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A Simple Ocean Bottom Hydrophone
with 200 Megabyte Data Capacity

by

K. R. Peal, G.M. Purdy, D.E. Koelsch, and F.B. Wooding

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Technical Report

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A Simple Ocean Bottom Hydrophone with 200 Megabyte Data Capacity

by

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Technical Report

Approved for Distribution:

George V. Frisk, Chair
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Background

The Ocean Bottom Hydrophone instrument developed and operated by the Woods Hole Oceanographic Institution records the digitized output of a single hydrophone sensor at rates between 250 and 1200 samples per second with a dynamic range of 98 dB and can be deployed in the ocean to depths of up to 6000 meters. The 200 megabyte disk recorder allows continuous operation for nearly 5 days at 250 samples per second or just over one day at 1200 samples per second. The system stops recording when the disk is full and battery capacity is sufficient to operate the clock for 10 days thus easing recovery logistics. The instrument is intended for short deployments required by typical marine seismic refraction operations.

This instrument is based on an earlier Ocean Bottom Hydrophone developed in 1975 (reference 1). Eight of these instruments were produced and proved to be extremely reliable, being used in over 100 deployments over many years (e.g. reference 2,3). In the late 1970's, it became obvious that significant improvements in dynamic range and resolution could be achieved by the addition of an analog to digital converter and a digital recorder, so a new instrument, the Digital Ocean Bottom Hydrophone (DOBH, reference 4) was developed. By 1990, the digital tape recorder of the DOBH was obsolete so an upgrade was performed. In the present system, the selected recording medium is a Winchester-type disk, the microprocessor has been replaced, and the analog front end has been modified.

In all changes the overall goal has been to improve performance while retaining reliability. We believe that consistent return of useable data is the most important aspect of instrument performance. This guided many of our design decisions and has contributed to field successes.

Specifications

Table 1 shows the principal specifications of the instrument. Figures 1 and 2 show the instrument ready to be deployed and identify its components.

Experimental Applications

At the time of writing these new OBH instruments have been used successfully in a wide range of active seismic experiments in the ocean: long-range refraction studies of the deep structure of the East Coast continental margin (e.g. Holbrook et al 1992 ref 5), high resolution measurements of the uppermost young oceanic crust using a deep-towed controllable explosive source (e.g. Christeson et al 1992 ref 6) and precise wide-angle reflection studies of gas hydrate deposits on the continental slope (e.g. Katzman et al 1992 ref 7). One example of a record section of high quality data is provided in figure 3.

Instrument Description

General

The system uses a single hydrophone sensor that is mounted with the recording electronics

Table 1: System Specifications

Sensor type	OAS E-2SD pressure compensated hydrophone
Sensor sensitivity	-87dB re 1 V/ubar (-187dB re 1 V/uPa)
Instrument frequency response	1 to 80 Hz or 1 to 400 Hz
Ultimate resolution	1 bit at A/D represents 0.22 ubar (0.022 Pa) at the hydrophone
Saturation level	full scale is 17,768 ubar peak to peal (1776.8 Pa)
Digitizer	12 bit A/D
Gain ranging	two outputs of the hydrophone, separated in gain by 26dB are continuously digitized and the optimal output is selected for recording sample-by-sample in software
Dynamic range	98dB
Timing	an oven-controlled crystal oscillator provides timing precision to a few parts in 10**8; typical clock offset is 1 to 3 msec after a three day deployment
Controller	Onset Computer Corporation Tattletale model 6, single board computer (modified)
Recorder	200 megabyte Winchester disk (by Conner Peripherals, part of the Onset Tattletale)
Data format	each one megabyte buffer has a small ASCII header with gain and 'housekeeping' data followed by binary data
Operating program	performs data acquisition and recording; also controls setting and checking of real time clock and delayed acquisition turn-on (written in BASIC)
Current drain	approximately 1.5 watts (dominated by oscillator)
Batteries	separate analog and digital stacks of alkaline cells in the main pressure case
Deployment duration	10 days, determined by clock battery life
Deployment frame	square fiberglass tubing with glass ball flotation; approximately 4 feet square and 4 feet high
Weight in air	700 lbs including all electronics plus 300 lb anchor
Recovery release	tandem EG&G 8242 acoustic transponder release
Positive buoyancy (after anchor release)	120 lbs
Recovery aids	two strobe lights, radio beacon, flag

2
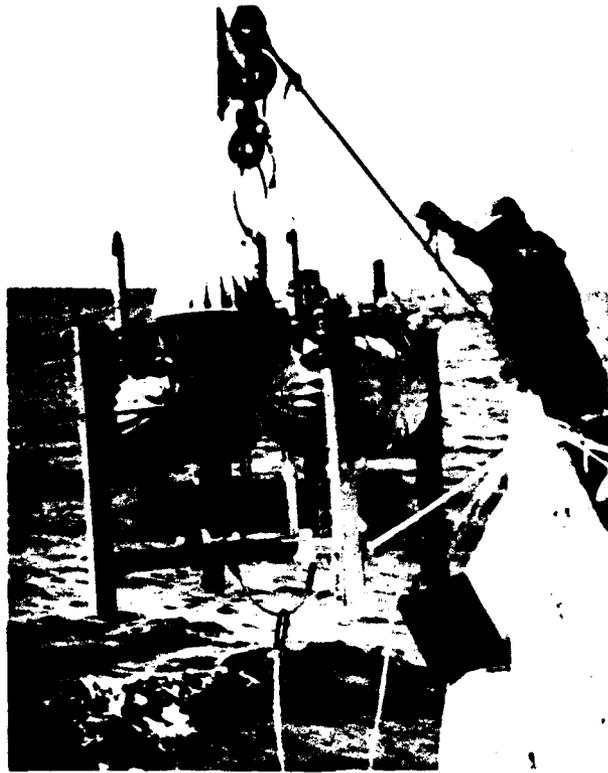
Figure 1: The Ocean Bottom Hydrophone instrument in the process of being deployed.
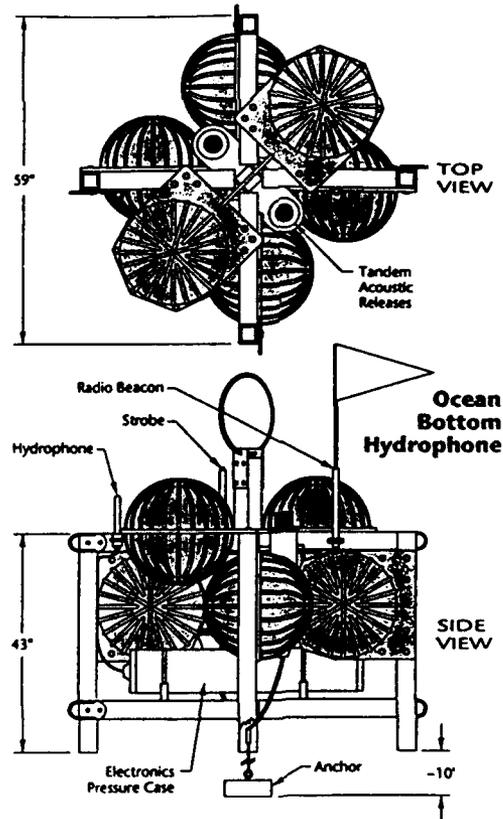
Figure 2: Schematic diagram of the instrument showing the primary components.

3
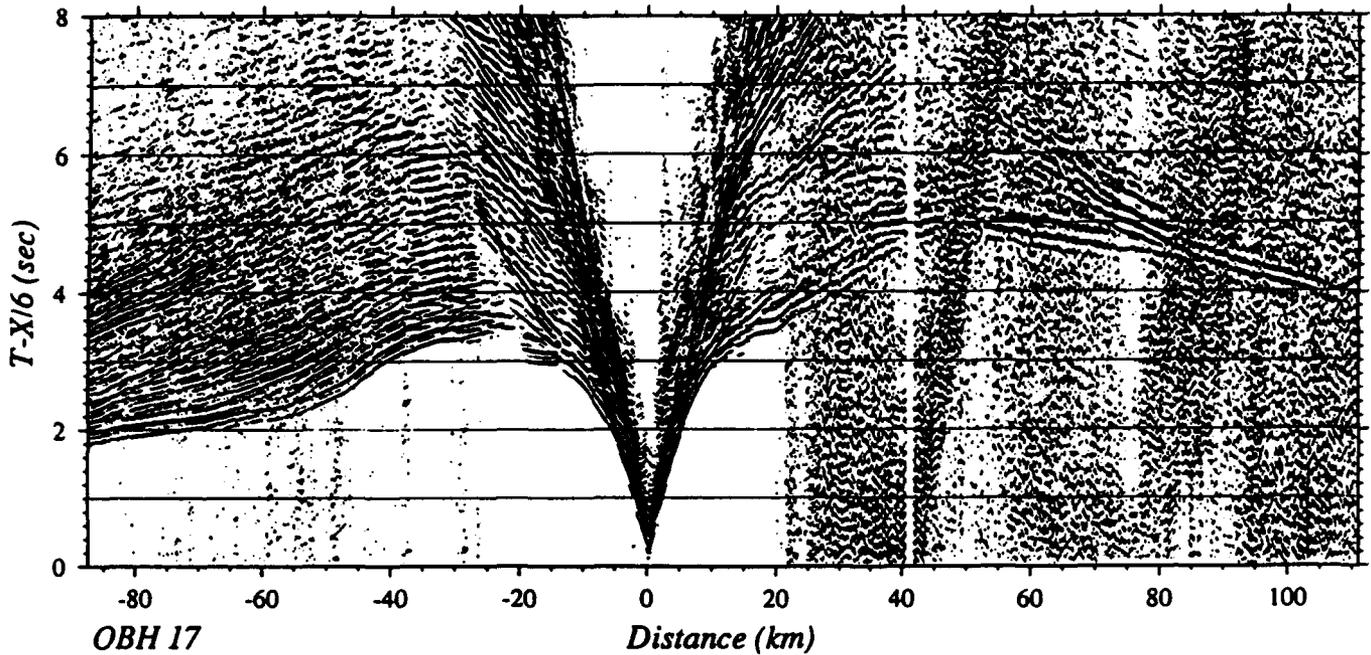
Figure 3: An example of a refraction record section collected off the U.S. East Coast by an OBH monitoring a 10,000 cu. in. airgun array towed by a commercial multichannel seismics vessel. Note the excellent signal-to-noise ratio for first arriving refracted phases out to ranges of 80 to 100 Km. The OBH was located in shallow water near the edge of the continental shelf. The noise level on the left hand portion of the section is apparently lower because the water-borne energy that causes the previous shot interference is attenuated by the shallow water.

on a fiberglass frame with an anchor, glass ball flotation and recovery aids (figure 1,2).

The front-end analog signal conditioning is similar to that in the DOBH (reference 4) with minor changes to take advantage of improvements in semiconductors. The new system consists of this improved front-end with the addition of a commercially available single board computer: a Tattletale model 6 from Onset Computer Corp. (reference 8) which includes a 12 bit digitizer, a processor and a 200 megabyte disk recorder. To increase the dynamic range, the output of the hydrophone preamplifier is connected to two analog channels with different gain. Both channels are digitized and the higher gain channel stored if the voltage is less than a specified percentage of full scale; otherwise the low gain channel is used.

Mechanical and Deployment Description

The structure used for deployment consists of a fiberglass frame on which are mounted the hydrophone sensor, flotation, recovery aids and the pressure case containing the electronics - see figure 2. The complete package is attached to an anchor by approximately three meters of line.

The electronics package with recorder and battery (see figure 4) is mounted in a 6" inside diameter pressure case. The hydrophone sensor is clamped to the frame and wired to feed-throughs (single-pin Burton connectors) on the end-cap. The pressure case is mounted horizontally in polyethylene saddles on an aluminum plate and held in place with two U-brackets.

Dual acoustic releases (EG&G model 8242) are used for instrument recovery. They are mounted vertically in the center of the frame and connected to the anchor by a length of line. At the end of a deployment, a command from the surface causes either release to drop a link which releases the package from the line and anchor, causing the instrument to return to the surface for recovery.

The recovery aids are a flag, two strobe lights, and a radio beacon. When the system is at depth, the lights and radio are disabled by pressure switches. When the released package reaches the surface, the switches activate the internal electronics of the recovery aids. The package is then located using a radio direction finder if necessary until visual sighting is achieved.

Electronics Description

Block Diagram

The block diagram (figure 5) shows the main signal flow. The hydrophone is mounted external to the pressure case; all other components are inside. The filter and amplifiers comprise the analog section. The 12 bit digitizer and recorder are part of the single board computer. The timing is performed by the computer and an external oscillator.

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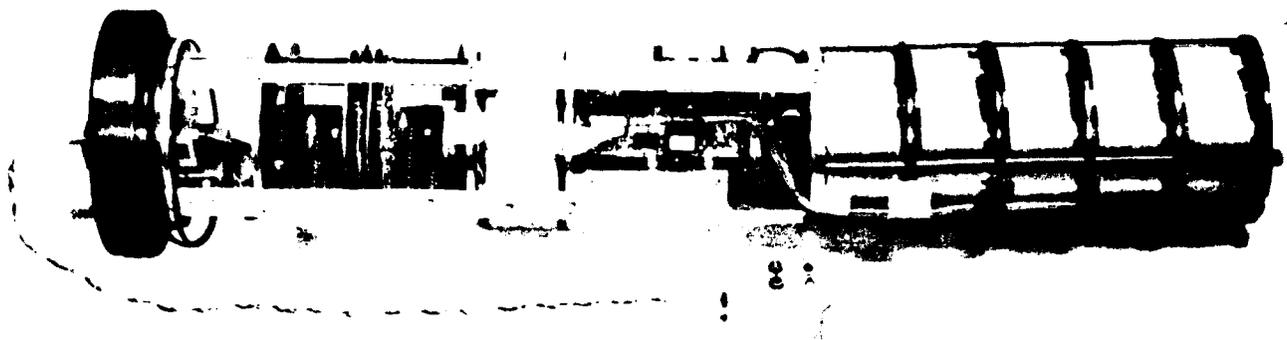
Figure 4: The electronics portion of the instrument showing the batteries, disk recorder and analog circuit boards.
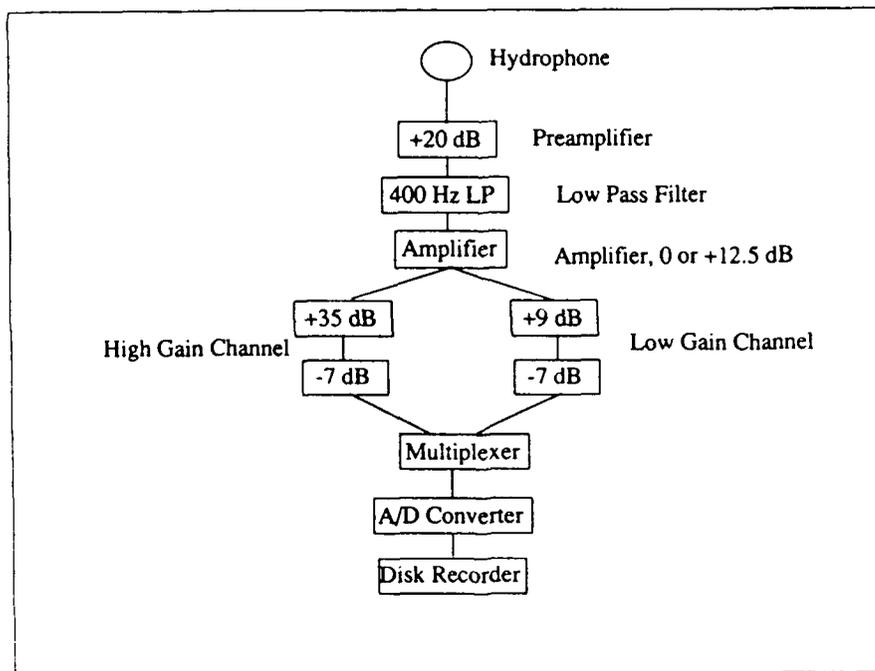
Figure 5: Block diagram of the instrument electronics.

Analog Section

A hydrophone preamplifier (based on a low noise JFET-input operational amplifier) is located on the inside of the end cap close to the hydrophone connection. It provides impedance conversion and gain (usually 20 dB). The anti-alias filter is a three-stage Chebyshev low-pass at 80 or 400 Hz providing roll-off of 36 dB per octave and 2 dB ripple in the pass band. An additional stage can be used to add gain if needed.

The filtered signal is then fed in parallel to the input of two fixed gain amplifiers which provide gains of 9 dB and 35 dB respectively. These are followed by attenuators to prevent overdriving the A/D converter since the analog section operates on ±10 volts and the digitizer operates on ±5 volts.

Transfer Function

To accurately represent the frequency response of the analog section, a transfer function based on circuit analysis has been derived in terms of the Laplacian variable 's'. This appears in appendix A.

Digitizer and Recorder

The single board computer provides a 12 bit digitizer with an eight-channel multiplexer; two channels are used here. A unity gain buffer stage is added between the attenuator and the multiplexer for impedance matching. The two channels are digitized and the results transferred to the processor where selection of the high or low gain channel is carried out in software. This is described in the software section below.

The data to be stored on disk are first placed in a one megabyte RAM buffer in the computer. When the buffer is half full, the data are written to disk while acquisition continues using the other half of the buffer thus providing continuous data collection.

The recorder is an industry standard 3 1/2 inch Winchester disk with nominal 200 megabyte capacity which has been tested successfully at ocean bottom temperatures. A total of 208 buffers can be written to disk requiring 416 write cycles. Each such write cycle consists of the following steps:
- power is applied to the disk
- the disk spins up to operating speed,
- the data is transferred
- power is removed.

Thus each deployment which fills the disk causes the disk power to be cycled over 400 times. Since statistical reliability data indicate that the disk lifetime may be limited to 10,000 power cycles, it is advisable to plan on disk replacement after about 25 full-disk deployments.

Timing

The processor as supplied by Onset Computer Corp. maintains a software clock based on its own crystal frequency. To provide accurate timing, the simple crystal is replaced with an oven-controlled crystal oscillator that operates at the same frequency. The additional steps required to achieve accurate data time tagging are described below under clock and timing functions.

Operation

Setup for test and deployment

Standard preparation and debrief procedures are performed for each deployment. Figure 6 shows the laboratory setup used.

The function generator and hydrophone simulator serve to generate signals in the laboratory with appropriate characteristics to simulate the hydrophone. This permits tests to be performed which verify correct operation of the analog electronics both in level and frequency response.

The bench power supply permits testing for long periods without draining the system's internal batteries. However, prior to deployment, final tests are performed with the system on its internal battery power.

The computer is an IBM-PC clone used primarily as a terminal emulator connected to the instrument's internal processor to select menu items. It is connected to a number of OBH instruments using SAIL (Serial ASCII Instrumentation Loop, reference 9). Functions include set up and test of the instruments for a deployment and occasional monitoring of the instruments when they are awaiting deployment. It is also possible to collect the results of short tests by capturing serial data from the instrument for evaluation on the computer.

Modes of operation

In line with the objective for this to be a simple instrument, only a few selections need to be made by an operator prior to deployment - these are discussed below. Several other features of operation can be changed but need to be set up in advance because they require hardware and possibly software changes. These items are:
- sample rate and antialias filter cutoff frequency
- enabling or disabling bursting (described under Data Sampling, below)
- enabling or disabling interpolation (also described under Data Sampling)
- use of the filter gain stage
- the gains and gain differences of the two channels.
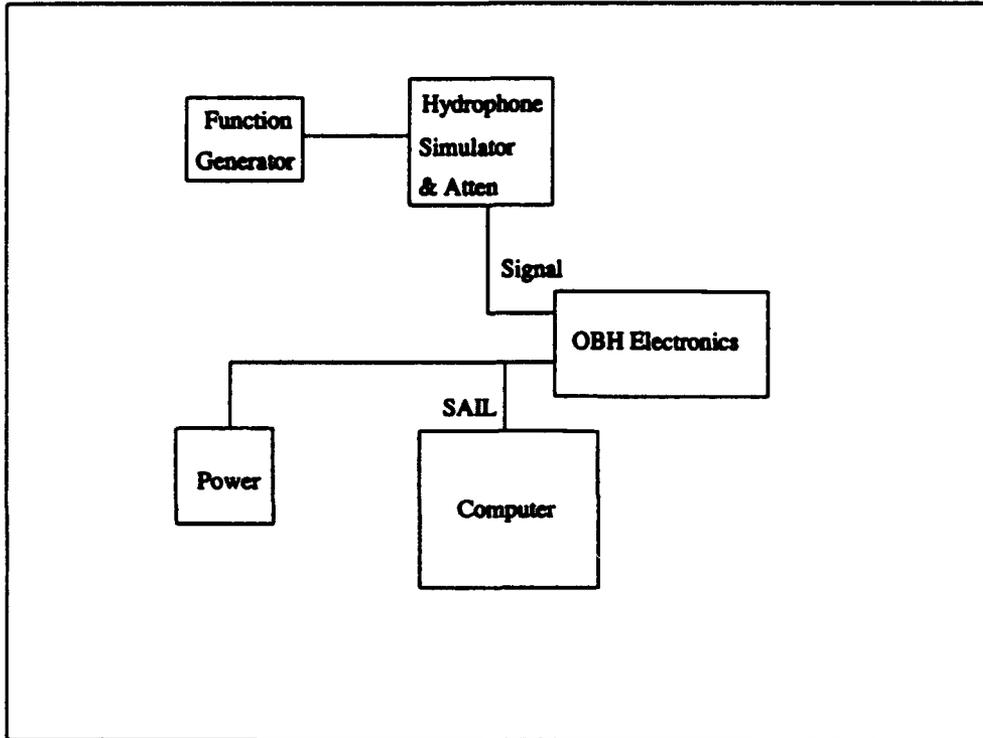
Figure 6: Setup of test equipment used for instrument checkout before and after deployment.

Deployment and recovery

Before and after each deployment, a series of tests is performed to check for correct system operation. These consist of recording voltages and clock offsets and performing short standard data recordings to verify instrument calibration and transfer function. Sample check sheets used in this process are included in appendix B.

After checkout, the electronics package is inserted into the pressure case and the tube is purged before installing it on the deployment frame. The purging process consists of three cycles to about 6 psi with dry Nitrogen each followed by sudden release and a final pump down to about -2 in. of Hg (a single gauge is used which measures pressure in psi and vacuum in inches of Mercury). A tube runs inside the pressure case from the purge plug to the bottom of the instrument ensuring that the Nitrogen displaces the ambient air during the process. Experience shows that pumping down to a vacuum of greater than about -2 in. of Hg causes problems with the disk recorder mechanics.

On recovery most tests are performed via an electrical connection through the end cap purge plug before removing the electronics from the tube. After each deployment, a series of standard debriefing tests is performed, then the electronics package is removed to allow the disk to be connected to the computer for data retrieval.

Clock Checks

Figure 7 shows the laboratory setup for instrument clock checking.

The scheme is based on two clocks: a SAIL clock and a GPS clock. The SAIL clock (purchased from Seascan, ref 10) is a specially designed clock which has the ability to latch times on demand and communicate the times and other information to the computer using SAIL protocol. It uses a Rubidium standard as its frequency source and is initially set using an external time reference.

The GPS clock serves as the external time reference. It receives signals from the U.S. Department of Defense Global Positioning System (GPS) satellites and provides time locked to UTC (Universal Time, Co-ordinated) to better than 1 usec. It also provides various inputs and outputs for other timing functions.

For this application the SAIL clock is the primary device for two reasons. First its ability to be controlled by a computer and communicate via SAIL enables automatic measurements to be made. Second its use of a local frequency standard with battery backup ensures a continuous time reference with no breaks caused by power outages, broken antennas etc. The GPS clock enables us to check the SAIL clock accurately against UTC at any time and perform other special measurements when necessary.

When the system is initially set up aboard ship, the SAIL clock is set using the GPS clock

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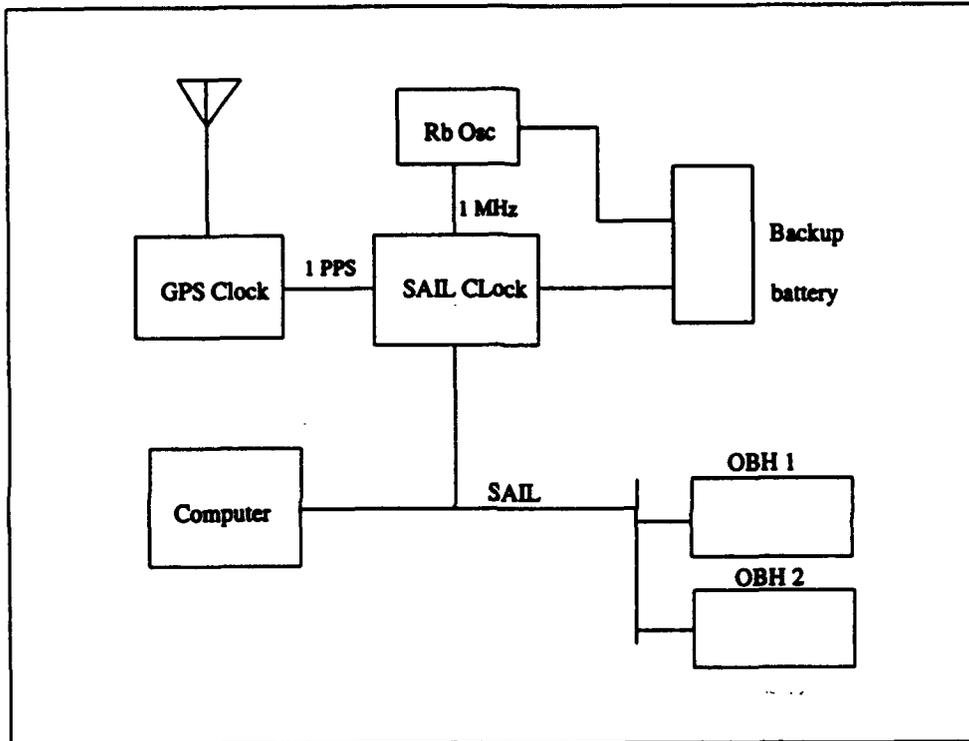
Figure 7: Setup of timing equipment for performing instrument time checks.

and adjusted as closely as possible to UTC. Thereafter the SAIL clock's time is used as the reference for instrument clock checks. The GPS clock is used to measure the offset of the SAIL clock from UTC to enable correction for the drift of the Rubidium standard relative to UTC.

Appendix C describes in detail the process of performing clock checks and deriving timing corrections.

Support Personnel

Most seagoing operations require a support team of four: electronics and mechanical specialists to prepare and maintain the instrument electronics and frame respectively, a technician to support the engineers, and a computer specialist to perform record keeping a 'ata transcription and preliminary processing.

Shoreside support is also required for instrument refurbishment and preparation and to maintain the support equipment required for operation of the instruments.

Power

The system is powered by two battery packs both constructed of alkaline D cells. The analog section (preamplifier, filter and amplifiers) operates on plus and minus 10 volt rails provided unregulated from a double 7-cell stack. This will operate the analog section continuously for many months. The digital section (oscillator, computer, digitizer, and recorder) operates on a 20 volt stack made up of five parallel strings of 14 cells. Two regulators provide 12 volt power, one for the oscillator the other for the computer and recorder. The battery pack has sufficient energy to operate the oscillator and computer for about 10 days and to fill the disk several times. Thus one battery pack could be used for one 10 day deployment which fills the disk, or for four or five shorter deployments over a period of about 10 days each of which fill the disk.

Power Control

A computer operated switch controls the power to the analog section allowing it to be turned off by operator command when the instrument is prepared and awaiting deployment in the laboratory. During these periods the digital power is provided from a laboratory connection so the main battery is not drained. Prior to deployment, laboratory power is disconnected causing switchover to the main battery. When acquisition begins, the computer automatically turns on the analog power.

Voltage Monitoring

The six A/D multiplexer channels not needed for sensor signals are used to monitor the status of the batteries and the regulated voltages from an external terminal when the system is prepared and awaiting deployment.

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Software Description

Introduction

Although the basic function of the software is simple - the processor runs the A/D converter and stores the data on disk - several important features of the instrument are implemented in software. Good timing is assured by the inclusion of an oven-controlled oscillator but the implementation of clock checks and data time tagging is done in software. Also gain ranging, sample bursting and interpolation (explained below) are software controlled. Operation of the program (including these features) is described in the following paragraphs.

The operating program is written in Onset's TTBASIC with some assembly code where necessary to perform time-critical or I/O functions. The program has a single main menu which allows selection of the various items needed to begin and finish data acquisition. Operation is controlled by an external computer which acts as the operator console for use before and after deployment.

Operation and menu selection

The main operation menu (Table 2) shows the items required for instrument operation. Normally this menu is reached by using the keyboard control-C interrupt. It is important to note that a hard reset is not normally used because this causes the instrument's clock time to be lost. For this reason, a timer circuit is included which requires that the reset button be pressed and held for several seconds continuously before a reset occurs.

Preparing the program for operation consists of using the menu items to perform tests, to check time and voltages and to set appropriate header and disk information. Similarly after an instrument is recovered, time checks and other tests are performed. The following paragraphs describe the menu items in detail.

Menu item 1 - start acquisition - is selected to start acquisition of data as in table 3. When this item is selected, a start time is requested followed by the start and stop tracks to be used on the disk. The system then enters a wait mode until the start time occurs. After that, acquisition begins and continues until the disk is full or the specified tracks are recorded. It then enters a low power wait mode until a control C from the operator returns it to the menu.

Menu item 2 - read data - is selected to allow a specific datafile to be read from the disk for test purposes as in table 4. The whole file is read in to the RAM buffer, then the data header and the first few data samples are listed. This is used as a check that the disk is working correctly. After reading and displaying the header, the system returns to the menu.

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Table 2: Basic Operating Menu

OBH OPERATION MENU (ver 22 16 May 92)
    (1) Start acquisition
    (2) Read header data and sample data
    (3) Set clock
    (4) Read clock
    (5) Check/set header information
    (6) Read voltages (and switch analog)
    (7) Exit program
CONTROL-C RETURNS THIS MENU
ENTER DESIRED SELECTION NUMBER

Table 3: Starting Acquisition

ENTER STARTING TRACK # 2
ENTER ENDING TRACK # 55

To set start time for data acquisition

    Enter year (0-99) 93
    Enter month (1-12) 5
    Enter day (1-31) 5
    Enter hour (0-23) 18
    Enter minute (0-59) 00

Start time is 93/5/5 18:00.00
Is this correct (Y/N)? Y
Acquisition: 1 channel(s), at 600 samples/sec/chan
with interpolation, no bursting, threshold 49%
Is this correct (Y/N)? Y
Analog power ON
Waiting for start time *.......

Table 4: Reading header and sample data from disk

```
DATAFILE #23
Header and initial samples:

    TIM    07:10:56 92/06/27
    PTR    42330
    GN1    0900
    AT1    0700
    GN2    3500
    AT2    0700
    DF#    023
    ERR    01
    STM    920627020000
    S/N         17
    EXP    HYDR03
    S/S         0600
    VER    22

        23  1    160
        23  2    32
        23  3    0
        23  4    48
        23  5    144

Is this correct (Y/N)? Y
```

Menu item 3 - set clock - is selected to set the real time clock. This is required only in the following circumstances:

- initial power up
- if the clock has been corrupted by certain system functions such as writing to, or reading from, the EEPROM (the operating program never accesses the EEPROM but an operator could do so using immediate BASIC commands)
- if for any reason it is necessary to perform a processor reset.

The desired clock set time is requested, then the system waits for a hardware edge (usually generated by a GOES or GPS time standard) to start the clock. The program then returns to the menu.

Menu item 4 - read clock - is selected to allow the internal real time clock to be compared with an external reference for drift calculations - see table 5. The system waits for a "special" second to occur and thereafter it outputs a hardware tick along with the time every second for accurate comparison with an external time reference. This output continues until interrupted by a control-C. The process is explained more fully in the time checking section below.

Menu item 5 - check/set header info - is used to enter and check information which will be included in the header of every datafile on disk as in table 6. After the data is entered, the program returns to the menu.

Menu item 6 - read voltages - is used to read and display the internal voltages as in table 7.

Menu item 7 - exit program - is used to return to the BASIC system. This allows use of direct BASIC commands such as "offload" which transfers data to the computer for evaluation.

Gain Ranging

The system uses software-based gain ranging. Two versions of the hydrophone signal separated in gain by 26 dB are presented to the A/D multiplexer. Both inputs are converted then a software algorithm selects one of the two inputs for recording and discards the other. This is performed on a sample-by-sample basis during acquisition so that only one of the signals is recorded. Thus additional dynamic range is achieved without consuming data capacity.

The selection algorithm is simply a threshold on the higher gain channel. If the high gain channel signal level exceeds the threshold (nominally 76%), the corresponding value from the low gain channel is recorded. If the high gain channel signal level is less than the threshold, the high gain channel value is stored.

To correct for the actual gain difference between the two channels, calibration values stored in the data header are used in post processing to normalize the data. The values stored are the two gains and the two attenuation values - nominally +35, +9 -7 and -7 dB - see Figure 5.

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Table 5: Checking the time of day clock

```
17  37  59
17  38  0
17  38  1
17  38  2
17  38  3
17  38  4
17  38  5
17  38  6
17  38  7 is a goodie
Time  17:38:08
Time  17:38:09
Time  17:38:10
Time  17:38:11
Time  17:38:12
Time  17:38:13
```

Table 6: Setting header values

Receiver number: 17
Enter new number or <CR> to use old one
Experiment ID: HYDR01
Is this correct (Y/N)? Y

Gain/atten values follow, enter new values or
<CR> to use current values

Chan 1 gain: 900 (9.00 dB)

Chan 1 atten: 700 (7.00 dB)

Chan 2 gain: 3500 (35.00 dB)

Chan 2 atten: 700 (7.00 dB)

Is this correct (Y/N)? Y

Table 7: Reading Voltages

READING VOLTAGES:					
5 Volts:	5.1	-4.99			
12 Volts (Vectron, Model 6):	11.42	10.18			
Analog:	10.31	-10.28			
Batteries:	14.0	13.80	14.9	17.7	13.45
Shore power:	17.78				
Analog voltage is ON					
Is this correct (Y/N)? N					
Analog voltage OFF					

Data Sampling and Recorder Format

The above selection process causes some distortion when switching between the different gain channels because the two samples were acquired at slightly different times - see figure 8. To correct for this time difference, interpolation is performed on each pair of samples of the low gain channel. This is an attempt to minimize the distortion caused when switching between the high and low gain channels.

In figure 8, the sample times are H1, H2, H3, ... for the high gain channel and L1, L2, L3,... for the low gain channel. At time L2, interpolated value I1 is calculated. At time L3, value I2 is calculated. At time H2, the decision is made to store H1 or I1 on the basis of the threshold value compared to H2. Likewise, at time H3, the decision is made between H2 and I2. From the figure, it can be seen that this minimizes the time shift caused when the signal crosses the threshold causing a change between a low gain and a high gain value.

An additional method used to reduce distortion is called bursting. To implement bursting, all eight channels of the multiplexer are converted but only the two hydrophone signals are stored - see figure 9. As a result, the two channels which are in use will be converted and stored at the A/D rate which can be much higher than the desired sample rate. However since all eight channels are being scanned by the A/D, the actual time between conversions of any given channel corresponds to the desired sample rate.

Thus for example if the converter is run at 1600 samples per second, the two conversions of the channels in use will be separated by only 625 usec thus minimizing distortion, but each of these conversions will be separated from the corresponding next conversion by 8 x 625 usec = 5 msec so that the actual rate is 200 samples per second. The increase in power drain caused by the higher converter sample rate is small compared to the drain of the crystal oscillator.

Data Format

Each complete buffer of data is treated as a unit called a datafile on the disk. Each of these 1,015,808 byte datafiles contains a header and a large data block. The header uses 160 bytes and the data block uses the remainder, 1,015,648 bytes.

The header format is in table 8.

The format of the data portion of the record is simply 507824 2-byte values - see figure 10. Each value contains a 12 bit A/D value left justified, followed by four bits. Three of these bits are zero. The fourth bit (bit zero) is a high/low flag: it is zero if the value is from the high gain channel, or one if it is from the low gain channel. When the value is from the low gain channel, the upper bits are actually the average of two A/D values. As a result of the division by two,
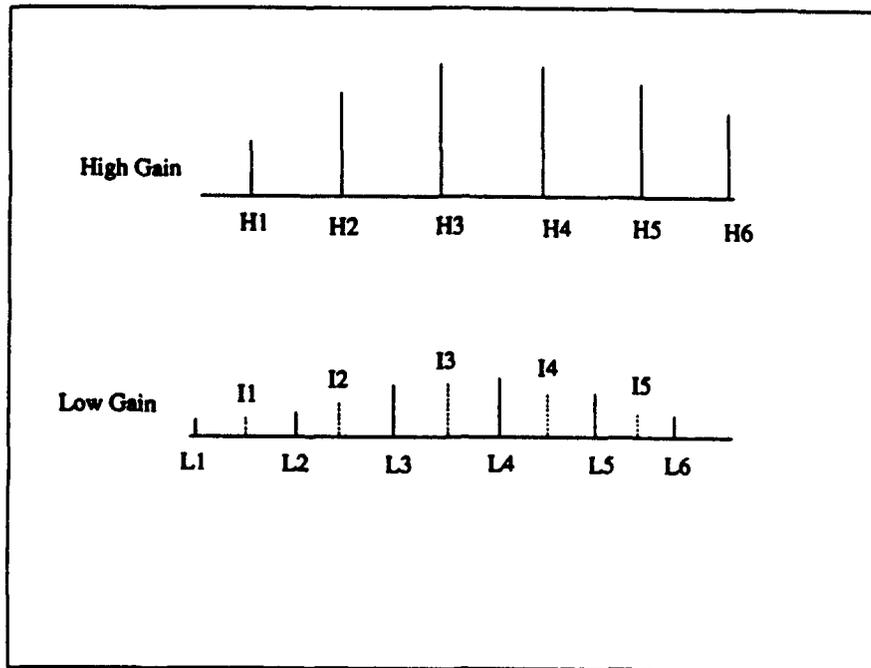
Figure 8: Representation of the method used to interpolate between samples in order to minimize signal distortion when changing between high and low channel.
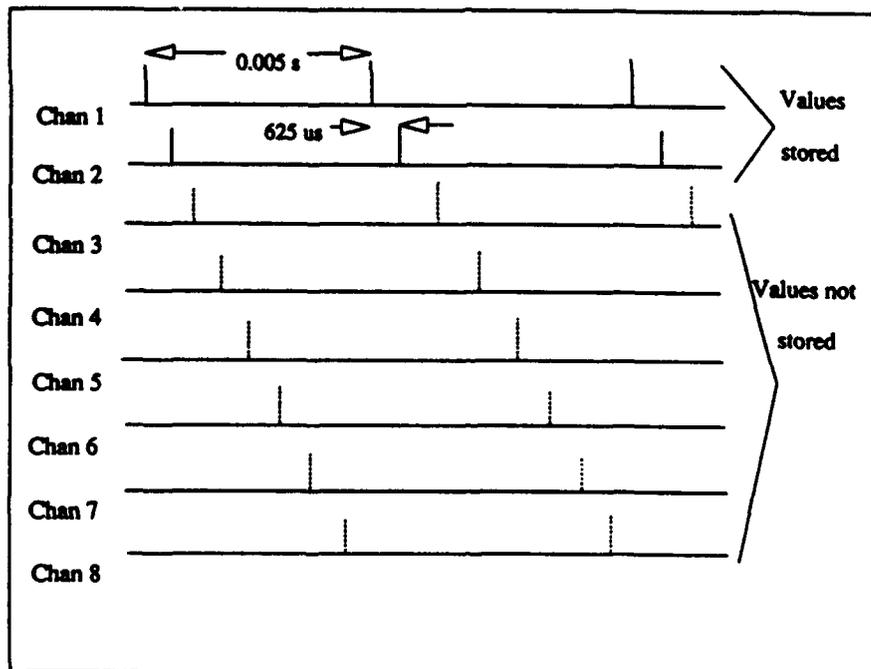
Figure 9: Timing diagram of the scheme used to minimize signal distortion by using burst sampling.

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Table 8: Recorded Data Header Format

Record time		TIM hh:mm:ssYY/MM/DD	23
Data pointer	bytes offset	PTR xxxxxx	12
Channel 1 gain	dB x 100	GN1 xxxx	10
Channel 1 atten	dB x 100	AT1 xxxx	10
Channel 2 gain	dB x 100	GN2 xxxx	10
Channel 2 atten	dB x 100	AT2 xxxx	10
Data file number		DF# xxx	9
Error count		ERR xx	8
Experiment start time		STM YYMMDDhhmmss	18
Receiver number		S/N xx	8
Experiment ID		EXP ccccnn	12
Sample rate (samples/sc)		S/S xxxx	10
Program version		VER xx	8
(unused)			12
Total			160

Note: each item is followed by CR LF (two ASCII characters).
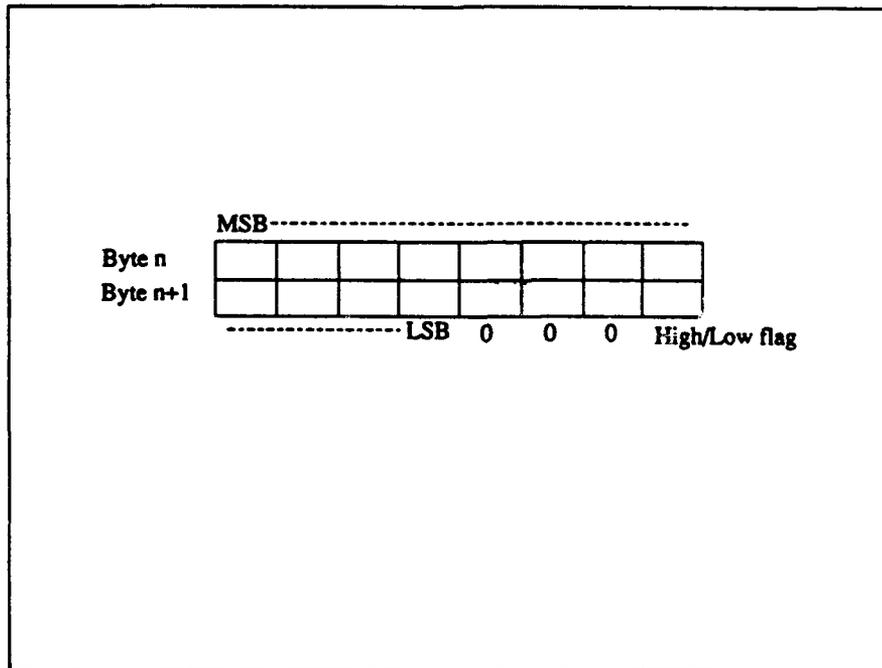
Figure 10: Binary data format

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there may be a one in the bit three position. Processing required to normalize these values is described below under data handling.

Clock and Timing

Although the Onset Model 6 has many capabilities suited to this application, it is not capable of the very accurate time keeping required. The system as delivered uses a BASIC operating system and a software clock so time checks are not possible to a resolution of better than large parts of a second. This section describes the scheme used to achieve a resolution of approximately 1 microsecond.

First the inexpensive crystal used by the processor was replaced with an oven-controlled crystal oscillator of the same frequency (9.8304 MHz). This provides the basic stability required for our application (a few parts in 10e9). It is then necessary to set and read the clock to the desired resolution.

The solution for setting the time is to use an accurately time-synchronized rising edge as input to an I/O bit which is detected by an assembly language loop. When setting the clock, the operator first enters the desired set time, then the program waits in the assembly language loop for the rising edge on the I/O bit. When the edge occurs, the assembly language detects it within a few microseconds and starts the clock. In this way, the ambiguity of the actual set time is limited to the time of a few assembly language instructions.

The software clock in the Model 6 uses the processor's internal counter/timer registers. The clock count chain starts from pulses which occur at a 10 millisecond rate. These pulses are counted with an 8-bit register which thus rolls over every 2.56 seconds. The BASIC system software uses these rollovers to generate a count which it converts to a time-of-day clock. Each day the 8-bit register rolls over exactly 33750 times (86400/2.56). Although many of these roll overs occur at fractional second times, the count value is such that roll overs occur on one second boundaries at 00:00 hours (midnight) each day and every 64 seconds through the day.

When one of these seconds occurs, we know that the counter rolls over on the exact second. Thus to check the time, a section of the program reads the current clock time then calculates and waits for the next one of the "special" seconds to occur. At this point an I/O bit is toggled, the time is displayed and a count is begun. Thereafter, the bit is toggled and the time is displayed whenever the count changes by 100. The repeated rising edge of this I/O bit is an on-time one pulse per second signal from the internal clock which is compared with an external time reference to perform the clock check.

Time tagging

Time tagging refers to the process of accurately identifying the time of occurrence of the data samples. For convenience we tag one sample in each file on the disk since the time of all other samples can be determined by counting samples from the tagged sample.

The data are collected using a special foreground/background capability of this version of BASIC - the A/D values are collected in the background. To perform a time tag, the program waits in the foreground for one of the "special" seconds as described above then stores the current value of the A/D memory address which is available from the background process. This is stored in the data header of each file along with the time that it occurred. The address is called the "pointer" since it points to the sample that corresponds to the time recorded.

Thus the pointer and the time together form the time tag since they identify (point to) one sample and provide the time to which it corresponds.

Data Handling

Since the recorder uses a sealed recording medium, it is not possible to physically remove the data after a deployment. It is necessary to transcribe the data from the disk to another device and make a backup copy before the instrument is deployed again.

Data Transcription

Data transcription uses the technique developed by Onset which requires that the disk be connected to a PC by a relatively short cable to achieve fast transfers. To accommodate this, the model 6 is mounted so that it can be easily removed from the instrument chassis and connected to a PC.

Depending on the speed of various peripherals, the process of transcribing 200 Mbytes to a PC disk then backing it up onto tape takes about an hour.

Data Quality Checking

After each deployment, data quality control is performed before the instrument is redeployed. The time required for this function depends strongly on the details of the mission being performed and on the type of data recorded - periods from a few minutes to several hours may be required for each instrument.

The first step is to normalize the data. This is done with a special program called GOB which reads the files created during the transcription process and applies the gain and attenuation values from the record headers to the raw recorded values. The program can also display graphically time domain samples of the data or perform various conversions which provide files suitable for other forms of analysis such as record sections.

The gains are stored in the header of each file as follows (see also table 8):
- ch 1 GRA gain (nominal 9 dB) referred to as @(11)
- ch 1 attenuation (nominal 7 dB) referred to as @(12)
- ch 2 GRA gain (nominal 35 dB) referred to as @(13)
- ch 2 attenuation (nominal 7 dB) referred to as @(14)

The raw value recorded on disk for each sample will be one of these (see figure 10):

- ch 1   xxxx xxxx xxxx 0001
- ch 2   xxxx xxxx xxxx 0000

where xxxx xxxx xxxx are the 12 bit A/D values. These are two's complement signed values.

The post processing performed in GOB is as follows. First the gain difference is calculated (this is performed once per data file on disk):

$$\text{gain diff} = \text{alog}(((@(13) - @(14) - @(11) + @(12))/20).$$

Next each data value is converted:

right shift 4 places (propagate top bit)
multiply by 5/2048
if the original data value was an even number (i.e. it
was the high gain channel) then divide by gain difference.

The result is values which are normalized to low gain channel volts. To retain the ultimate resolution of 0.22 ubar (0.022 Pa) at the hydrophone when represented in this way, the converted values have a range +5 to -5 volts and need enough digits to display a resolution of 122 uvolts.

Acknowledgements

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Appendix A - Analytical transfer function of instrument

OBH Transfer Function - cruise AII-125

Figure A1 shows a block diagram of the OBH for purposes of the transfer function. Note that data from program GOB have the DC portion of the switched gain and attenuation stages already applied to normalize all samples to the low gain channel (9dB).

1. Preamplifier

The preamplifier is made up of an input and a gain portion. Figure A2 shows the circuit for the input portion whose transfer function is

$$\frac{V_o}{V_i} = \frac{S(R_1+R_2)C_1C_2\left(S\dfrac{R_1R_2}{R_1+R_2}C_3+1\right)}{(C_1+C_2)\left(S^2R_1R_2C_3\dfrac{C_1C_2}{C_1+C_2}+S\left(\dfrac{(R_1+R_2)C_1C_2}{C_1+C_2}+R_2C_3\right)+1\right)}$$

The gain portion is simply 20 dB and is not a function of frequency.

Thus the complete preamplifier transfer function is

$$A_{PA}(S) = \frac{10\,S(R_1+R_2)C_1C_2\left(S\dfrac{R_1R_2}{R_1+R_2}C_3+1\right)}{(C_1+C_2)\left(S^2R_1R_2C_3\dfrac{C_1C_2}{C_1+C_2}+S\left(\dfrac{(R_1+R_2)C_1C_2}{C_1+C_2}+R_2C_3\right)+1\right)}$$

Inserting the values shown, the result is

$$A_{PA}(S) = \frac{2.35\,S\left(\dfrac{S}{2\pi(0.0319)}+1\right)}{\dfrac{S^2}{(2\pi(0.147))^2}+\dfrac{4.78S}{2\pi(0.147)}+1}$$

The upper panel of figure A3 shows this result graphically.

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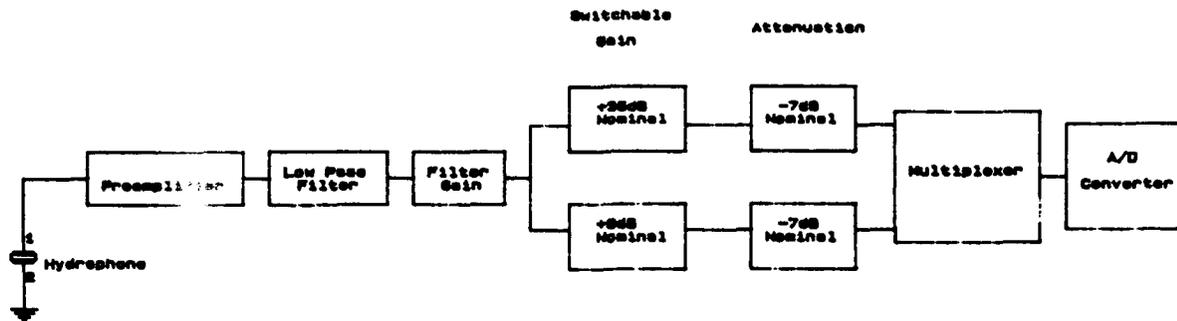
Figure A1: OBH Block Diagram

Figure A2: Preamp input

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WHOI OBH Pre-Amplifier Stage

WHOI OBH Low-Pass Filter Stage

WHOI OBH Switchable Gain Stage
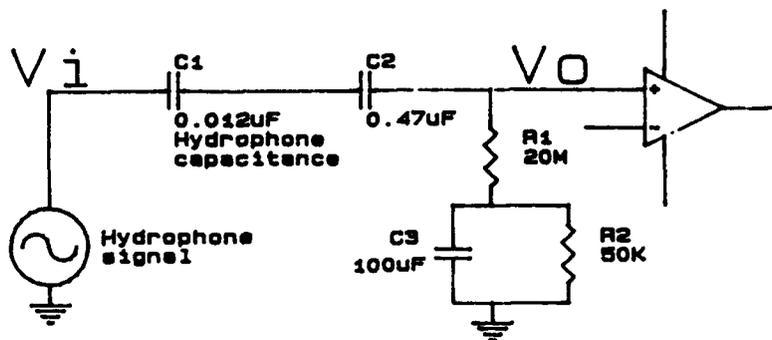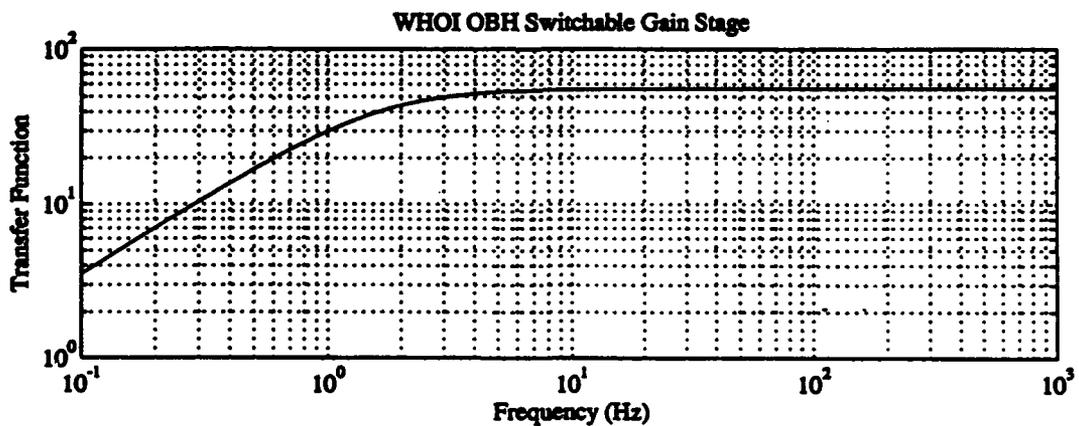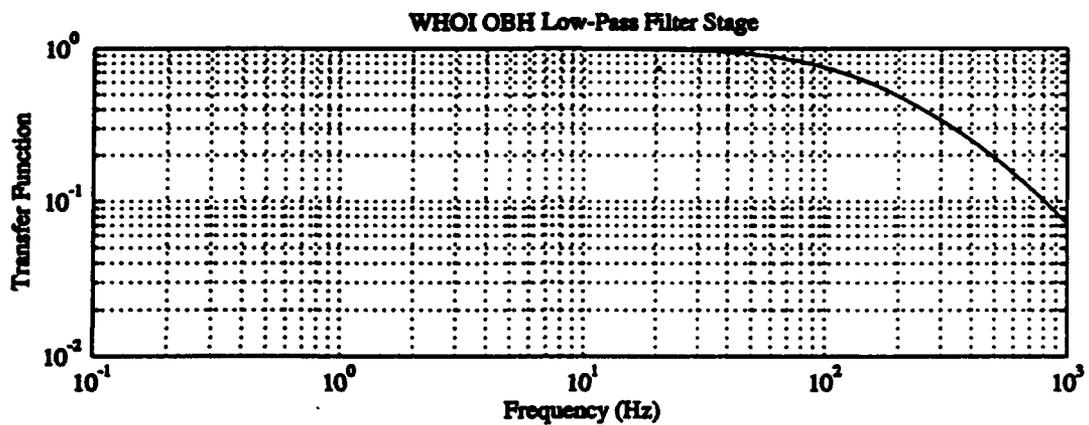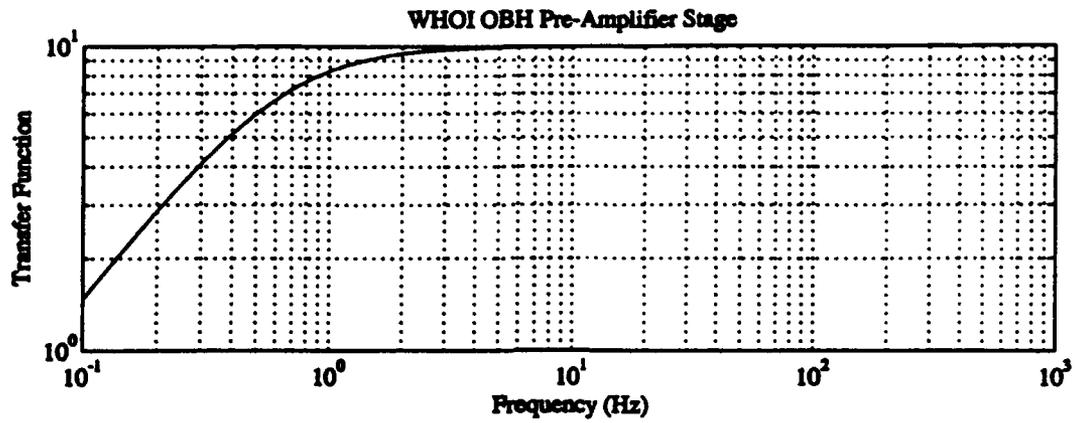
Figure A3: Plot of the transfer functions for the three portions of the instrument which have frequency dependency. These plots use circuit values from the instrument. The text provides the analytical expressions.

2. Low pass filter

This is a 6 pole 400 Hz low pass filter with a 2 dB ripple Chebyshev characteristic. Figure \4 shows the circuit of each of the three stages which has a transfer function of

$$A_{FI}(S) = \frac{1}{S^2 R_1 R_2 C_1 C_2 + S(R_1 + R_2)C_2 + 1}$$

This is often expressed in the following form

$$A_{Fi}(S) = \frac{1}{\dfrac{S^2}{(2\pi f)^2} + \dfrac{\alpha S}{2\pi f} + 1} \quad for \ i = 1,2,3$$

$$where \ f = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}}$$

$$\alpha = \frac{(R_1 + R_2)C_2}{\sqrt{R_1 R_2 C_1 C_2}}$$

In the case of the first stage, this is not strictly true because of the capacitor coupling between the preamplifier and the filter input. Figure A5 shows the equivalent circuit used for a rigorous analysis of the circuit. This gives a transfer function of

$$A_{FI}(S) = \frac{1}{S^2(R+R_1)R_2 C_1 C_2 + S\dfrac{C_2}{C}\left(C(R+R_1) + R_2(C+C_1)\right) + \dfrac{C+C_2}{C}}$$

This is of the same form but with different coefficients. Because of the circuit values however, the filter characteristic is virtually unchanged from the nominal values (see table).

The table below shows the frequency and damping function values for the three stages along with the circuit values. The center panel of figure A3 shows the filter response graphically.

Stage	R1	R2	C1	C2	f	a
First-nominal	26.7K	26.7K	0.0837uF	0.0257uF	128.6	1.108
First-rigorous	26.7K	26.7K	0.0837uF	0.0257uF	128.5	1.113
Second	26.7K	26.7K	0.114uF	0.00354uF	296.9	0.352
Third	26.7K	26.7K	0.311uF	716pF	399.7	0.096
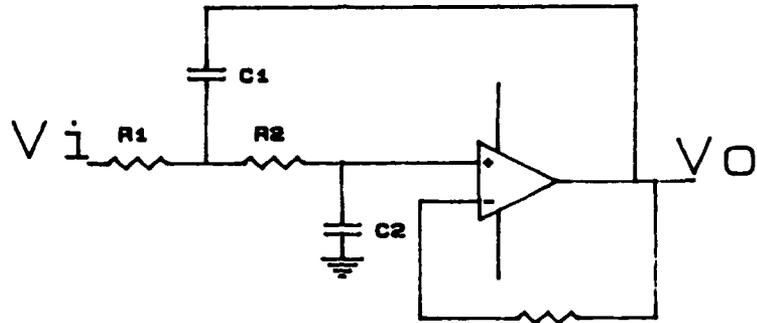
Figure A4: Filter Stage
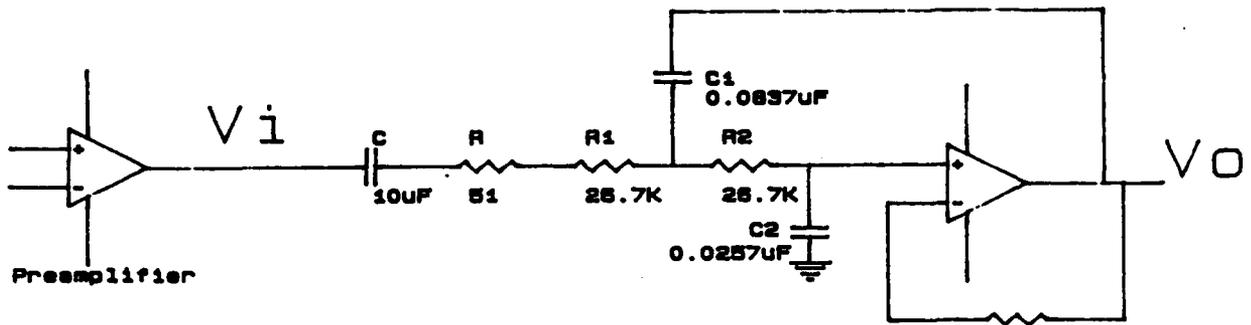
Figure A5: First Filter Stage

3. Filter gain

An additional gain stage - called the filter gain because it is on the filter card - can be used when manually selected before a given deployment. This gain has no frequency dependence. During the NERO cruise, the values were as follows:

for experiments   NERO_11
                       NERO_12
                       NERO_13
                       NERO_14

$$A_{FG} = 4.22 \ or \ 12.5 dB$$

for all other experiments

$$A_{FG} = 1 \ or \ 0 dB$$

4. Switchable gain

Figure A6 is the equivalent circuit of the input to this stage. The gain of the stage is 35dB (x 56.2). The transfer function then is

$$A_{SG}(S) = \frac{56.2 \ SRC}{SRC+1}$$

Inserting the circuit values used gives the following.

$$A_{SG}(S) = 56.2 \frac{\dfrac{S}{2\pi(1.59)}}{\dfrac{S}{2\pi(1.59)}+1}$$

The lower panel of figure A3 shows this result graphically.

5. Attenuation

This is a simple attenuator (-7.13dB) to limit the signal input to the A/D converter. The transfer function is

$$A_{ATT} = 0.44 \ or \ -7.13 dB$$
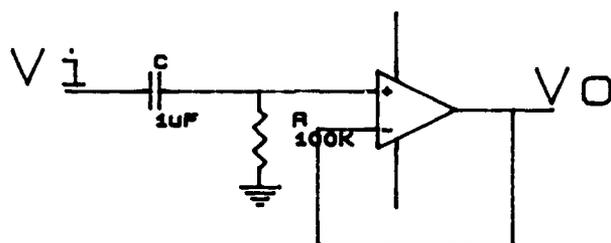
Figure A6: Coupling to Switchable Gain

6. Complete transfer function

Combining the above, the complete transfer function is

$$A_{OBH}(S) = A_{PA}(S)A_{F1}(S)A_{F2}(S)A_{F3}(S)A_{PG}A_{SG}(S)A_{ATT}$$

Figure A7 shows this transfer function graphically.
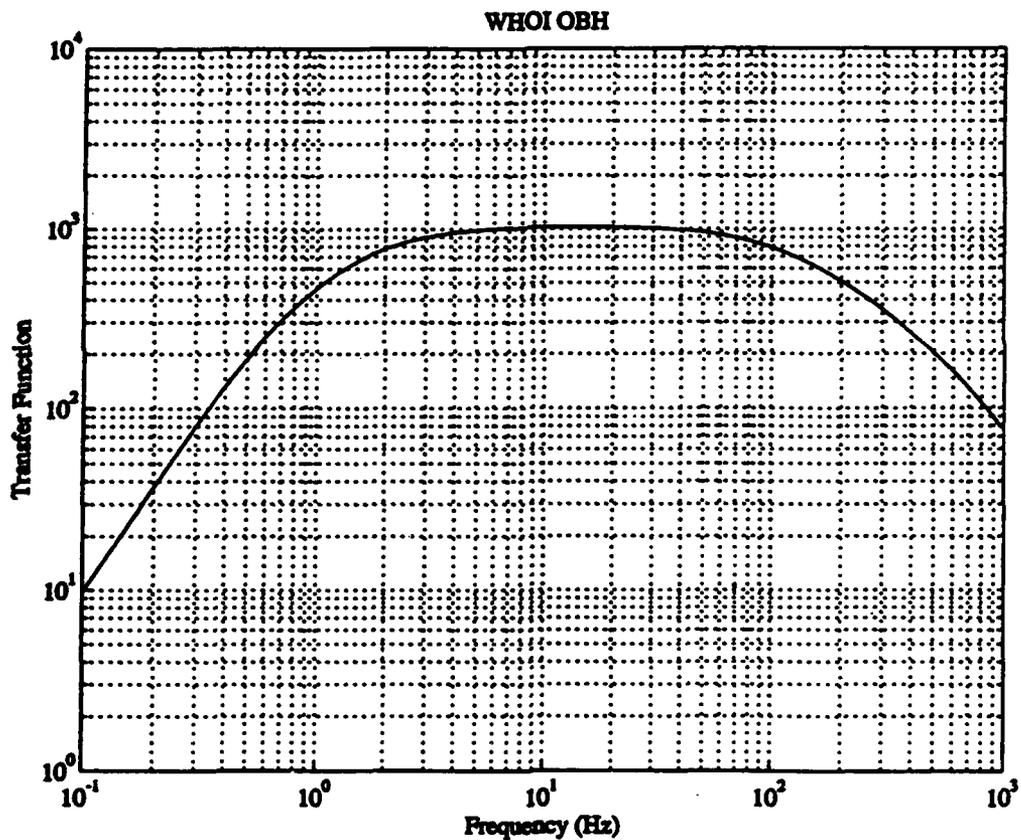
Figure A7: Plot of the transfer function for the complete instrument. This plot uses circuit values from the instrument. The text provides the analytical expressions.

Appendix B: Check sheets
OBH Pre-Deployment Preparation

Cruise_____   Experiment_____

OBH_____   Date_____

Record Times:

_____ start PROCOMM, open log file name_____

_____ serial line connected

_____ Switch to battery power (remove shore power)

_____ read voltages (option 6), leave analog on

_____ set experiment parameters (option 5)

_____ connect and record some WHOOPS

_____ read back and plot WHOOPS, file name_____
comments_____

_____ write disk file, check error flag

_____ do time check (option 4), switch to SAIL clock baud rate, get times:

_____ OBH times

_____ SAIL clock time

_____ Re-arm time (time of GPS 1 PPS)

_____ Calculated OBH correction: (SAIL time - OBH time)

_____ Calculated OBH correction: (-(GPS offset) or (1 - GPS offset))

_____ read voltages (option 6)

_____ set experiment parameters (option 5)

_____ set start time and tracks (option 1)

_____ "waiting for start time"

_____ serial cable disconnected, close and print log file

_____ electronics into pressure case

_____ pressure case purged, vacuum _____in. Hg

_____ pressure case to frame

OBH Post-Recovery Debriefing

Cruise_____   Experiment_____
OBH_____   Date_____

Record Times:

_____ OBH aboard

_____ Check vacuum, _____in. Hg

_____ start PROCOMM, open log file name _____

_____ connect serial line

_____ operation confirmation _____

_____ read voltages (option 6)

_____ do time check (option 4), swtich to SAIL clock baud rate, get times:

_____)BH time

_____ SAIL clock time

_____ Re-arm time (time of GPS 1 PPS)

_____ Calculated OBH correction: (SAIL time - OBH time)

_____ Calculated OBH correction: (-(GPS offset) or (1 - GPS offset))

_____ disk check (option 2), read track #_____
comments _____

_____ connect and record some WHOOPs

_____ read back and plot WHOOPS, file name _____
comments _____

_____ remove electronics from pressure case

_____ change to shore power

_____ close and print log file

_____ model 6 to computer, start OFFLD6 file name _____

_____ offload done

_____ start backup, tape name _____

_____ backup done

Appendix C - Clock checks and timing corrections

To perform an instrument clock check, the instrument generates the character '@' accurately related to its internal time, using the technique described in the clock and timing section above. The '@' from the instrument causes the SAIL clock to latch its internal time which it stores until requested by the controlling computer. At the same time, the offset of the SAIL clock from UTC is also checked. This is done by arming the SAIL clock to check the front panel input which is connected to the one pulse per second signal from the GPS clock.

Thus for each instrument clock check, two measurements are made: the SAIL clock's estimate of the time of the '@' from the instrument and the SAIL clock's estimate of the time of the GPS 1 PPS edge. The use of these numbers is as follows.

First the SAIL vs instrument number. In this case, the correction to be applied to the data recorded by the instrument is formed by subtracting the instrument time from the SAIL time.

Second the SAIL vs GPS number. Since the two clocks are always on the same second, only the fractional part is used. If this number is less than 0.5, use it as a negative correction to the instrument's clock. If it is greater than 0.5, use "one minus the subsecond part" as the correction (a positive correction).

As an example.
> the OBH time reads 01:23:45
> the corresponding latched SAIL time is 01:23:45.003456
> the SAIL "re-arm" time is 01:23:47.000214.

First the SAIL vs instrument correction. Subtract the instrument time (01:23:45) from the SAIL time (01:23:45.003456) giving the correction: +0.003456. Second, the SAIL vs GPS correction. Since the number (0.000214) is less than 0.5, the correction is -0.000214. The total correction to be applied to the OBH time is +0.003242.

Another example:
> the OBH time reads 01:23:45
> the corresponding latched SAIL time is 01:23:44.994231
> the SAIL "re-arm" time is 01:23:47.999932.

The SAIL vs instrument correction is -0.005769. The SAIL vs GPS correction is 1 - 0.999932 = 0.000068. The total correction is -0.005701 which is applied algebraically to the data.

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16. Abstract (Limit: 200 words)

The Woods Hole Ocean Bottom Hydrophone instrument records the digitized output of a single hydrophone sensor at rates between 250 and 1200 samples per second with a dynamic range of 98 dB and can be deployed at depths to 6000 meters. The unit's 200 megabyte disk recorder allows operation for periods up to 5 days. Designed for typical marine seismic refraction operations the unit is reliable and simple to deploy and recover. A detailed description is provided of the instrument design and application including transfer function, clock accuracy, data format, sample data and power requirements.

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