The Hawaii-2 Observatory

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***Abstract*—A permanent deep ocean scientific research facility—the Hawaii-2 Observatory (H2O)—was installed on the retired HAW-2 commercial submarine telephone cable in September 1998. H2O consists of a seafloor submarine cable termination and junction box in 5000 m of water located halfway between Hawaii and California. The H2O infrastructure was installed from a large research vessel using the Jason ROV and standard over-the-side gear. The junction box provides two-way digital communication at variable data rates of up to 80 kbit/s using the RS-422 protocol and a total of 400 W of power for both junction box systems and user equipment. Instruments may be connected by an ROV to the junction box at 8 wet-mateable connectors. The H2O junction box is a "smart" design, which incorporates redundancy to protect against failure and allows full control of instrument functionality from shore. Initial instrumentation at the H2O site includes broad-band seismometer and hydrophone packages.**

***Index Terms*—Deep ocean observatories, subsea telecommunications, seismology.**

I. INTRODUCTION

THE HAWAII-2 (HAW-2) submarine telephone cable was laid in 1964 between San Luis Obispo, CA, and Makaha, Oahu, HI. It was operated continuously by AT&T until 1989, when a cable break off California led to its retirement from commercial service. It is a second-generation vacuum tube repeater (AT&T SD series) analog system [1], which is characterized by a single coaxial cable 1.25 in in diameter carrying two-way telephone traffic and repeaters spaced at intervals of 20 nautical miles. In 1996, the entire HAW-2 sub sea infrastructure was acquired by the Incorporated Research Institutions for Seismology (IRIS) from AT&T on behalf of the U.S. scientific community.

Hawaii-2 Observatory (H2O) was installed close to the midpoint between two repeaters near 28°N, 142°W at about 5000-m water depth (Fig. 1). The physiography in this area is one of abyssal hills with a nominal but variable 50–100 m cover of clay sediment. The local relief around the H2O junction box is quite subdued; Surveys of the site reveal no rock outcrops and very gentle relief of a few tens of meters on a smoothly sedimented bottom.

The primary scientific motivation for H2O comes from the global geophysics and seismology communities [2]. The H2O site is located at a point on Earth's surface where there is no land for about 2000 km in any direction. For this reason, it is a high priority site for the Ocean Seismic Network (OSN) component of the Global Seismic Network (GSN) [3], and serves as the first operational OSN station. The geomagnetic community has also identified the H2O site as one of eight seafloor locations where permanent observatories are required [4]. Finally, H2O is located at a logistically convenient place for testing permanent seafloor instrumentation and observatory concepts in the deep ocean. Planned H2O upgrades include the addition of a geomagnetic observatory, a benthic biology monitoring system, and a downhole seismometer.

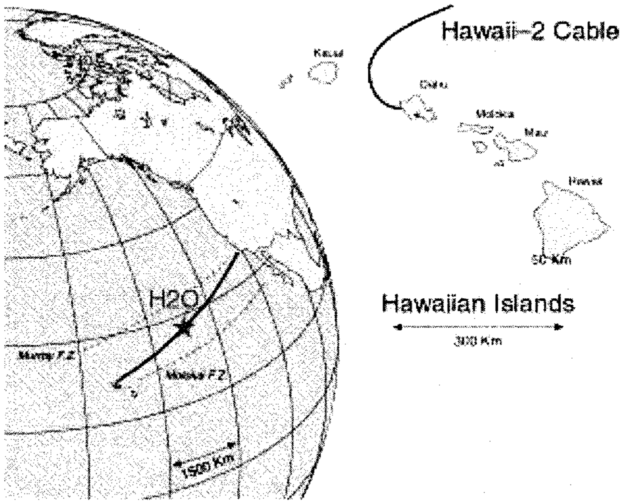

Fig. 1. The H2O is sited 1750 km east–northeast of Honolulu. The path of the Hawaii-2 cable runs between Oahu and Kauai, then heads northeast toward California.

II. SYSTEM DESIGN

The great challenge in designing a deep ocean observatory is trying to imagine and accommodate the requirements of future users. The ideal system would be infinitely flexible in allocating data bandwidth and power. Because of its remote location, it would be ultra-reliable, and, in the case of a failure, capable of self-healing by activating redundant components. Also, since the number of users is expected to increase with time, the system would make full use of the cable system resources. In addition to meeting these requirements, the H2O engineering team was confronted with another difficulty—designing the observatory around the 30-year-old SD cable system.

The SD submarine cable systems were designed in the late 1950s to carry analog signals between distant end stations and to provide power to amplifying repeaters at points along the cable. Filters within the repeaters and inline shaping networks were carefully adjusted to compensate for the frequency-dependent

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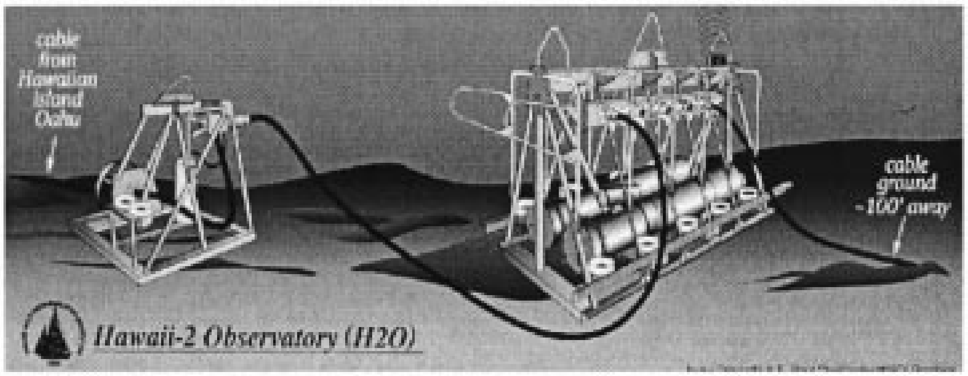

Fig. 2.Illustration showing the H2O site. The termination frame is shown at the left while the junction box is on the right. The sea ground is located off to the right.

loss of the cable. The resulting system provided a pair of unidirectional, 400-kHz-wide, lossless channels within which 128 telephone conversations were multiplexed.

The requirements of a seafloor observatory for flexible, multi-user communications at a seafloor site are not easily met by the static, point-to-point SD system. Power for the science users and for the junction box itself must be derived from the 370-mA dc current flowing through the SD cable's center conductor and returning through seawater electrodes. Since this current provides power to all the repeaters, it cannot be increased to deliver more power to the observatory and, for the health of the repeaters, should not be changed abruptly during operation. As a result, delivering a modest 400 W of power to H2O requires an awkwardly high sea floor voltage of 1200 V and a power conversion system that prevents rapid current fluctuations. Similarly, the SD communication system isn't well suited to the needs of H2O. The division of the cable bandwidth into two, unidirectional, 400-kHz channels is implemented within the repeaters and can't be changed. The shore-bound band falls between 116 and 512 kHz and so doesn't allow the simple implementation of baseband digital signaling. Also, most of the seafloor-bound band is likely to remain unused, carrying only occasional commands and timing signals.

The design solution was a compromise between optimum utilization of cable system resources through custom designs and the use of low-cost commercial hardware to reduce development costs and increase reliability. The first step was to specify general goals for H2O: 1) minimize the cost of instrument development by providing an industry-standard, digital communication interface and low-voltage dc power; 2) simplify instrument installation by providing a well-designed, ROV-compatible mechanical interface; and 3) make the system configurable to accommodate both low and high data rate users, and fault-tolerant to allow bypassing of failed components from shore.

From the general goals, a series of system requirements emerged which was based on minimum performance for an expected user community over the course of a 10-year program duration. These minimum requirements were often dictated by operational and mechanical considerations such as a reasonable number of connectors on the jbox frame and a maximum density of sensors at the site. The system requirements were: 1) eight user ports equipped with ROV-mateable connectors and providing current limited 48-V dc power and serial communications; 2) serial ports conforming to RS422 standard and running at up to 115-kb/s rate and a data throughput of up to 80-kb/s; 3) a variety of data paths for high– and low-bandwidth users with a provision for routing data from any user port through any or all data paths to shore, in case of equipment failure; 4) a robust system-monitoring and control capability; and 5) a time stamping system accurate to 1 ms.

As H2O began to take shape, one other requirement was added which helped to focus design decisions and led to a greatly simplified final system. It was determined that the junction box must be easily recoverable for service and that maintenance cruises would visit the site every two to three years.

III. SYSTEM DESCRIPTION

The mechanical layout of the H2O seafloor installation is shown in Fig. 2. The SD cable from Hawaii is terminated at a gimbal assembly recovered from a salvaged SD repeater. The gimbal is attached to the titanium termination frame. An oil-filled hose brings the SD cable conductors out to a wet-mateable underwater connector. The use of this termination frame allows the junction box to be easily retrieved and serviced for upgrades or in the event of a failure. The SD cable is connected to the main junction box by a short (∼30 m) oil-filled underwater-mateable umbilical. The power conditioning pressure case on the junction box contains a power converter to extract power from the constant current SD system. It is terminated by a sea ground deployed far enough from the junction box to alleviate corrosion concerns. The junction box electronics pressure case contains all of the systems necessary to control power and digital communications with instruments and to telemeter data to shore. The pressure cases are connected to an oil-filled connector manifold, providing eight, ROV-compatible, wet-mateable, 8-pin connectors, with four connectors on either side of the manifold. The connector manifold also houses two additional 4-pin connectors to which the termination frame and sea ground are attached. The connector manifold is designed to provide space for ROV access, and the connectors, based on the Ocean Design Nautilus family, are specifically intended to be compatible with a standard ROV manipulator. The entire junction box sits on a broad weighted base and frame that protects vulnerable pressure cases and associated connectors, yet places the connector manifold well above the seafloor.

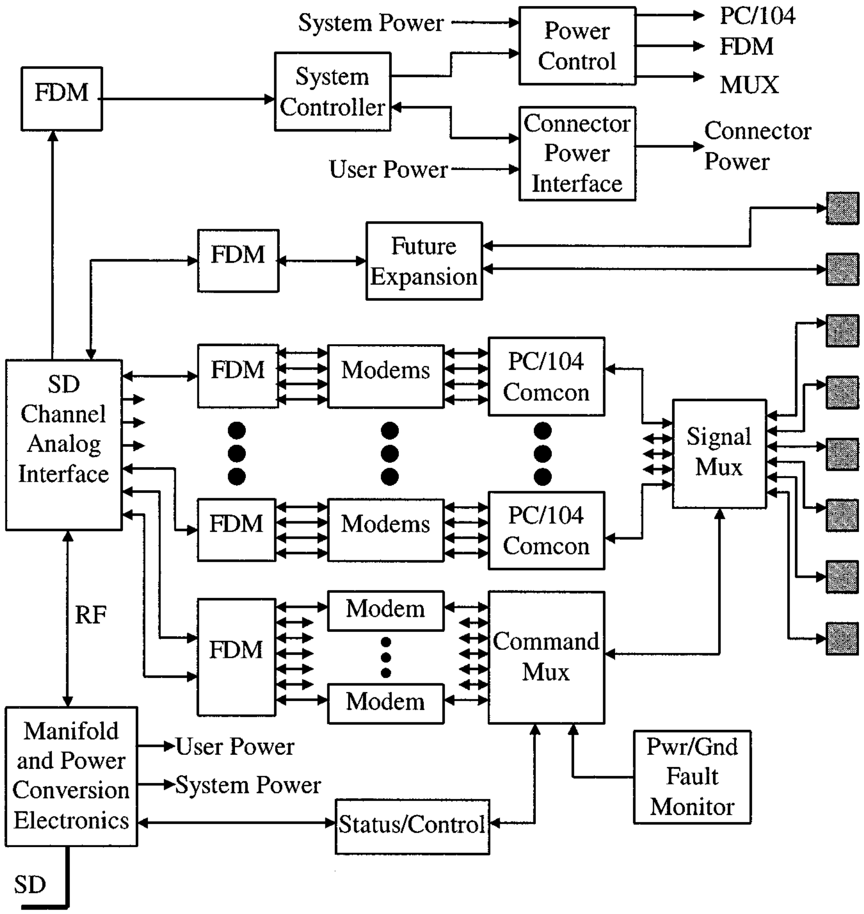

Fig. 3. Block diagram of the H2O electronics. The major subsystems include the power system, the FDM, the data concentrator and modem stacks, and the jbox control systems.

Fig. 3 summarizes the H2O electronics. Power from the SD cable is converted, regulated, and monitored by the power system. The SD channel analog interface is a passive filter and summing network, which separates the uplink (to H2O) high-band and downlink (from H2O) low-band signals while matching to the impedance of the SD cable. The frequency-division multiplex (FDM) system divides the SD channel into many narrow-band analog channels that are suitable for commercial telephone modems or any other analog signal with a bandwidth less than 4 kHz. Each FDM board includes four channels. The five data concentrators (Comcons) each consist of a PC/104 stack and four modems. They are responsible for multiplexing the high-speed instrument data onto the lower speed modem channels. In addition, there are seven individual modems for low data rate users. Overall, system operation is controlled and monitored by the junction box control systems. Dual microcontroller-based supervisor boards execute commands from shore to control power to users, power to system boards, and the routing path of data flow. A separate subsystem monitors and reports power and ground-fault status. The subsystem functionality is further described in the following sections.

IV. POWER SYSTEM

The dc and RF components arriving from Hawaii on the SD cable are separated at a power separation filter (PSF) located in the oil-filled manifold. The dc component is sent to the power supply pressure case as a 370-mA constant current with a return through a seawater electrode. The H2O power system uses custom made unregulated dc–dc converters with inputs in series and outputs in parallel (diode isolated). The output of each converter drives a shunt regulator so that the converters present a constant voltage load to the cable.

The regulators must dissipate excess power not used by the system and the users. In order to keep the power dissipation within reasonable limits, a series stack of power modules (in 150- or 300-V increments, providing about 50 or 100 W each) can be switched into the line as required, with the unused modules shorted out. These extra modules provide both flexibility (system power can be changed in convenient increments) and redundancy (modules will always fail in a shorted mode and a spare module can then be brought on line). Precautions must be taken when switching power modules to limit the rate of change of voltage and minimize the stress on the repeaters. The 1000-mile cable has almost 200 μF of capacitance. The capacitance of the cable is charging or discharging during switching and the resulting current change adds to or opposes the current through the repeaters. The ramping rate for H2O is designed to limit the momentary current fluctuations to less than 10%.

The standard AT&T power-up sequence for the SD system requires a very slow ramping of the current to avoid thermal shocks to the repeaters. A small 48-V startup module in the H2O

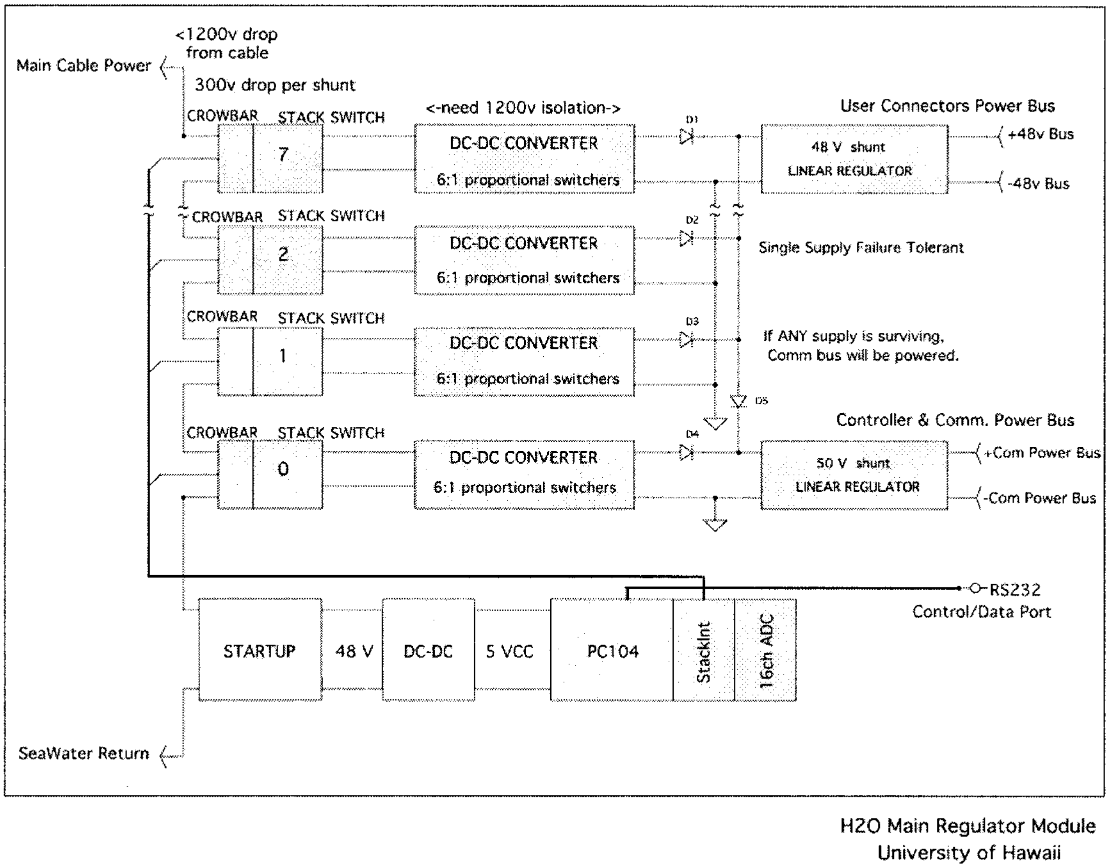

Fig. 4. Block diagram of the H2O power system shows proportional switching regulators with series inputs and paralleled, diode-isolated outputs. A 50-V system bus provides power to H2O electronics and a higher capacity 48-V user bus powers external instruments.

power supply monitors the line current to determine when cable power is stable. Fig. 4 illustrates the operation of the H2O power system. When the cable is powered on, two stacks come up automatically to support the system bus, and additional stacks can be brought on line as needed to power the user bus. It then automatically adds several power modules to provide power to the main observatory system, plus some power for users. Once communications have been established, the power system can be controlled and monitored from shore using a control computer, which is completely independent of the remainder of the junction box, providing a degree of failsafe operation.

Care must be taken to maintain adequate current in the shunt regulators at all times, particularly when initiating power to a user. Some user loads may draw several times their normal current during the start-up surge. If the current in the shunt regulators drops to zero for even an instant, the entire power system will become unstable and collapse to a low-voltage, out-of-regulation state. This will result in a complete system reset, returning to the default initial state.

V. FREQUENCY DIVISION MULTIPLEXING

The FDM electronics of the original SD system employed a sophisticated hierarchical scheme of channel carrier groupings based on a single, stable frequency standard. To conserve bandwidth and maximize signal efficiency, single sideband, suppressed carrier amplitude modulation was used. Single sideband AM uses half the bandwidth of standard AM and suppressing the carrier (which carries no information) eased the power rating requirement of the repeater amplifiers. However, the more efficient modulation scheme of the original system is complicated to demodulate and greatly increases circuit complexity. For the H2O communication system, circuit simplicity and fault tolerance took precedence over channel efficiency thus standard amplitude modulation (AM) was used with each channel carrier derived from an independent crystal oscillator.

Each FDM channel for H2O includes two carriers separated by 455 kHz. This is the standard IF frequency used in commercial AM radios and many low-cost signal-processing components are available off-the-shelf. General-purpose oscillator, modulator/demodulator and amplifier integrated circuits for the 100-kHz to 1-MHz frequency range are also readily available. The final required element is a 2-wire to 4-wire converter for interfacing to a telephone modem, which is easily constructed from common commercial parts.

Fig. 5 is a simplified block diagram of a single FDM channel. Amplifier and filter stages are left out for clarity. The audio signal from the telephone modem is directed toward the modulator by an audio transformer. The on-board crystal oscillator drives both the modulator and the down-converting mixer. The amplitude-modulated carrier is directed to the analog channel of the SD system by a balanced signal combiner. The received signal contains all of the multiplexed carriers that were transmitted from shore. However, only the one that is exactly 455

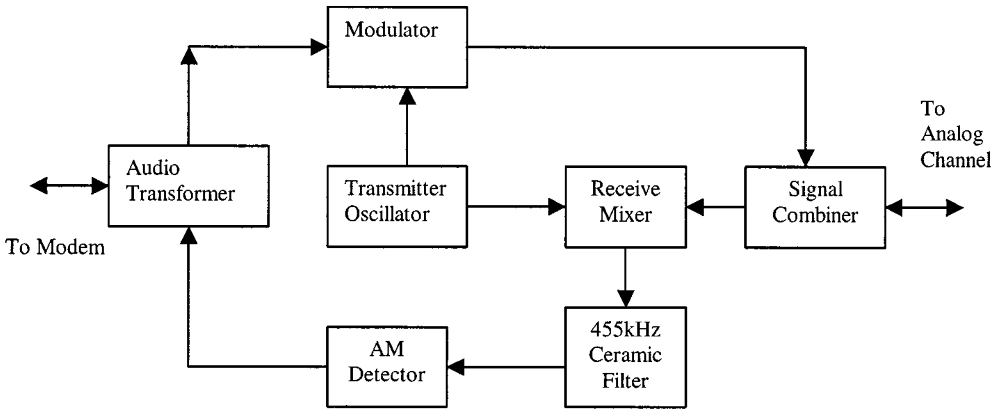

Fig. 5. Block diagram of a single FDM transceiver.

kHz above the on-board oscillator passes through the ceramic filter. A simple diode detector produces the audio frequency modem signal, which is routed through the transformer.

Each FDM channel occupies 10 kHz of bandwidth including guard bands. Each communications block thus occupies about 40 kHz of spectrum, so the five blocks plus seven modem channels require about 270 of the available 400 kHz. The remaining approximately 130 kHz of bandwidth is held in reserve to accommodate future expansion.

VI. DATA CONCENTRATOR AND MODEMS

The science connectors at the H2O junction box are required to provide a full-duplex, serial port with a data throughput of up to 80 kb/s in the shore-bound direction. However, the telephone modems that carry all the system's data traffic are capable of a maximum rate of 33.6 kb/s. In practice, reliable modem connections are limited to about 19.2 kb/s due to channel characteristics. In order for users to send data at the full port rate, the data must be divided up and transmitted on separate paths by the Comcon stacks. Onboard software is responsible for establishing and maintaining data flow between an attached instrument and the shore computers using four commercial modem pairs.

On power up, the Comcon attempts to establish a connection to shore on one of its four modems. If a connection is not established within about one minute, the attempt is abandoned and the next modem is dialed. This process continues until a modem establishes a connection or power to the Comcon is removed. Once a connection is established, the shore computer connects the three remaining modems. For the current requirements, each connection is forced to a rate of 19.2 kb/s.

With all four modems connected, packetizing software runs on the Comcon to transfer instrument data to shore. The high-speed serial port on the Comcon receives data from the instrument at bit rate of 115.2 kb/s. This serial stream is buffered until there is a 2-ms pause in the data. Then the data is loaded into a packet with a header byte count and checksum. Packets are transferred to modems in sequence, so with four modems connected at 19.2 kb/s the absolute limit of data that can be transferred is 7680 bytes per second. With the overhead of processing the actual throughput rate is 5800 bytes per second.

The H2O science requirements specify that data be time stamped with an absolute accuracy of 1 ms or better. Since the data telemetry system can introduce delays in data delivery to shore, it was necessary to provide a time keeping signal to the sea floor. At the time of system design, it was difficult to anticipate the needs of future experiments so the time stamping strategy was tailored to the ULF seismometer data stream. The time signal is sent to a dedicated precision clock, which resides on a board in each of the Comcon PC/104 stacks. The analog signal is encoded with timing information in the IRIG-B format and is sent from a GPS clock at the cable station on redundant FDM channels. Data packets coming from the seismometer are time stamped on arrival by the Comcon based on a read of its on board precision clock. When data packets are reassembled on shore the time stamp information is combined with knowledge of fixed telemetry delays to correct the time of the ULF data record.

VII. JUNCTION BOX CONTROL SYSTEM

The H2O communication and power systems on the seafloor require a simple control system to allow for reliable monitoring and command from shore. The need for reliability and fault-tolerance suggested a dual redundant microprocessor-based system, which is well isolated from other system failures. Each processor must have its own independent communication channel (and preferably two). The failure of one processor should in no way degrade the operation of any other part of the system.

A system controller, consisting of a dual-tone multiple-frequency (DTMF) interface to the junction box and user power systems, provides control of junction box functions. The system controller provides the ability to turn junction box subsystems on and off, select backup systems in the event of failure, halt and reboot junction box computer systems individually or collectively, and control power distribution to users.

The control system processor board or supervisor for H2O includes a microcontroller module, a DTMF decoder and two serial to parallel converters (shift registers). The microcontroller module has 12 control lines, a 232/485 serial port, two 12-bit A/D inputs, two interrupt inputs, and three timers inputs and is programmable in BASIC. Commands are sent to H2O over a dedicated FDM channel from a touch-tone keypad or DTMF generator. Each command consists of a 10 character ASCII string with five start bytes, two data bytes, two address bytes, and a termination byte. The data and address bytes are in hexadecimal format and control a system wide write-only 8-b data and address bus which in turn controls all H2O communication system functions. The H2O power supply in its own pressure case has an independent DTMF channel for control of power supply functions. Both the communication system and power supply have their own serial ports for bi-directional serial communication The H2O system includes two supervisor boards which are continuously powered directly from the system 48-V power supply. They communicate to shore via independent DTMF and serial channels and are independent of each other. The supervisor boards are designed to fail gracefully for optimum system fault tolerance.

A separate system telemeters junction box electronic parameters like system and user bus voltages and currents or subsystem status information back to shore on a dedicated channel. It also provides a ground-fault detection capability to protect connectors and pressure cases from damage in the event that a component failure allows electric current to flow through the pressure case wall. Overcurrent protection at each user connector is provided through a foldback current limiter, preventing a single user from drawing more than about 75 W. The Power/Fault monitor board controls the operation of the voltage monitoring subsystem. The Power/Fault board includes an onboard microcontroller, identical to the one on the Supervisor board. The microcontroller's serial port is configured for RS422 operation and it is used to report power readings to shore and to allow for remote reprogramming of the processor. Two on-board 12-b A/D converters are used for auxiliary measurements. Two 16-b shift registers are used to command the isolated switch boards that interface to the voltage measurement points in the system. The shift registers and the A/D converters are commanded by processor I/O pins configured as a synchronous serial channel.

The three A/D converters of the Power/Fault board take analog input from two isolated switch boards and from an on-board temperature sensor. Each Iso-switch board allows for electrically isolated measurements of up to 12 single-ended or seven balanced test points. By careful connection of switch inputs the system automatically monitors the eight user currents, A (system) and B (Science) bus voltages and currents and B bus ground fault. By switching the Power/Fault system to manual mode, user voltages can be measured as well.

The H2O control system also allows for extensive control of data routing. In order to allow for maximum utilization of system telemetry resources and to permit removal of faulted components, a system of remotely programmable cross point switches was implemented. The cross point switches are referred to as multiplexers since they control the digital side of the H2O multiplexing architecture.

VIII. SHORE STATION ELECTRONICS

The H2O shore system (see Fig. 6) includes power supply and signal processing amplifiers from an original SD system as well as FDM electronic boards and the telephone modems essentially identical to those in the seafloor system. All the H2O equipment at the cable station runs off the main station 48-V power supply, which is backed up by batteries and diesel generators.

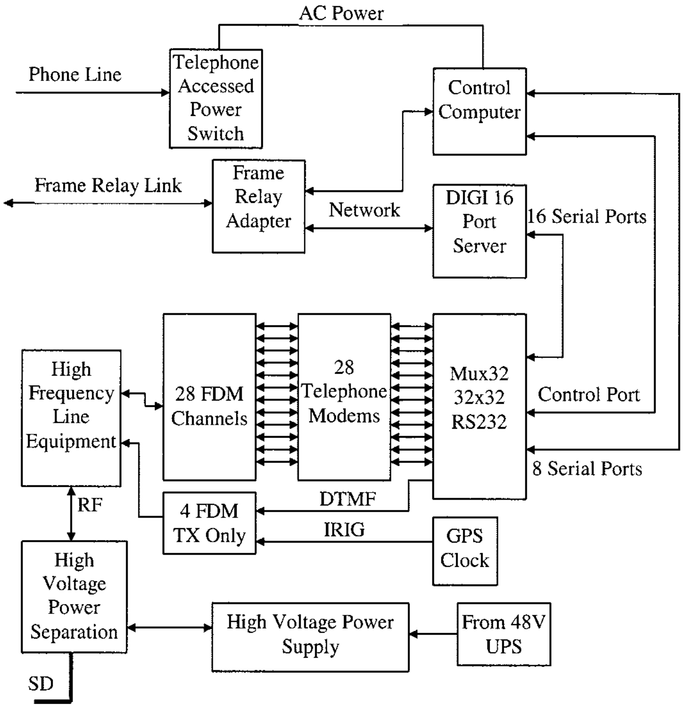

Fig. 6. Block diagram of the H2O shore station electronics.

A control computer at the station continually monitors the H2O system. It is connected to the Internet through a Frame Relay link to the University of Hawaii campus in Honolulu. The control computer is Web-accessible by any authorized computer through a remote control software package. Nine of the control computer's ten available serial ports connect to the MUX32 for normal control and monitoring functions. The tenth port is connected to a back-up DTMF generator as a fallback. Graphical User Interface (GUI) software running on the control computer affords the operator a logical and easily controllable system view of H2O.

The MUX32 provides all the capabilities required by the control computer to manage the seafloor and shore-based subsystems. In addition to acting as a fully configurable crosspoint switch between H2O modem channels and frame relay serial ports to the outside world, the MUX32 also includes DTMF control channels and modem monitoring functions. The MUX32 system consists of a control board and eight port boards. Each port board has 8 RS232 serial ports for a maximum of 32 A-side and 32 B-side ports. The design is modular so that ports can be added in multiples of 8 up to a maximum of 32. The system is wired with two main signal buses, a control bus, and a daisy chained serial data I/O channel. The boards are laid out in such a way as to allow the TX bus from the A-side to line up with the RX bus from the B-side and vice versa. This arrangement simplifies the physical placement of the boards and connections to the bus cable. A control board with an onboard microcontroller provides a simple serial interface to the user and all the control signals to the port boards. The system is set up so that any port on the A-side can receive from any port on the B-side and vice versa. This allows multiple ports to receive from one port (broadcast). The MUX32 also can read the DCD status of the serial ports, which allows it to check whether a modem is connected. The MUX32 also includes a DTMF tone generator for commanding both the local and the seafloor supervisor boards.

Visual Basic was chosen as the programming language for the control computer GUI because of its simple development environment. The H2O system is complex so the interface had to be as simple as possible to avoid inadvertent (and potentially damaging) operator actions. The logical approach was to make the user screen look like a block diagram allowing the operator to see the whole system at a glance. Each block of the diagram, or node, is associated with a component in the H2O system. The nodes are manipulated by the mouse pointer with each action resulting in one or more control codes being sent. Clicking on one of the nodes might, for example, power on/off a component or change the signal routing through one of the systems three-signal multiplexers. The results of an action are immediately displayed on the screen. Eight general-purpose text windows are provided for modem initialization, debugging, or programming. The text windows also work as a terminal window to a serial port.

Modem dropouts due to noise or other causes have been a fact of life for H2O, happening on average about once a day for 19.2-kb/s connections. The control software is able to detect these dropouts and automatically reconnect dropped modem pairs. The response of the system to modem dropouts is user-configurable through a pull down menu on the control system GUI. With the use of data buffering in the user's instrument and short reconnect times data loss due to modem dropouts is rare.

The operating system running on the control computer is Windows 95. Since applications running on this OS lock up occasionally, the system is designed to survive crashes gracefully. All configuration information is stored on the hard disk. In the event of a crash or lockup, the computer can be power cycled via a telephone line power switch. The OS is set up to boot without user input and all necessary programs restart automatically. Since H2O system hardware does not depend on the control computer input for normal operation, it is unaffected by the outage.

IX. H20 DEPLOYMENT

The H2O junction box was installed in September 1998 using a large U.S. oceanographic research vessel (R/V Thomas G. Thompson) and the Woods Hole Oceanographic Institution ROV, Jason. The installation site was selected based on prior site survey data to be approximately halfway between the lay positions of repeaters to minimize the possibility of damage while handling the SD cable. Navigational tools available at the time the cable was laid produced position uncertainties of a mile or more, but since the cable trends roughly east–west, a line starting well south of the presumed location and running north was certain to cross the cable.

The Jason ROV, operated by the Deep Submergence Laboratory at Woods Hole Oceanographic Institution, was used to locate and cut the cable. During the first Jason survey line, the cable was found about 0.75 nm south of its nominal position lying completely exposed due to the extremely low sedimentation rate in the area. Once the site environment had been inspected, the ROV preceded about one water depth ($\sim$5 km) to the east, and using a hydraulic tool, cut the cable. This offset was required so that the cable would not slip out of the grapnel during subsequent recovery operations.

Next, a grappling operation was carried out using the ship's 9/16-in trawl wire and a telecommunications-standard flatfish grapnel to bring the SD cable to the surface. Again, a south-to-north line was steamed to pass over the cable at the observatory site. This resulted in hooking the cable one water depth west of the cut and raising a bight of cable to the surface. The bight of cable was brought aboard the ship through a purpose-built stern chute using a secondary, deck-mounted winch.

Once aboard the ship, both legs of the SD cable were stopped off, the grapnel was removed, and the SD cable was cut at the bight. Measurements were made to determine which leg of the cable was connected to the Hawaii shore station, and the other leg was discarded over the side. The recovered cable was spliced to the termination frame's pigtail using standard telecommunications industry techniques. For the next four days, the complete system was tested and tuned with the cable over the side. Once testing was complete, the cable termination was maneuvered over the stern to be lowered to the seafloor on the end of the trawl wire through a set of acoustic releases. During this operation, the 1/2-in chain holding the load on the acoustic releases failed, sending the cable and termination plunging to the seafloor. The resulting pile of cable was surveyed using a towed camera system and the termination frame was found to be intact, upright, on top of the cable pile, and within 2 m of open seafloor. Though the termination frame was undamaged, its final location was about 2 km west of the intended installation site.

The junction box itself was also deployed using the ship's main trawl winch. It was overboarded on a 30-m length of polyester line using a secondary, deck-mounted winch (Fig. 7). Once in the water, the main winch wire was attached to the polyester line via acoustic releases and the load transferred to the ship's winch. This polyester soft tether served multiple purposes. First, it allowed the main wire to rotate without introducing hockles when the load on it was released as the junction box landed on the sea floor. Second, it enabled slack to be paid out after sea floor contact without the heavy steel wire contacting the junction box, and finally, it kept the releases away from the junction box, giving them proper vertical orientation and a clear acoustic path to the ship. A 12-kHz pinger and a relay transponder were clamped to the wire above the junction box. The pinger provided an accurate distance to bottom, and the transponder provided accurate location relative to the termination frame. The ship employed its dynamic positioning system to hold station over the termination during lowering. When the pinger indicated distance to bottom of a few tens of meters, the ship maneuvered to position the junction box within 10-m horizontal distance of the termination. Once acoustic navigation showed proper positioning, the junction box was set on the bottom. The pinger record, the acoustic navigation coordinates, and a decrease in wire tension confirmed touch

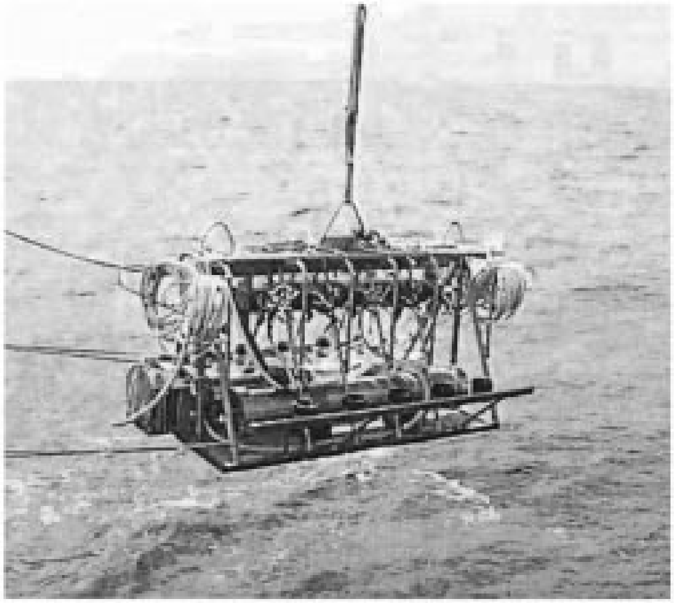

Fig. 7. Junction box ready for deployment.

down. At this point, the acoustic releases were fired, and the ship's wire retrieved. The soft tether was later disconnected by the Jason ROV and returned to the surface.

Recovery of the junction box is accomplished by the Jason/Medea ROV system. The Jason vehicle is connected to a second depressor weight vehicle (Medea) by a neutrally buoyant tether. Medea, in turn, is suspended from the ship via a 17-mm steel-armored fiber-optic cable. Although the ROV lacks the power or tether strength to lift the junction box, Medea's armored cable is capable of that task. In preparation for the recovery, a 30-m length of Spectra line with a large snap hook is attached to Medea. This line is carefully coiled into a releasable container, and the snap hook engaged in a release that can be opened from the ship. The first step in junction box recovery is powering down the SD cable system. Once power is off, the Jason vehicle disconnects instrumentation from the junction box and the junction box from the termination. At this point, the ROV moves to the side, and the release on Medea is fired, dropping the snap hook. Jason grasps the snap hook, attaches it to the lifting bail on the junction box, and once again moves out of harm's way. The junction box, Medea, and Jason are then raised to the surface. Once the ROV and Medea are aboard, the Spectra is transferred to the deck winch and the junction box brought aboard. To date, the junction box has been recovered three times using this procedure.

About two months after installation in 1998, the ULF seismic package failed due to catastrophic flooding of its current meter. In September 1999, the H2O site was visited to replace this package and install some upgrades to the junction box to improve performance. A separate high-frequency hydrophone was also added to the instrument suite. The H2O system and sensors have operated continuously since this time. Seismic data from H2O are archived at the IRIS Data Management Center in Seattle and are freely available to scientists around the world.

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Andrew Bowen, photograph and biography not available at the time of publication.

Dana Yoerger, photograph and biography not available at the time of publication.