INVERTED ECHO SOUNDER DEVELOPMENT

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ABSTRACT

The Inverted Echo Sounder (IES) is now being widely used to study the temporal variability in large-scale features of the temperature field of the oceans. The latest generation of instruments is microprocessor controlled for functional flexibility. Optional additional measurements of bottom pressure, temperature and ambient noise are now available. The latest system incorporates new echo detection electronics and a simplified anchor release mechanism. The instruments are small, easily manageable, and may be moored in water depths up to 6700 m for 18 months.

1. INTRODUCTION

As temperature and salinity vary in ocean waters, the velocity of sound and, consequently, the acoustic travel time through the water column change. The inverted echo sounder (IES) is an ocean bottom moored instrument which measures the time for an acoustic pulse to travel from the sea floor to the ocean surface and back.

The travel time, T, can be represented as $T = 2 \int_B^h dz/c$, where z is the vertical distance, h is the sea surface elevation, B is the bottom depth, and c is the sound velocity in sea water. Fluctuations in travel time are due to changes in the above integral of the sound speed profile within the water column above the instrument. Rossby (1969) first showed conceptually that such a measurement can be used effectively to monitor changes in the depth of the main thermocline. Watts (1975), in discussing IES data from MODE I, showed that changes in dynamic height can be resolved with an accuracy of better than one dynamic centimeter. A unique capability of the instrument is that it can sense these quantities from the ocean bottom unattended; thus it can work in high current regions or other hostile environments.

The configuration of the inverted echo sounder (Bitterman, 1976) has been evolving since its initial development. The first multi-instrument deployment was in MODE I (Watts and Rossby, 1977). An array of IESs was used to observe a ring interacting with the Gulf Stream (Watts and Olson, 1978). Recent deployments (1981-1984) were under the Gulf Stream off North Carolina (e.g., Watts and Johns, 1982), in the equatorial Pacific in EPOCS, 1980-81), and equatorial Atlantic (by Katz in SEQUAL, 1983-84). The present instrument has newly designed analog and digital circuitry. The new analog echo detector is less noise sensitive and cheaper to manufacture. The digital portion of the circuitry is now based on a low-power microprocessor which allows greater flexibility in programming system functions. The anchor release is a reliable and inexpensive eletrochemical mechanism.

Optional additional measurements on this IES model are hydrostatic pressure and temperature at the sea floor and acoustic ambient noise level, Evans, et al., 1984.

Pressure and acoustic travel time measurements combined are used to determine an accurate total surface height. The acoustic travel time has been shown to give an accurate measure of surface dynamic height, with small additional variation due to barotropic water depth changes. Bottom pressure is sensitive primarily to barotropic variability, with a possibile additional component due to imperfect baroclinic adjustment of the surface dynamic height. Hence, each measured parameter may be used to correct for the second-order effects of the other and determine the combined barotropic and baroclinic variations of the sea surface height, as discussed in Watts and Wimbush (1981).

2. DESCRIPTION

Electronics System

A block diagram of the IES electronics system is shown in Figure 1. The IES operating characteristics are listed in Table 1.

There are two large printed circuit boards, one round (12" diam.); the processor board) and one square (12"x12"; the transmit/record board), connected by a single 25-conductor cable. The large round board contains the microprocessor (Motorola 146805E2) with its related RAM, ROM and clock circuitry, a separate clock for time keeping, timing control logic, and travel time

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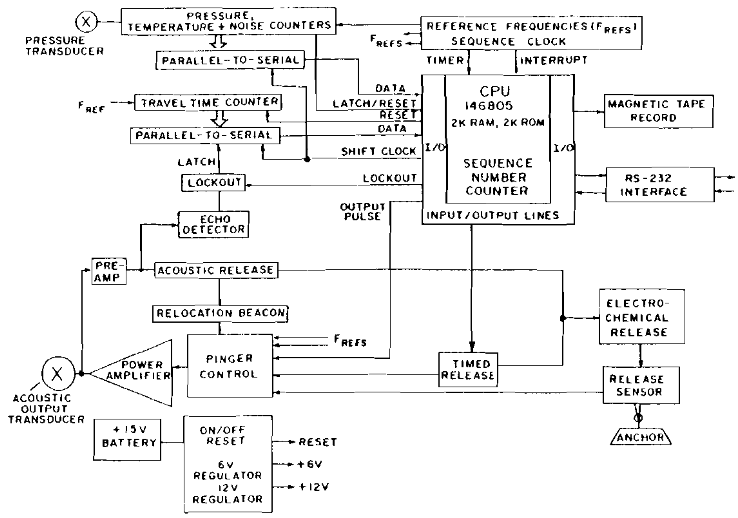

Fig. 1 BLOCK DIAGRAM OF INVERTED ECHO SOUNDER

counter. The large square board contains the ON/OFF/RESET circuits, voltage regulators (+12V and +6V), output power amplifier, release relay and connectors to mount 2 echo detector cards, 6 Sea Link Systems series-200 release cards, 3 Sea Data model 610 recorder cards and tape transport, and optional space for auxilliary data channels (pressure, temperature and ambient noise - Sea Data XP-35, DC-37, DC-35 cards, respectively).

The two large boards are mounted on a PVC battery-holding frame capable of holding eight sticks of "D" or "DD" lithium cells. Typical battery capacity at 14VDC is 90 Ah.

The master oscillator runs at 4.19 MHz. After being divided by 2^{11}, the 2048 Hz is fed into two parallel phaselocked loop multipliers. The first multiplier (x10) generates two signals: 20.48 kHz to drive the travel time counter and 10.24 kHz for the acoustic pulses. The second multiplier (x .125) drives the time keeping clock, generates pulses at 1 sec. and multiples thereof (selectable by jumpers), and provides reference frequencies for auxilliary data channels and the CPU timer.

The sequence and timing of events which comprise an IES data scan are determined by the program stored in ROM. This program is chosen by the user and many variations are possible. To illustrate the function of the circuits under program control, a typical data scan will be described.

The ON/OFF/RESET circuits are activated by push buttons on the square board or by light-sensitive transistors which may be activated by shining a flashlight through the glass sphere. When the reset circuit is activated, the CPU first checks to see if there is a terminal attached to its RS-232 I/O lines and, if so, will send a prompt to the terminal and continue polling the input line until it receives further instructions. The ROM contains a modified version of a Motorola monitor program written for the HMOS 6805 micro-processor. Memory locations and CPU registers can be examined and changed, programs can be executed starting at any address and test programs can be loaded and run in RAM allowing the system to be used for program development as well as data aquisition.

If a terminal is not attached when the reset circuit is activated, the CPU will begin executing the user's program in ROM. After configuring the I/O lines and initializing its interval counters, the CPU will start our typical data scan. The acoustic pulse is transmitted and the travel time counter is started simultaneously. When the echo is received by the echo detector, the contents of the counter are loaded into a parrallel-to-serial shift register. The resulting 18-bit number is equal to the acoustic travel time. From the shift register the travel time is stored in RAM just prior to the next acoustic transmission. This sequence is repeated for each measurement until the burst of 20 pings is completed, whereupon the RAM buffer contains each of the individual travel times. The IES then stops in a low-power state until the next interrupt pulse is received from the timekeeper clock.

The program in ROM determines the number of travel time measurements performed during each burst. In our typical burst sampling program, a group or burst of travel time measurements is generated at a fixed rate of one measurement every 10 seconds with a total number of 20 measurements per burst. The number of measurements per burst is limited only by the size of the buffer memory (2k X 8 RAM).

Between measurements the CPU operates in a reduced power WAIT state and between bursts it operates in a low-power STOP state. In the STOP state the CPU simply waits for the next interrupt pulse from the time-keeper clock. The operating state of the CPU does not affect the relocation or recovery functions as the circuits operate independently.

In our typical example, when the CPU receives the subsequent interrupt pulse, it first increments the 16-bit sequence number which is attached to every data record and then compares this number to the timed release number stored in ROM. If they are the same, the IES will automatically be released from the bottom. (See relocation and recovery section.) If the numbers are not the same,the CPU will return to the users program and latch any optional data into a shift register and store it with the travel times in the temporary RAM buffer. The CPU then sends a record request pulse to the tape recorder system whose internal clock shifts all of the data record (sequence number, travel times, optional data) from RAM to magnetic tape. After recording a data record, the CPU will check if a terminal is attached and, if so, will display the data record on the CRT.

If a terminal is not attached, the CPU will enter its low-power STOP state and wait for the next 15-minute interrupt pulse. This next pulse will cause the CPU to increment the sequence number, compare it to the timed release number and start another travel time data scan. This cycle will continue until the IES is reset or recovered. Notice that, in this example, the sequence number is not the number of data records but the number of elapsed 15minute periods, and hence uniquely specifies the time.

Housing

The electronics and batteries are contained in a 17" diam. (o.d.) glass sphere (from Benthos, Inc.). The sphere has a wall thickness of 9/16 ", a weight in air of 39 lbs., and a buoyancy in seawater of 56 lbs. (sphere only).

Figure 2 shows the physical features of an IES moored at the ocean bottom. The glass sphere is housed in a polypropylene "hardhat" with the pinger and its protective cage bolted to one end. The electrochemical release block is bolted to the other end (see Fig. 2). When deployed, the pinger points vertically up toward the sea surface; when released from the bottom, the IES turns over and the pinger points down. When the instrument reaches the surface, the OAR radio and flasher, which were on the bottom of the IES for deployment are then out of the water and the pinger remains in the water. A polypropylene rope loops around the rim of the hardhat to facilitate retrieval.

Anchor

An 80 to 100 lb. anchor is attached by a 1 meter length of 5/16" diam. nylon line. This tether line must be short (about 20 cm. longer than the radio antenna) so that any swinging motions caused by varying bottom currents do not cause the instrument to vary significantly in depth. Also, the anchor must be rigid enough, so that varying drag does not cause bobbing.

Relocation and Recovery System

An acoustic beacon is used as the primary relocation aid. If a modified (lengthened) AMF Sea Link transpond pulse is projected from a hydrophone on the ship, it initiates a continuous series of 10 kHz pulses from the IES at an 8 sec. (selectable) repetition rate. The relocation

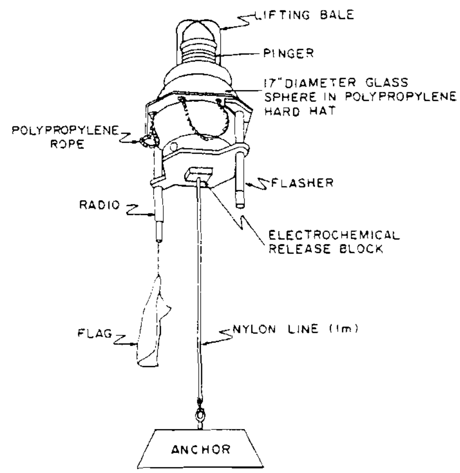

Fig.2 Diagram of Moored IES.

pulse rate is an exact intergral number of seconds (8) so they are received at the same spot on the chart of a line scan recorder with a 2 sec. sweep rate. The ship can be maneuvered to minimize the distance from the instrument, to a position directly above the moored IES. The relocation beacon is shut off by the first pulse of a data scan but, if need be, can be reinitiated after the data scan is complete, by another signal from the Sea Link shipboard system.

When the ship has been positioned close to the IES, the appropriate release code is sent via the Sea Link deck set. When the release code is accepted by the IES and current is detected in the electrochemical ballast-release system, the release sense pinger (a 10 kHz pulse train with a 4 sec. rate) is initiated and within 16-20 minutes the IES will release its ballast anchor and rise to the surface. The IES can be acoustically tracked to the surface using a line scan recorder and, if need be, the ship maneuvered to remain close while the IES rises.

Because the IES is small, an OAR (Ocean Applied Research) radio beacon and strobe flasher, as well as a flag, are used as recovery aids.

A backup release timer has been built into the IES. It is programmed in ROM prior to launch and will activate the electrochemical release in case the instrument is unable to receive or detect the acoustic release command. This timer is usually set to activate several months after the expected recovery cruise.

Data Sample

Figure 3 is a data sample from an IES, showing each echo as a function of time . It is a strip chart record, obtained by direct digital-to-analog conversion of the cassette data, and shows the measured acoustic travel times. The instrument was deployed in 3500m of water near the north edge of the Gulf Stream off Cape Hatteras, North Carolina in November 1983.

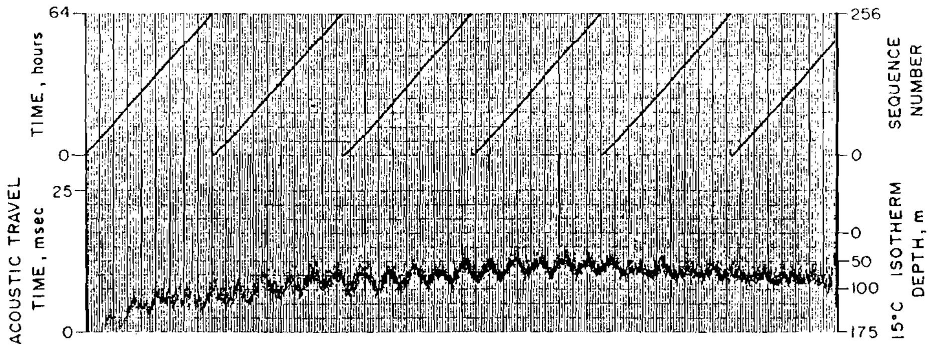

Fig. 3 IES Data Sample - Strip Chart Record

The straight lines at the top half of Figure 3 are plots of the sequence number (bits 0 -7), which roll over every 64 hrs. In the lower half of Figure 3, the semidiurnal tides show up clearly as low amplitude high frequency signals and exibit a beat frequency of about 15 days, corresponding to spring and neap tides. The large, low-frequency excursion corresponds to changes in the thermocline depth due to Gulf Stream meandering. The approximate conversion factor is a change of 1 msec = 20 m change in depth of the 15°C isotherm and is incorporated into the scale on the right.

3. COSTS

The major components in each instrument and their costs are listed in Table 2. With the exception of the electronics, nearly all the major cost items have been purchased from outside vendors. Thus the total instrument cost is fixed rather firmly.

4. SUMMARY

The microprocessor controlled model Inverted Echo Sounders described above have proven reliable in several short engineering tests and all 27 scientific deployments thus far, of durations 6-14 months. Presently about 29 more are deployed in the Gulf Stream and the equatorial Atlantic, for intervals of 10-15 months. The significant improvements in this model are: (a) instrument checkout and deployment procedures are simplified and standardized, (b) the echo detector is less sensitive to extraneous signals, (c) there are no crucial external parts subject to corrosion, (d) instrument costs and machining complexity have been reduced in several ways (e.g., the electro-chemical anchor release mechanism), (e) deployment times are extended to 18 months, (f) the micro-processor controller allows for flexibility in burst sampling or addition of optional measurements. These instrument developments make the IES simple to handle at sea and a cost effective means to measure the low frequency variability in the large scale temperature structure of the oceans. The IES combined with the bottom pressure sensor has a wide range of applications for monitoring changes in the principal baroclinic and barotropic pressure fields in the oceans.

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TABLE 1.
IES OPERATING CHARACTERISTICS

PRESSURE CASE	17" Diam. glass sphere
OPERATING DEPTH	6700 m (max.)
WEIGHT IN AIR	80 lbs.+ 100lb. anchor
BUOYANCY IN WATER	20 lbs.(with full set of batteries)
BATTERY	lithium,+14 volt 90Ah.
DATA STORAGE	Sea Data model 610 tape recorder
DATA CAPACITY	10 million bits
DEPLOYMENT TIME	18 months (max.) consistent with data capacity and battery life
RECOVERY SYSTEM	self contained with electronics from Sea Link series 200 decoder; electrochemical release mechanism
RELOCATION AND RECOVERY AIDS	10 KHz acoustic beacon OAR radio and flasher, flag, backup release timer
SAMPLING CHARACTERISTICS	All programmable, typically:
Burst rate	30 min.between bursts
Burst length	20 pings/burst
Ping rate	10 sec. between pings
Ping length	6 msec.
Ping frequency	10240 Hz
TRANSDUCER CHARACTERISTICS	Special ITC MODEL 3293 stacked piston
Transmit bandwidth	9 to 11 kHz @ -3dB
Beam width	80 degrees (typ.)
Acoustic power	197 (typ), 203 (max.) dB re 1 uPa at 1 m
Electronic power	250 watts pulsed
TIMING STABILITY	0.02 ppm/ C (typ) for 0 - 25 C 0.03 ppm/mo.(max) after 3 months
TRAVEL TIME ACCURACY	0.049 msec. resolution 0.5-1.5 msec. standard deviation of single measurement 0.1-0.3 msec. standard deviation of 20 measurements
OPTIONAL SENSORS	
Bottom Pressure	Paroscientific Digiquartz model 410K (0 - 10,000 psi) powered and counted by Sea Data XP-35 electronics card with 0.28 ppm resolution
Temperature (of pressure sensor)	YSI thermistor and Sea Data DC-37 electronics card (0-25 C)
Acoustic ambient noise	@ 11kHz in 2 kHz bandwidth using Sea Data DC-35B or C electronics card with 60dB dynamic range

TABLE 2. COSTS OF IES COMPONENTS

TAPE RECORDER SYSTEM	$ 1,800
AMF RELEASE RECEIVER	2,300
GLASS SPHERE ASSEMBLY	800
ELECTRONICS FRAME	300
ANCHOR RELEASE	100
TRANSDUCER	400
ELECTRONICS	800
MISCELLANEOUS FITTINGS	300
OAR RADIO AND FLASHER	1,100
TOTAL	$ 7,900
COSTS PER DEPLOYMENT (CONSUMABLES)	500
OPTIONAL DATA CHANNELS:	
PRESSURE	3,800
TEMPERATURE	600
AMBIENT NOISE	600
TOTAL	$ 13,400