap (Figure 6).

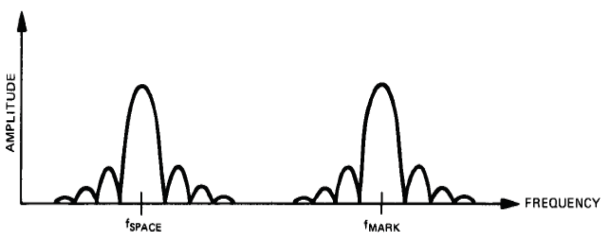

Figure 6: Mark and space bandpass filters used in Mooring Modem receiver

The vertical and horizontal speeds of 1 m/s (significantly above the average speed of 1 cm/s experienced by the instruments on the CHARM) contribute to a frequency deviation of 1 to 40 Hz depending on the mark and space frequencies used. The bandpass filters were designed to withstand a frequency deviation of 40 Hz, but we have yet to test if they in fact do withstand these deviations.

5.8 Acoustic Interference

The ADCP used on the CHARM operates at 300 kHz. The mark and space frequencies chosen for the Mooring Modem (1040Hz and 1360Hz respectively) are significantly out of band from the ADCP and therefore should not interfere with ADCP transmission.

6. FUTURE WORK

Section 5 proves that the prototype Mooring Modem is on its way to meeting the requirements of an underwater acoustic modem for moored oceanographic applications. We would like to test the Mooring Modem on the SB CHARM by placing four modems at depths 0, 4, 10, and 22m respectively and interfacing the 4, 10, and 22m modems with the sensor packages at those depths. Before we can actually test the Mooring Modem with these subset of the sensors on the CHARM we have to:

(1) Implement error correcting codes to reduce the bit error rate.
(2) Determine how to network the Mooring Modems together to make sure the data transmitted from one modem does not interfere with the data transmitted from another modem.
(3) Interface the Mooring Modem with an oceanographic sensor using the RS-232 protocol
(4) Reduce the size of the Mooring Modem design and waterproof the electronics

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