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The development of a unique Deep-Towed Array Geophysical System (DTAGS) is nearing completion at the Naval Ocean Research and Development Activity (NORDA). Newly developed hardware for the system includes a low frequency sound source, multichannel hydrophone array, and a high data rate telemetry system compatible with operating in the deep-ocean environment. The system is towed near the bottom (altitude of 100 m) in the deep ocean (design depth 6000 m) and provides the capability to determine detailed geophysical character

of the sea floor and the upper subbottom structure (acoustic penetration of 500 m).

The sound source located in the deep-towed vehicle consists of a Helmholtz resonator projector and a 16-kVA power amplifier system. The source operates over an acoustic band of 260 to 650 Hz with a peak source level of 201 dB//1μPa @ 1 m.

The multichannel hydrophone array attached as a tail to the deep-towed vehicle is an oil-filled hose design with 24 active groups spaced over its 1000-m length. The telemetry system is a duplex digital configuration capable of communicating over the 9150-m coaxial tow cable. The uplink system operates at a 1.5 M bit/sec rate and the downlink operates at a 10 bit/sec rate.

This paper discusses the total hardware suite for the deep-towed geophysical system; a detailed description of the sound source, hydrophone array, and telemetry system; and reviews a recent field engineering test during which the system was operated at a depth of 4500 m.

NORDA Report 71

Deep-Towed Array Geophysical System (DTAGS): A Hardware Description

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April 1984

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Foreword

The development of the Deep-Towed Array Geophysical System (DTAGS) is nearing completion at NORDA. The system will provide the marine science community with a new deep ocean measurement capability to determine the detail geophysical character of the sea floor and near subbottom structure. This report describes the characteristics of major DTAGS hardware subsystems, summarizes system specifications, and provides the ocean technologist and scientific user with a definitive description of the hardware performance capabilities.

G. T. Phelps

G. T. Phelps, Captain, USN
Commanding Officer, NORDA

Executive Summary

The development of a unique Deep-Towed Array Geophysical System (DTAGS) is nearing completion at NORDA. Newly developed hardware for the system includes: a low frequency sound source; a multichannel hydrophone array; a high data rate digital telemetry system; a microprocessor-controlled, dual tape transport, digital data record system; a real-time engineering sensor display system; a short baseline navigation system; deployment/retrieval tow vehicle handling system; and portable instrumentation vans. The system is towed near the bottom (altitude of 100 m) in the deep ocean (design depth 6000 m) and provides the capability to determine detailed geophysical character of the sea floor and upper subbottom structure (acoustic penetration depth of 500 m). This publication describes the characteristics of the major DTAGS hardware suite and reviews a field engineering test during which the system was operated at a depth of 4500 m. A list of system specifications is included.

Acknowledgments

The authors are indebted to other NORDA project members for their technical contributions in the successful development of DTAGS: Mr. John Cranford, Dr. Norman Gholson, Mr. Richard Wilkinson, Dr. Darrell Milburn, Mr. Bruce Eckstein, Mr. George Moss, Mr. Allen Albrecht, Ms. Christine Mire, and Dr. Charles Rein. Thanks are extended to Dr. Charles Alexander who participated in the development but is presently not employed by NORDA. The development of the sound source transducer was performed by the Naval Research Laboratory, Underwater Sound Reference Detachment. The principals responsible for this successful development are also recognized for their outstanding efforts: Mr. A. M. Young, Mr. A. C. Tims, and Mr. T. A. Henriquez.

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Illustrations

Deep-Towed Array Geophysical System (DTAGS): A Hardware Description

I. Introduction

The Naval Ocean Research and Development Activity (NORDA) carries out research and development in ocean science and technology to understand the effects of ocean environment on Navy systems and operations. Specifically, one area of responsibility is developing definitive models of the ocean floor and subbottom as a transmission medium that refracts, defracts, and dissipates, as well as reflects acoustic energy. These models are used to predict and thus improve the performance of naval systems. Critical for development of these models is high-resolution data to describe the geological, geophysical, and geoacoustic character of the deep ocean sea floor (6000 m) and upper subbottom structure (500 m). This high-resolution data can be obtained using a low-frequency sound source and multichannel hydrophone array system, as depicted in Figure 1, capable of operation in the proximity of the bottom (altitude of 100-500 m). The fundamental advantage of this deep-towed system, as opposed to a surface-towed system operating in a deep ocean environment, is simply that the measurement system is much closer to the geophysical feature being investigated.

A development program, entitled "The Deep-Towed Array Geophysical System" (DTAGS), was initiated by NORDA in 1980 to produce a deep-towed hardware suite to meet this deep ocean measurement

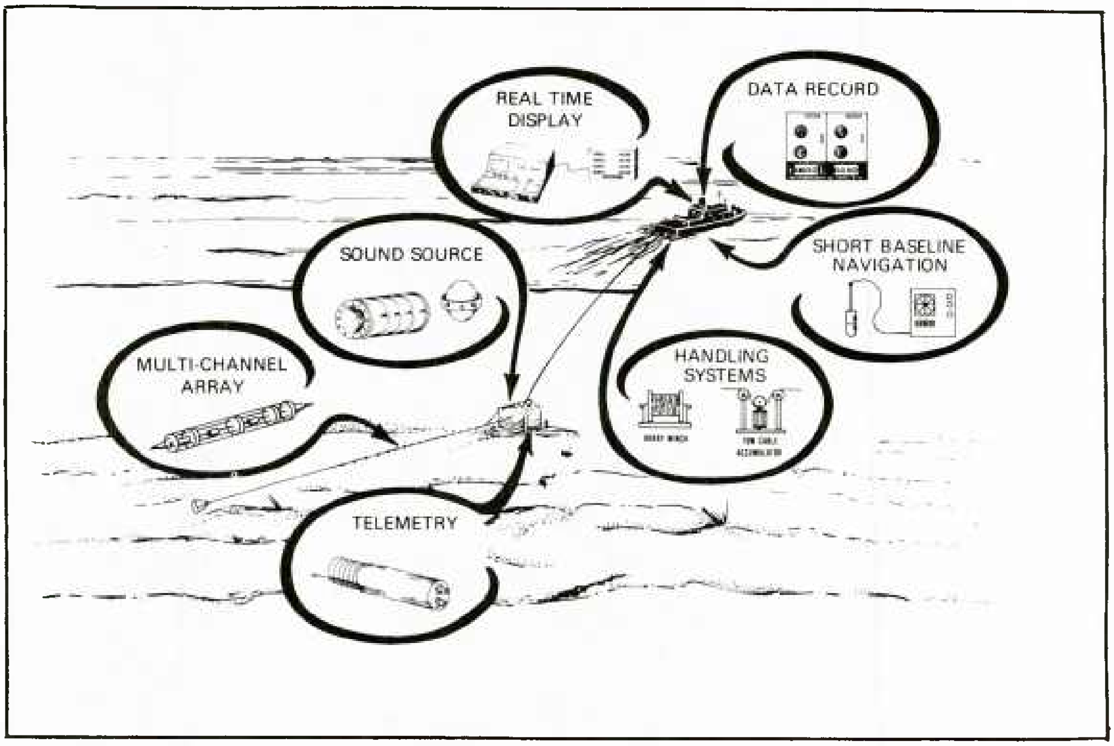

Figure 1. System tow configuration and major subsystems

requirement. System studies were performed by Milburn (1979), Fagot (1980 and 1981), and Gholson (1983) that predicted substantial improvement by implementing the deep-towed concept. The initial effort focused on developing and testing the sound source system (Fagot, 1982). Subsequent effort concentrated on developing the multichannel hydrophone array and high data rate telemetry system. These systems were integrated with the sound source system and sea tested to a depth of 4500 m during the summer of 1983. The present effort focuses on completing the development of a digital data record system and short baseline navigation system. The total system will be integrated and an engineering evaluation sea test performed in the summer of 1984. Upon completing this test, the system will be available for geophysical research.

This paper discusses the total hardware suite while focusing on a detailed description of the sound source, hydrophone array, and telemetry system. A summary of system specifications is given in the Appendix. The paper concludes with a review of the 1983 sea test.

II. Hardware Description

The system concept, towed sound source and array, is similar to the present configurations used by the marine oil exploration community with a prime distinction--the system is required to operate at tow depths down to 6000 m and at altitudes of 100-500 m above the bottom. The major subsytems are depicted in Figure 1. The sound source transducer and power amplifier system, telemetry system, and associated electronics are located within a deep-towed vehicle (fish) towed at the head of a multichannel array. The deep-towed system is tethered to the tow ship with a 9150 m long coaxial steel tow cable. A duplex digital telemetry system communicates via the tow cable with the deep-towed system. Data from the fish system is then digitally recorded at the tow ship. Monitoring of system performance is through a real-time display system. This system monitors critical engineering parameters of the fish system and also provides displays of selected acoustic channels for quality control. The position of the fish relative to the tow ship is provided by a short baseline navigation system. Global position is obtained through satellite and Loran-C navigation. A tow cable heave accumulator and an array handler winch constitute the system handling hardware. The operation systems are located in a portable van with a maintenance facility and spares storage located in a second van. Figures 2 and 3 are block diagrams showing the interconnect relation of the major subsystems. The component designs of these major subsystems are optimized to meet the basic geophysical data requirement while still maintaining a hardware suite that can be easily deployed, operated, and maintained.

A. Sound Source System

A deep ocean sound source system has been developed and tested for the deep-towed geophysical system. The implementation of this system provides the deep geophysical system with a unique but necessary capability, that being a low frequency deep-towed source capable of providing sufficient energy to acoustically penetrate the subbottom structure.

The sound source system hardware consists of a piezoelectric Helmholtz resonator sound source and power amplifier. Since it is not practical to drive the source with a power amplifier via the long tow cable (due to the high-power losses in the cable), the amplifier was designed and packaged for operation at full ocean depth. Figure 4 shows the Helmholtz transducer sound source mounted in its shipping cradle. The power amplifier is shown in Figure 5 with the upper hemisphere of its pressure housing removed. The sound source and power amplifier are mounted together in the

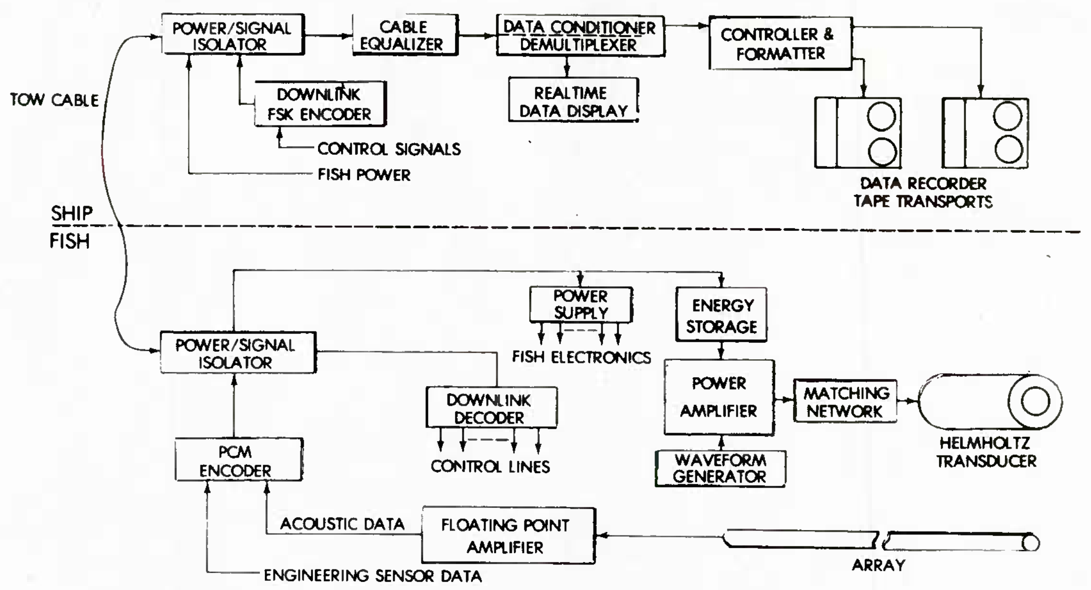

Figure 2. Deep-towed hardware configuration

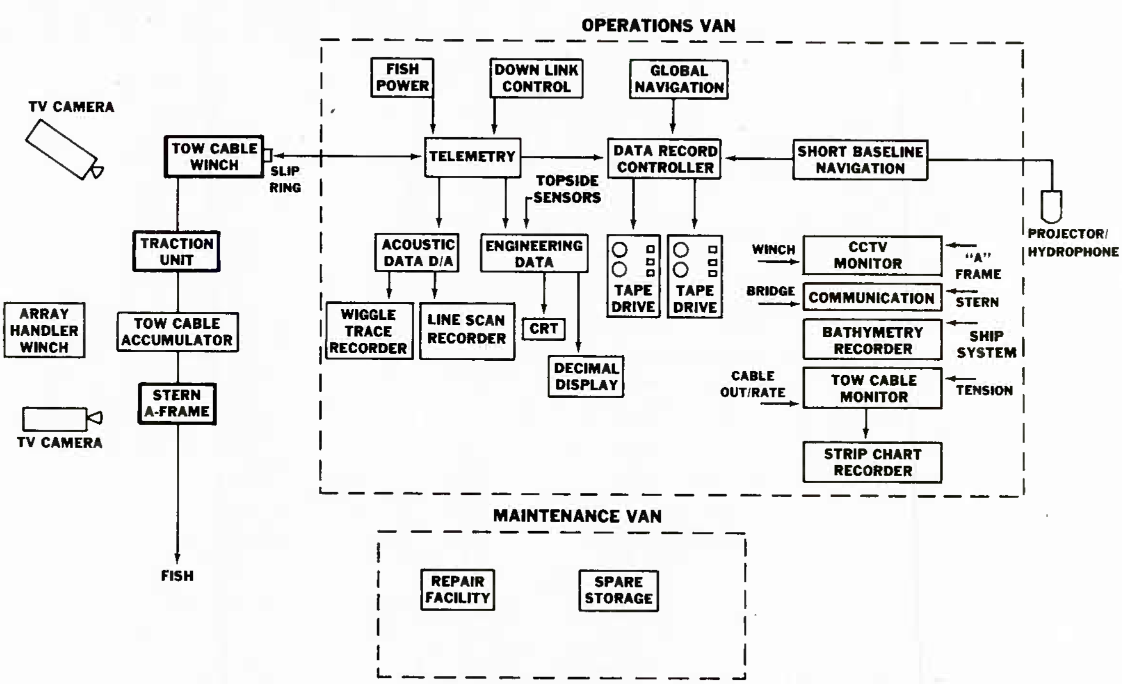

Figure 3. Topside systems

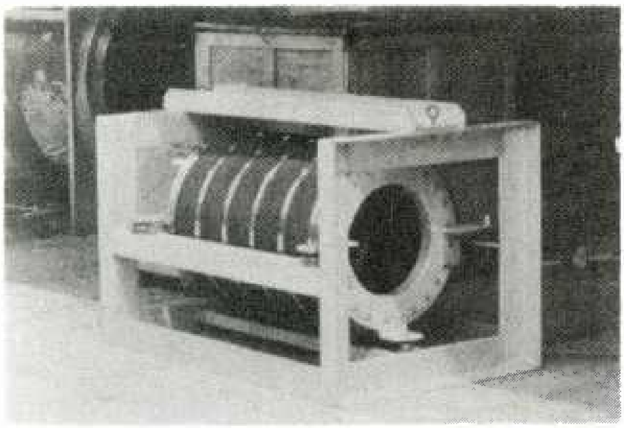

Figure 4. Sound source Helmholtz transducer in shipping cradle

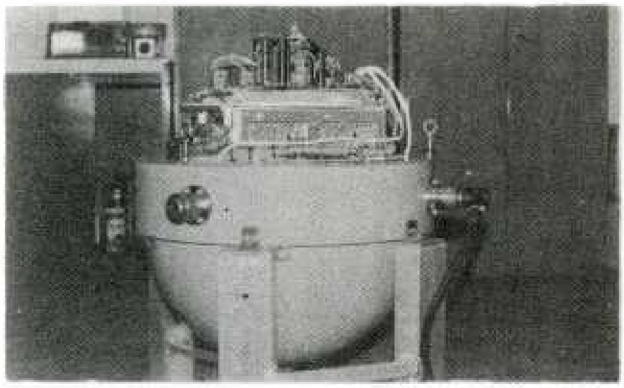

Figure 5. Sound source power amplifier

deep-towed vehicle as shown during deployment in Figure 6.

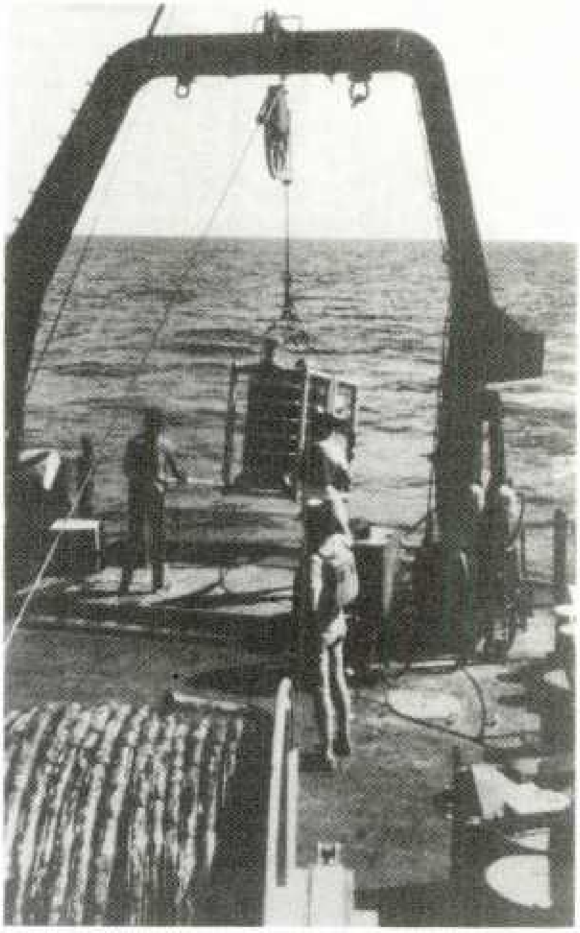

Figure 6. Deep-towed fish during deployment

A Helmholtz resonator transducer was selected as the acoustic source for the sound source system. The primary reason for the choice of the Helmholtz resonator transducer was keyed to the system operational depth requirement of 6000 m. This transducer's operation is independent of depth due to its basic oil-filled design. Other requirements of the system called for a nominal sound pressure level of 201 dB//1μPa @ 1m, and a useful bandwidth of 200 Hz in the 200-500 Hz frequency range. Also, size constraints, a towable package, imposed on the source system supported the choice of a Helmholtz resonator transducer. The design, development, and fabrication of this transducer were performed by the Naval Research Laboratory, Underwater Sound Reference Detachment, and is decribed by Young (1982).

The sound source system is capable of full performance from near surface to full ocean depth. The system is capable of a nominal peak source level of 201 dB//1μPa @ 1 m. This level can be achieved over a frequency range from 260 Hz to 650 Hz. Directivity over this range of frequencies is omnidirectional. Output pulse length is programmable from 5 ms minimum to a maximum of 250 ms in duration. The system is capable of a full power 250 ms output pulse once every 12 sec. The transmitting voltage response of the sound source system is shown in Figure 7.

The transducer consists of a Helmholtz cavity and orifice driven by five piezoelectric-segmented ceramic ring drivers. One surface of the ceramic ring drives the Helmholtz cavity, while the other surface radiates into the medium. At the Helmholtz resonance frequency (260 Hz), radiation from the orifice and exposed surface are in phase, thus, boosting the low-frequency response of

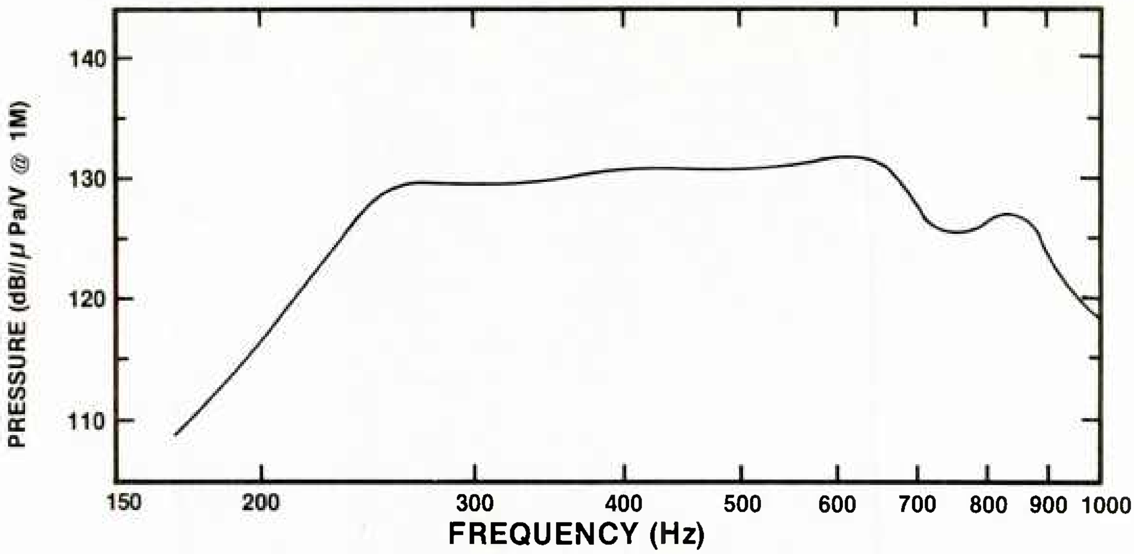

Figure 7. Sound source transmitting voltage response

the ceramic driver. This low-frequency response combined with the natural higher frequency response of the ceramic driver produces a relatively broadband, high-level acoustic signal. As built, the transducer is approximately 0.7 m in outside diameter, 1.1 m long, and weighs 800 kg. The transducer assembly consists of approximately 275 kg of lead-zirconate-titanate piezoelectric ceramic divided into five segmented rings. The ceramic rings are individually supported by metal rings that are fastened to form the "exoskeleton" of the transducer. Elastomer boots are installed on the outside and inside diameters and the intervening cavity filled with castor oil.

Prior to proceeding with the fabrication of the Helmholtz resonator transducer, an exact scale model was designed and fabricated to evaluate the proposed conceptual design. The development of the working model demonstrated the feasibility of untested assembly and fabrication techniques. This effort resulted in a scale model sound source capable of operating to full ocean depth at frequencies of 1100-2600 Hz at a nominal source level of 186 dB//1μPa @ 1 m. This transducer is approximately 23.5 cm long and 16.5 cm in diameter.

A Class S switching amplifier was chosen as the driver for the Helmholtz resonator transducer. The primary reason for this choice was the limited space available for electronic hardware on the tow vehicle. A linear amplifier such as a Class B would require more than twice the volume of the Class S for the same output power. The Class S power amplifier system previously shown in Figure 5 weighs approximately 232 kg (including pressure vessel) and is housed in a 0.6 m diameter spherical pressure vessel. Due to the inefficiency of a deep water broadband sound source the power amplifier is required to deliver 16 kVA of reactive power. Other requirements of the system called for control of output waveshape and frequency. Also, due to inaccessibility and remote location of electronics during an at-sea operation, reliability of the power amplifier was of prime concern. The design, development, and fabrication of the power amplifier were performed by NORDA.

The power amplifier system located at the tow vehicle consists of a waveform generator, power amplifier modules, energy storage bank, and a load matching network. Four drive waveforms are stored in an erasable programmable read only memory (EPROM) that is programmed prior to deployment. Selection of the source drive waveform, along with the source firing key signal, is accomplished via the downlink telemetry system. Energy for the high-power output pulse is stored in a 0.132-F capacitor bank. This bank is trickle charged between pulses at an average rate of 300 W via the tow cable. The power amplifier module controls the power drive level and waveshape supplied to the Helmholtz resonator transducer. Power transfer to the source is optimized through the load matching network that consists of a power factor correction network and an impedance matching transformer. The matching network is housed in a separate pressure vessel.

Commercially available 1 kVA power amplifier modules are used as the basic building blocks for the power amplifier system. Sixteen of these units are integrated to form the 16 kVA power section. All circuit components for a 1 kVA Class S module are mounted on a printed circuit card measuring 16 cm wide by 31.4 cm long. Each module is a complete amplifier in itself, requiring only a DC power source and drive signal. The 16 modules are combined by connecting the secondaries of the individual on board transformer in series. The amplifiers are configured such that if a module fails the system continues to operate at a reduced power level. For example, if one amplifier output stage fails the 16 kVA system will operate at 15/16 of maximum capacity, or a 0.56-dB reduction in source level. The power amplifier system is designed to fail-safe when open circuit, short circuit, and overtemperature conditions exist.

B. Array System

The array design selected for the deep-towed geophysical system is a multichannel hydrophone array similar to the type used by the marine exploration community. The standard oil-filled design, hose, spacers, and oil-emersed electromechanical coupling presently used are compatible with high operating pressures. The array is 1000 m long consisting of 12 active sections containing a total of 48 hydrophone groups. Only 24 groups will be used for a specific configuration to reduce the telemetry data rate requirement. A 2-m interconnect section is located at the head of each 82-m active section. The interconnect sections contain heading sensors, depth sensors, and hydrophone preamplifiers. Each active section contains four hydrophone groups. Figure 8 shows the array on the handler winch.

The array design is optimized to operate at tow depths in the 3000-6000 m depth range. Neutral buoyancy is attained by adjusting the amount of fill oil to attain a stable tow attitude. Additional tow stability is achieved by attachment of a drogue parachute to the array tail swivel. Future plans call for a drogue release at the tail in the event the drogue snags on the sea floor and to aid in retrieving the array. The head of the array is attached to the tow vehicle by a 50-m, oil-filled stretch section that provides mechanical isolation from the deep tow vehicle. The stretch section interfaces electrically to an oil-filled junction box that allows for easy field selection of the array acoustic channels.

The array mechanical construction is typical of the type used in the marine exploration community. The array strength member consists of steel wire rope and (lexan) spacers except for the stretch section in which nylon rope replaces the steel strength members. The array is sheathed with a transparent polyurethane jacket housing the array chassis and fill oil. Isopar L is used for the fill oil. Each 82-m active section has an outside diameter of 4.61 cm, the 2-m interconnects are either 7.62 cm or 10.16 cm depending on the sensor suite, and the stretch section has a diameter of 6.6 cm. The entire array is designed to have a tensile strength greater than 910 kg for a maximum tow speed of 1.5 m/sec (3 knots).

The array acoustic design is tailored to the deep tow geophysical system operational performance requirements. Forty-eight hydrophone groups are spaced uniformly along the array with a 21-m

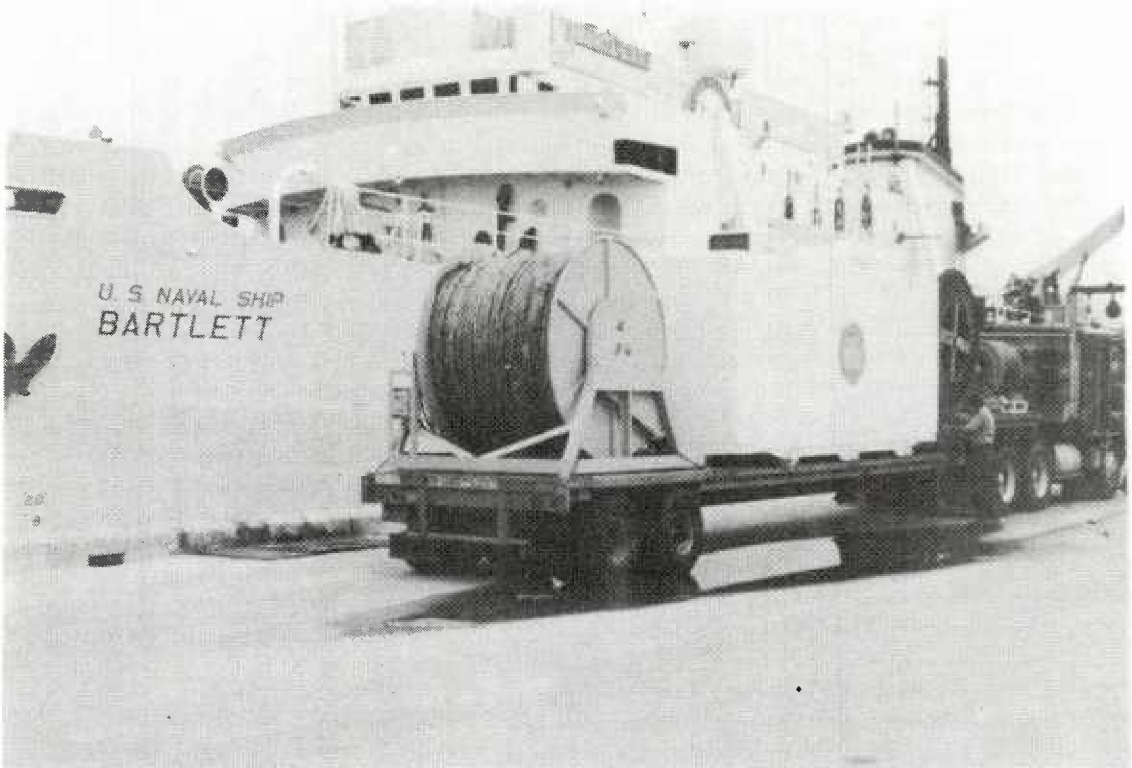

Figure 8. Array handler winch and operations van

separation between adjacent groups. Each hydrophone group consists of six elements with a total length of less than 60 cm. The individual hydrophones are of a piezoelectric cylinder type that are tolerant to the high operating pressures. Outputs of the hydrophones are connected to the preamplifiers located in the 2-m interconnect section at the head of the associated active section via a twisted pair shielded cable. Placement of the preamplifiers in a short interconnect section was chosen for easy access and field repairability. Because of the large separation between the hydrophone group and preamplifier (approximately 74 m for the last group of each active section) and the low group capacitance, a balanced input charge amplifier is used for the preamplifier to accommodate these conditions. The combined sensitivity of an acoustic channel (hydrophone group plus preamplifier) is a nominal -150dB//1 V/μPa with a frequency response from 150-1000 Hz. The bandwidth is limited by filters in the preamplifier and can be opened to a band ranging from 10-2000 Hz by appropriate component changes in the preamplifier. The self noise of each acoustic channel is less than 35 dB (// 1μPa/$\sqrt{Hz}$) over the operating frequency band, which is less than deep ocean Sea State 0 ambient noise. Each channel preamplifier has a built-in calibration oscillator with a unique frequency that provides easy channel identification and an in situ functional check of the entire acoustic channel including the hydrophone group. Gain of the preamplifiers can also be lowered 20 dB by an external control signal.

The array is equipped with a suite of engineering sensors to measure array tow dynamics such as array shape, tension, and tow attitude. Each interconnect section contains a depth sensor with a relative precision of better than 1 m and an absolute depth accuracy of 3 m over the entire operating depth. Four heading sensors are spaced uniformly over the array length with a resolution of 0.35° to represent array shape in the horizontal plane. A load cell at the head of the array is used to monitor in-line array tension in real time. During the next engineering test accelerometers will be installed in an interconnect section near the head of the array. The accelerometers will be of a potentiometric type to measure low frequency mechanical isolation from the tow fish and to characterize the array stretch section performance.

A 672 m long array of the type described was tested during the summer of 1983. This array consisted of eight active sections giving a total of 32 acoustic channels. The array was towed at an operating depth of 4500 m at a tow speed ranging from 0.25 m/sec to 1.0 m/sec (0.5 knots to 2 knots) in Sea State 2 conditions. With these operating conditions, the array stabilized in the vertical plane with a 15° tilted down attitude, measured with no tail drag. Acoustic channel performance allowed for the recording of reflection profiling data described in more detail later. System tow noise measured to be a nominal 65 dB ($//1\mu Pa/\sqrt{Hz}$) over the operating frequency band and channel to channel crosstalk was less than -70 dB. A plot of noise spectrum level for a single hydrophone group measured at a depth of 4400 m during this field test is shown in Figure 9. The group noise level is compared against a typical deep water ambient spectrum level for the Sea State 2 conditions experienced during the measurement. Plans call for testing of the entire 1000-m array (48 channels) during late summer of 1984.

C. Telemetry System

The telemetry system for the deep-towed geophysical system provides full duplex communication between the tow ship and the tow vehicle via a 9150-m coaxial tow cable. System requirements call for a data transfer rate of 1.5 M bit/sec. Constraints of ocean engineering require the tow cable to be free of repeaters; therefore, cable equalization at the tow ship is used. The telemetry system is capable of handling tow fish power (300 W) down the cable as well as the 1.5 M bit/sec pulse code modulation (PCM) uplink data and low data rate FSK downlink control signals. The acoustic signals from the towed array are digitized by a floating point amplifier at a 3125-Hz sample rate. The FSK downlink control

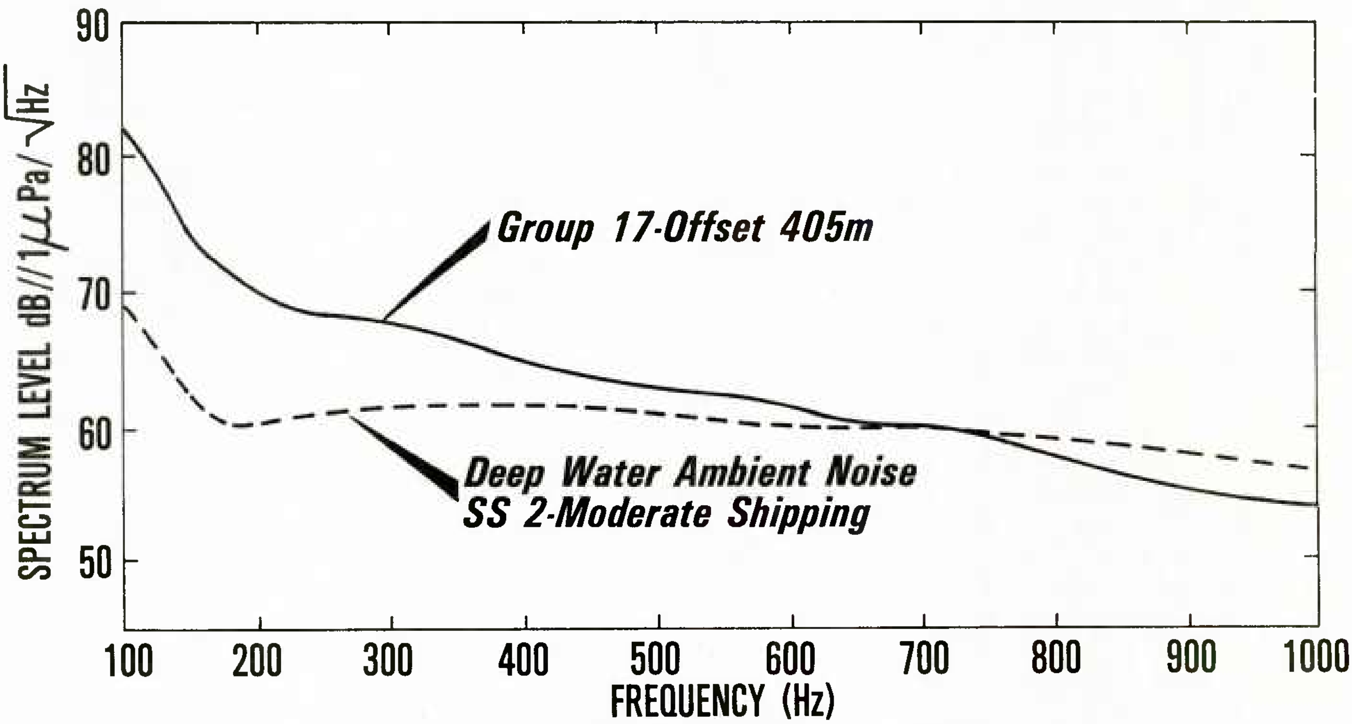

Figure 9. Array spectrum noise level measured at a depth of 4400 m

system operates at a 10 bit/sec rate. The telemetry equipment contained in the tow vehicle includes the PCM encoder and FSK decoder electronics as shown in Figure 10. The cable equalization circuits are located on the tow ship.

The FSK downlink system provides transmission of 23 command bits to the tow fish. Also provided is the transmission of a key pulse to trigger the Helmholtz resonator sound source. The transmission of the command bits is initiated by either a key pulse or by command of the operator. The command and key pulse bits along with the synchronization bits are transmitted serially to the deep-towed vehicle using 10,960 and 11,210 Hz mark and space tones. The tow fish FSK decoder circuits demodulate these signals and convert the command and key pulse bits to parallel form to control the tow fish systems. The command bits received on the tow fish are echoed to the surface via the PCM uplink system for command verification.

The PCM uplink system provides 30 16-bit multiplexed channels for data transmission from the deep-towed vehicle to the tow ship. Twenty-seven of these channels are utilized for the transmission of acoustic channel data that has been digitized by a common floating point amplifier. The floating point amplifier samples each of the analog channels 3125 times per second and computes a 16-bit representation of the analog channel sampled value. The digital representation consists of a 12-bit mantissa and a 4-bit exponent. Each of the 27 acoustic channels is interfaced to the telemetry system by a balanced input instrumentation amplifier. The output of the amplifier is connected to an active eighth-order Bessel low pass filter having a cutoff frequency of 800 Hz. The 27 analog channels are then sequentially digitized by the floating point amplifier. The digital outputs of the floating point amplifier are time division multiplexed with two 16-bit frame synchronization words and a submultiplexed engineering sensor channel to form a frame containing 30 16-bit words. This data stream is Manchester encoded and transmitted to the surface via the tow cable.

The submultiplexed engineering sensor channel is capable of handling 256 sensor channels. The channels have a sample rate of 12.2 Hz with a 16-bit channel data word consisting of an 8-bit address followed by an 8-bit data word. The commands received by the FSK downlink system are echoed using three of these subchannels. Data such as the array depth sensors, array heading, and other engineering sensors are transmitted via these subchannels. The subchannels are also used to transmit subsystem operational status for real-time monitoring by the system operator.

The cable interface circuits provide power isolation for power transmission to the tow fish, signal separation for full duplex operation of the FSK downlink control channel and the PCM uplink data channel, and equalization of the cable attenuation characteristics for the PCM uplink channel. The cable interface at the tow fish consists of a power

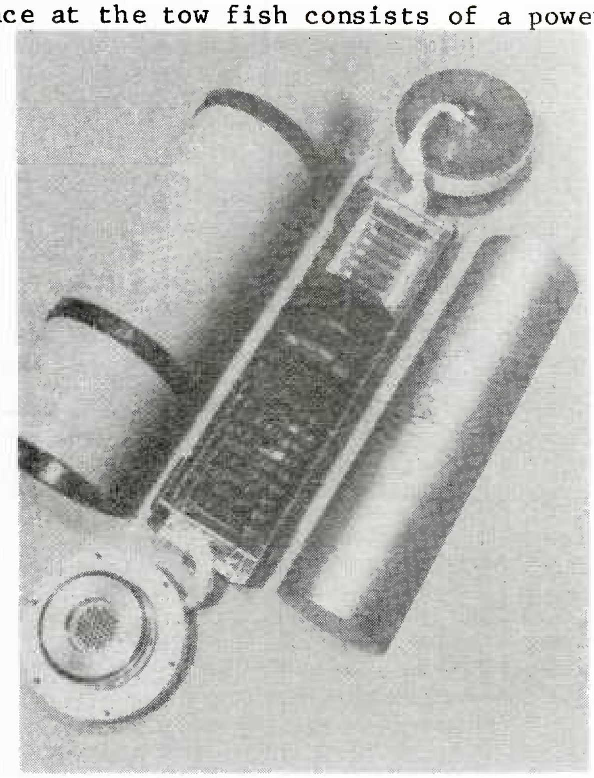

Figure 10. Telemetry chassis and pressure vessel

isolator, a diplexor, and the cable driver. A power isolation circuit block DC voltage from the signal diplexor. The diplexor consists of a low pass filter that passes the downlink FSK signal while presenting a high impedance to the PCM uplink, and a high pass filter that represents a high impedance to the downlink FSK signals. The coaxial tow cable is driven by a 5-V bipolar Manchester encoding of the 1.5 M bit/sec PCM signal.

The top side cable interface consists of a power isolator and a diplexor as in the tow fish cable interface. Also included in the top side interface are the cable equalization circuits, which compensate for the attenuation across the signal bandwidth of the tow cable. The tow cable has electrical characteristics that are similar to RG-8U coaxial cable and exhibits an attenuation of 1.85 dB per 305 m at 1 MHz. The equalizer input is first amplified, then passed through bridged-T lead-lag filter sections. The output of the second section is amplified and passed through a third lead-lag section. The output of this section is again amplified and passed through a high pass filter section. A final gain stage precedes a comparator that squares the resulting signal. The PCM signal is then interfaced to the data record system and a D/A converter provides real-time monitoring of eight acoustic channels.

The telemetry system was integrated with the deep-towed system and tested during the summer of 1983. The system successfully transmitted deep ocean geophysical reflection data via a 7000-m tow cable during the field evaluation. The data was transmitted at a rate of 1.5 M bit/sec and received essentially error free. The quality of the data was not compromised by the telemetry system due to low equivalent input noise and good channel-to-channel gain accuracy. Plans call for the integration of the telemetry system with a 9150-m tow cable for the field test planned in the late summer of 1984.

D. Data Record System

The data record system provides the capability to record the high data rate and large volume of data generated by the deep-towed system. The data is tape formatted in the Society of Exploration Geophysicist's SEG-D (Demultiplexed) as defined by Society of Exploration Geophysicists (1980). This format is accepted and used by the geophysical community in both the government and private sectors--commercial and academic. The format provides the flexibility through header blocks to record both the global and short baseline navigation parameters simultaneously with the geophysical reflection data. Thus, each data tape will contain all the information required for geophysical processing. The capability is also incorporated into the system design to record the geophysical data word in either the SEG-D 2-1/2 Byte Binary Exponent-Demultiplexed word format or the F_ Floating Point (Single-Precision Floating) word format standard for VAX computers. This is an operator option selected during system turn-on initialization.

The record system consists of a data controller/formatter, I/O operator CRT-terminal, and a dual tape transport system. The controller/formatter subsystem provides the function of: (1) converting the PCM serial bit stream from the telemetry decommutator to the format acceptable to the transport subsystem; (2) formatting the data into the SEG-D (Demultiplexed) or VAX F_ formats; (3) an input buffer/formatter for external RS-232 formatted data to be recorded, such as navigation; and (4) controlling the data record sequence. This latter function includes the flexibility to record engineering and acoustic data at selected intervals either before or after recording the geophysical reflection data. For example, recording acoustic arrival time data to the array for the deep-towed sound source to sea surface reflection path for use in computing array shape would implement this function.

The I/O operator CRT-terminal subsystem provides the function of: (1) initializing record operating parameters; (2) monitoring critical set-up parameters during normal record sequence; (3) an input device for the operator to insert cruise unique parameters; (4) monitoring system diagnostic test; and (4) dumping CRT display listings to an external printer. This latter feature allows a permanent log of record parameters to be generated during the field cruise. The design of the I/O subsystem has been tailored to ease the operator burden. The set-up parameters are given in a set of questions requiring a single keystroke for entry. Critical operating parameters are always available to the operator through the CRT display. These include time, source event number. record length, source repetition rate, unique cruise parameters, and the active tape unit.

The transport subsystem employs standard, high-reliability, dual tape drive. These units record data at a packing density of 6250 BPI and a speed of 125 IPS. Two units are used to allow changing tape without loss of data and to provide a backup for a single transport failure.

The ability to play back prerecorded data is also incorporated into the system. The engineering sensor data for the deep-towed system is extracted from the recorded data tape in a format directly compatible with the engineering realtime display system. Also, up to 8 channels of acoustic array data can be input directly into the real-time D/A converter for display. This playback feature primarily will be used to assess the engineering performance of the deep-towed system. It also will be used to review selected geophysical data for identifying the precise geophysical section to be processed.

E. Real-Time Display System

The capability to monitor the performance of the deep-towed system is provided by a real-time display system. This system, located in the operations van, includes: monitoring, displaying, and recording engineering sensor data from the array and fish located sensors; displaying acoustic array data; monitoring and recording tow ship located subsystem sensor data; and closed circuit television monitoring of the handling systems. Refer to Figure 3 for the following discussion.

The engineering data display system is designed around a desk-top calculator. Data from the telemetry decommutator and topside-located sensors is buffered, reformatted, and processed by the calculator system. Selected data is output to a digital decimal display readout panel in true engineering units. This display panel also includes status indicators, go/no go, for critical subsystem parameters. Display software is specifically tailored for the system operator's convenience to provide display formats, which facilitate operation. Such formats include, for example, array-shaped pictorials derived from depth sensors. This type format is displayed on a CRT screen or dumped to a printer-plotter. A disk storage capability is incorporated in the engineering data display system. This provides the option to record fish and topside engineering data independently of the prime recording system. This option is employed primarily when only the sound source system is required for a scientific experiment (array not used).

Acoustic data from the array/fish system is converted (D/A) for real-time display by such devices as a wiggle trace recorder, line scan recorder, and a conventional spectrum analyzer. This system also provides the ability to monitor sound source signatures. The acoustic data display system provides a real-time quality assurance check on system performance.

Tow ship located subsystems critical to system operation are also displayed and recorded. They include tow cable tension, amount of cable deployed, and the deployment/retrieval cable rate. The bathymetric profile of the tow ship is displayed on a line scan recorder. This data is derived from the host ship's bathymetric profiling system operating simultaneous with the deep-towed system. The bathymetric display provides a preview of large features that could be hazardous for the deep-towed system. This preview allows time for evasive action such as increasing system altitude or performing ship maneuvers. Since the system is normally towed at an altitude of 100-500 m, it is only these large features that are hazards. For example, response time is 1 hr and 45 min to reach a hazard at a tow speed of 0.8 m/sec (1.5 knots) and a tow depth of 5000 m.

A closed-circuit television system is incorporated into the display system. Two TV cameras are employed to monitor the handling subsystem. One unit views the stern lead sheave and provides the operator with constant monitoring of the tow cable lead angles. The second unit views the tow cable winch/traction unit and is used principally during deployments and retrievals.

F. Navigation System

The navigation suite consists of two subsystems: a short baseline system to position the fish relative to the tow ship and a global system to geographically position the tow ship. The output of both systems in RS-232 format is fed to the data record system.

The short baseline subsystem consists of a transponder located on the fish and an interrogating transducer and receiving hydrophone array and an acoustic processor located on the tow ship. This system provides the X, Y, and Z position of the fish. The interrogating system is also capable of receiving inputs from additional transponders for use as a long baseline system. The fish transponder is independent of the other fish located subsystems thereby providing the ability to locate the fish if the situation arises that the tow cable parts.

The global subsystem relies on standard navigation nets such as Satnav and Loran C for positioning. Incorporating the Global Position System will be made in the future if more precise navigation is required.

G. Deep-Towed Vehicle (Fish)

The fish is an aluminum open-framed structure as previously pictured in Figure 6. Since the fish drag is small at low tow speeds (0.5 - 1.5 knots) in comparison to the tow cable, an unstreamlined structure is employed. The fish envelope size is 1.83 mL X 0.86 mW X 1.35 mH. The fish consists of two substructures of approximately equal size.

One substructure houses the Helmholtz transducer shock-mounted to provide vibration isolation. The other substructure houses the sound source power amplifier spherical pressure vessel, two oil-filled junction boxes, motion sensors, a current meter, an array tensiometer, and an acoustic transponder. Three cylindrical pressure vessels containing system electronics are located vertically between the two substructures. These cylindrical vessels can be easily removed for maintenance and repair by separating the two substructures.

An oil-filled interconnect wiring harness and junction box configuration was selected for reliability, ease in maintenance, and to facilitate wiring reconfiguration. Engineering sensors can easily be added or removed and different combinations of hydrophone groups can be selected via the junction box wiring. The array is terminated in its own junction box that can be easily attached to or removed from the fish. The fish engineering sensors are terminated in a separate junction box. An oil-compensated bladder system, positively charged, is incorporated into the design. The bladder helps assure no sea water leakage into the closed system if small leaks should occur. Over pressure valves are used to allow oil bleed-off if expansion occurs, for example, while the system is on deck.

H. Handling Systems

1. Accumulator System

The ship surge motion effects on the towed system are minimized with a tow cable tension accumulator system. This spring-loaded sheave system is adjustable to fish weight and maintains constant cable tension. The unit is primarily effective when the fish system is near the sea surface. The range of loads for a full compensation distance of 1.78 m are from 1818 kg to 5455 kg in 1818 kg increments. The system is rigged prior to fish deployment for the desired maximum load. The size envelope for the accumulator is 0.61 mH X 2.44 mW X 3.35 mL. This system can be configured for either a horizontal or vertical arrangement depending principally on the tow cable traction unit location in relation to the tow point. Incorporated into the system is a cable tension monitoring sensor. The lead sheave, separate from the accumulator system and located at the tow point, is instrumented with a cable-out sensor.

2. Array Handler

The array handler, a large motorized drum (pictured in Fig. 8 along with the operations van), is used for deployment and retrieval as well as storage of the array. The array termination oil-filled junction box, referenced earlier, is housed in a well within the core of the drum. The handler is mounted near the fish deployment area to facilitate array launch and retrieval. Guide rollers are placed at the stern to minimize wear on the array as it passes over the side.

3. Tow Cable

The tow cable is a coaxial-type construction with two contrahelically wound layers of galvanized, high-strength steel wires wrapped around a coaxial cable core. The core has electrical characteristics similar to RG-8U. The steel wire geometry provides a very low cable torsional characteristic. This results from interrelated parameters of wire diameters, wire lay angle, two-layer contrahelical windings, and individual wire spacing. This later parameter provides the reference given this type cable construction, titled, space-armored cable. The low-torsional feature eliminates the need for an electrical-mechanical swivel within the tow cable system. These swivels are generally required for a deep-towed system with high cable torsional characteristics to eliminate hackling (kinks) that can result if cable tension is suddenly reduced, for example, by the fish accidently touching down on the bottom.

4. Ancillary Systems

The host ship provides the deep-sea winch, cable traction unit, and the tow point stern "A" or "U" frame. This set of hardware is generally available on ships engaged in deep-sea geophysical research. The location of the winch/traction units can vary from ship-to-ship. This variation impacts the installation configuration of the accumulator system--horizontal or vertical. The deep-sea winch/traction unit must be capable of smooth and precise control of tow cable movement. Slow, creep, cable in/out speeds are required when lifting the fish off or placing the fish on the deck, and then speeds up to 45 m/min are required for deep deployment and retrieval. The ancilliary units are highlighted in Figure 3 by heavy, broader outlines. The slip ring assembly incorporated into the deep-sea winch for termination of the coaxial tow cable is a part of the deep-towed system hardware suite.

I. Portable Vans

The flexibility to meet a ship-of-opportunity operation scenario is provided by self-contained vans. An operations van and maintenance van are part of the deep-towed hardware suite. The vans are sized to allow air-shipment if necessary.

The operations van houses instrumentation subsystems required to operate the deep-towed system. Figures 8 and 11 are pictures of the operations van. Ship's power is conditioned through isolation transformers and fed to the electronic subsystems. A self-contained air conditioning/heating system is employed. A group of standard instrumentation racks house most of the equipment and non-standard units are bench-top mounted. Communication with critical ship personnel, for example, the stern deployment area, the deep-sea winch operator, and the bridge, is provided through an intercom system.

An electrical-mechanical repair facility is housed in the maintenance van. The van is sized to allow the fish substructure (1/2 of fish) to be moved inside for repair. This van also provides storage for system spares.

III. Engineering Field Test

System engineering tests have been performed with the completion of major subsystems throughout the development of the deep-towed system. The initial field test, principally of the sound source system, was performed in December 1981, close to a year after initiating hardware fabrication. The test successfully demonstrated the sound source system performance to the maximum planned tow depth of 2000-m.

The next major field test was performed in June 1983. This test incorporated the high data rate telemetry system and a 672 m long array. Also included was a redesigned and smaller fish. This redesign reduced the horizontal surface area of the fish thereby reducing the forces on the tow cable. This test was performed aboard the USNS BARTLETT during a

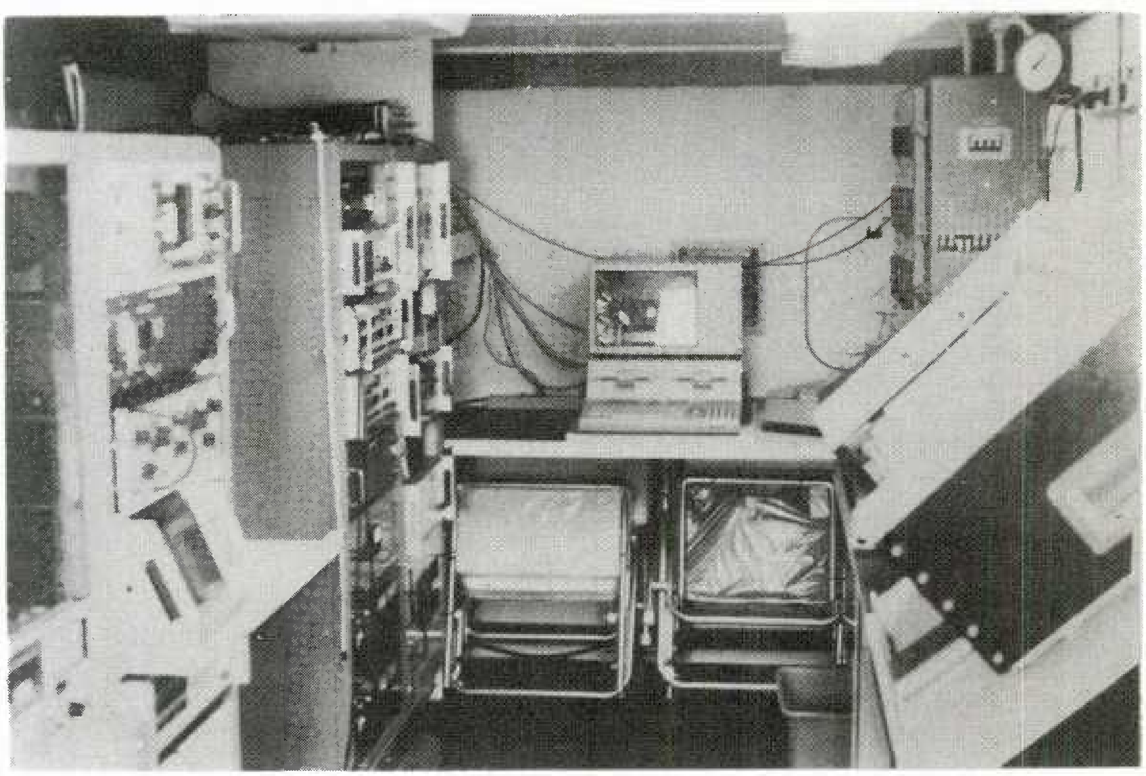

Figure 11. Operations van interior

cruise from Fort Lauderdale, Florida, to St. Croix, Virgin Islands. Figure 12 shows the major subsystem installed on the ship. A series of deployments with and without the array were made.

Figure 13 is an unprocessed reflection profile trace for a single array group offset from the source by a distance of 175 m. The fish/array system was at a depth of 4325 m and at an altitude of 1125 m above the bottom. This trace was produced by generating a composite from multi-passes of analog tape recordings of the uplink serial bit stream. The apparent noise spikes and vertical data shifts resulted from this playback process. As noted earlier, the digital data record system was not available for the test.

The steep slope at the far left of the trace was produced by the system being lowered closer to the bottom, and the steep slope at right resulted from retrieving the system. The gradual slope between these extremes is caused by the fish/array system increasing altitude. An increase in the nominal tow speed of 0.6 m/sec (1.2 knots) produced this result. The change in trace texture midway along the survey track was produced by switching the sound source acoustic waveform from a 125-ms FM slide to a 5-ms single frequency pulse. Subbottom penetration of 400 ms (two-way travel time) was achieved during this 2.2 km long tow track.

The system successfully operated to a tow depth of 4500 m meeting design objectives. System operational experience was gained by the field team and some areas for hardware improvement were identified. The present effort is focusing on increasing the array length to the full 1000 m, interfacing the telemetry system with a 9150-m tow cable, and completing the development of the data record and short baseline navigation systems. The total system will be integrated and an engineering evaluation field test performed in August-September 1984. The system will be available for geophysical research upon successful completion of this test.

IV. Summary

The development of the Deep-Towed Array Geophysical System (DTAGS) is nearing completion at the Naval Ocean Research and Development Activity (NORDA). DTAGS

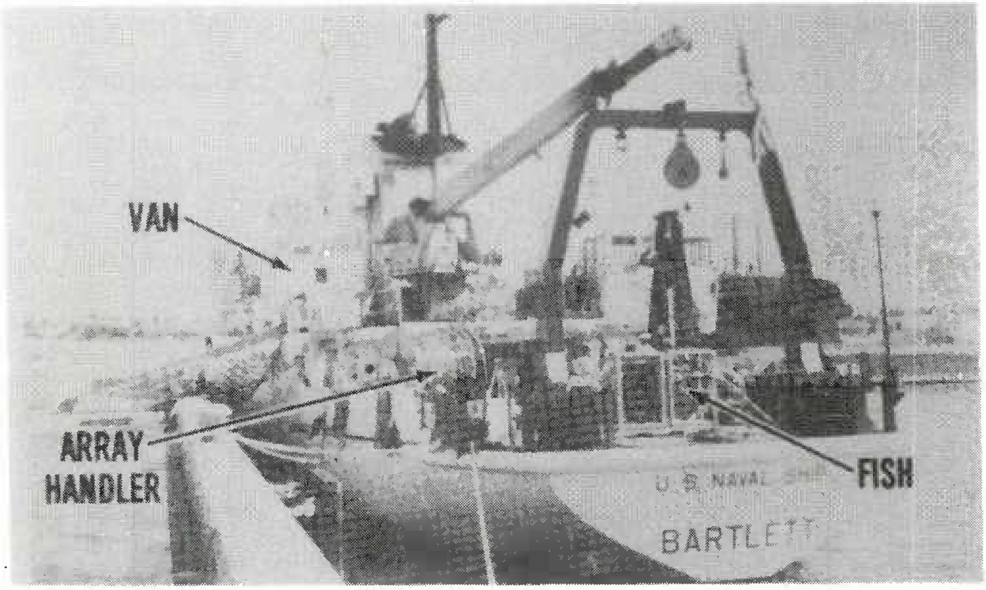

Figure 12. Major subsystems installed on the USNS BARTLETT

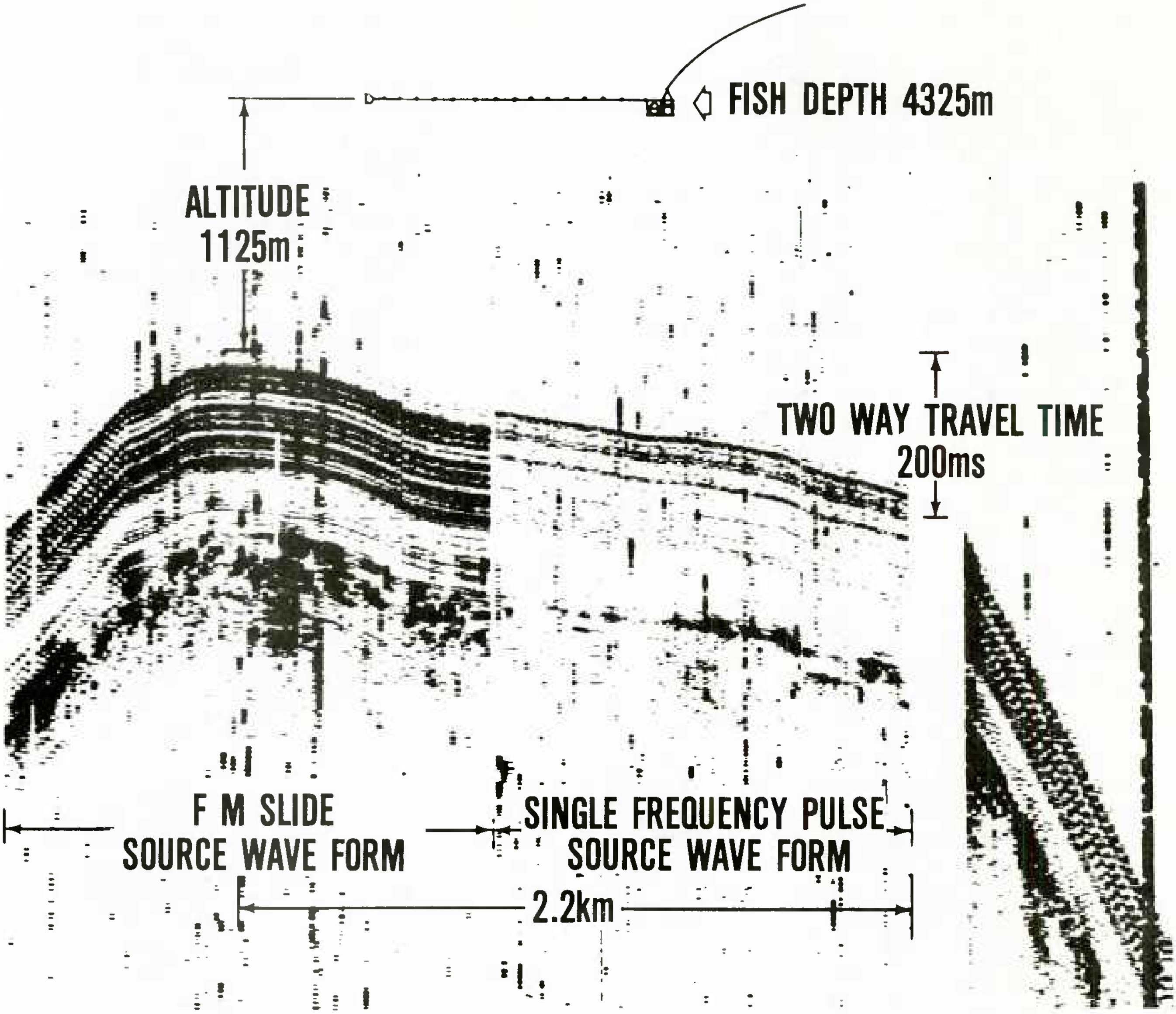

Figure 13. Single channel reflection trace obtained at 4325 m system tow depth

consists of a unique hardware suite capable of operating in the near proximity of the bottom in the deep ocean. Major subsystems include: a deep-towed, low-frequency sound source; a multichannel hydrophone array; a high data rate digital telemetry system; a digital data record system; a short baseline navigation system; and support subsystems for deploying, retrieving, and operating the system. DTAGS will provide the marine scientist with high-resolution data to describe the geological, geophysical, and geoacoustic character of the deep ocean sea floor (6000 m) and upper subbottom structure (500 m).

This paper describes the hardware characteristics of DTAGS. Emphasis is placed on reviewing, in detail, the major inwater subsystems: sound source, array, and telemetry. The design of DTAGS has been optimized to meet the geophysical measurement requirement while still maintaining a hardware suite that can be easily deployed, operated, and maintained. Results are presented from an engineering field test during which the system was operated to a depth of 4500 m. The results successfully demonstrate the system's ability to meet the hardware design goals for the deep-towed geophysical application.

The DTAGS development will conclude in September 1984 with an engineering evaluation field test of the total system. This test will incorporate new subsystems including additional array sections for a total array length of 1000 m, a 9150-m tow cable and equalizer, a digital data record system, and a short baseline navigation system. The system will be available to the Navy marine research community upon successful completion of this test.

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Appendix: DTAGS Specifications

I. Sound Source System

Transducer: Size	0.70 m diameter 1.08 m long
Weight	812 kg--air 612 kg--water
Power amplifier: Size	0.61 m diameter
Weight	232 kg--air 49 kg--water
Operating depth:	6000 m
Peak source level:	201 dB//1μPa@1m
Frequency range:	260-650 Hz
Pulse length:	5-250 ms
Repetition rate (max):	12 s

II. Array System

Active length:	1008 m
Off-set length:	50 m
Outside diameter:	4.61 cm
Hydrophone groups (total):	48 equally spaced over total active length
Hydrophone groups used (Max):	24
Active sections:	12
Interconnect sections:	13
Engineering sensors:	12 depth, 4 heading spaced over total active length, tensiometer at head
Hydrophone group/pre-amp sensitivity (combined):	-150dB//1V/μPa

III. Telemetry System

Acquisition amplifier:	
Type:	Instantaneous floating point (IFPA)
Sample frequency:	3125 Hz
A/D converter (Mantissa):	12 bit (11 + sign)
Gain word (Exponent):	4 bit
Uplink:	
Type:	Pulse code modulation (PCM)
Bit rate:	1.5 M bit/sec
Words/Frame:	30
Subframes/frame:	1
Bits/words:	16
Downlink:	
Type:	Frequency division multiplex (FSK)
Bit rate:	10 bit/sec
Number of commands:	23

IV. Data Record System

Input data:	Acoustic (PCM-NRZ), navigation (RS-232)
Tape format:	SEG-D (Demultiplexed)

Operator control: CRT-terminal

Tape transports: 2

Tape packing density: 6250 BPI (GCR)

Tape speed: 125 IPS

V. Real-Time Display System

A. Engineering sensor display subsystem:

Processing unit: Desk top calculator

Display devices: CRT, decimal panel readout, LED status indicators, alphanumeric printer/plotter, strip chart recorder

Displayed data: Array/fish depth, array heading, array tension, fish roll/pitch, fish yaw rate, fish tow speed, fish voltage levels, tow cable tension/wire out/rate.

B. Acoustic data display subsystem:

Processing unit: IFPA decoder and D/A converter

Display devices: Line scan recorder, oscillographic recorder (wiggle trace), spectrum analyzer.

Display data: Up to 8 array acoustic channels

C. Television monitoring subsystem:

Number of cameras: 2

Monitored locations: Deep-sea winch/traction units, stern deployment area

VI. Navigation System

A. Short baseline subsystem:

Fish system: Single transponder

Topside systems: Projector/hydrophone, processor, CRT display

Position data: X, Y, Z fish position

Range (max): 10,000 m

Accuracy: 1% of slant range for horizontal offsets up to 200% of water depth

VII. Deep-Towed Vehicle (Fish)

Size: 1.83 mL X 0.86 mW X 1.35 mH

Weight: 1410 kg--air
890 kg--water

VIII. Handling Systems

A. Accumulator System:

Compensation distance (full extension): 1.78 m

Number of spring accumulators: 3

Load-Extension (max):

2 accumulators: Load: 3636 kg
Extension: 0.89 m

3 accumulators: Load: 5455 kg
Extension: 0.89 m

Size envelope: 0.61 mH X 2.44 mW X 3.35 mL

B. Array Handler

Size:	2.59 mL X 2.16 mW X 2.27 mH
Weight:	2250 kg--empty 4500 kg--full
Reel Speed:	0-15 m/min
Line Pull:	Adjustable to 455 kg
Power:	230/460 VAC, 2 kVA, 3 phase, 60 Hz

C. Tow Cable:

Construction:	Space-armored
Electrical conductor:	Coaxial
Attenuation:	1.85 dB per 305 m @ 1 MH$_3$
Length:	9150 m
Diameter:	1.75 cm
Break Strength:	11,090 kg
Torque:	0.0693 m-kg per 455 kg applied tension

D. Ancillary Systems:

Host ship support:	Deep-sea winch, traction unit, stern A or U frame

IX. Portable Vans

A. Operations Van

Contains:	Operational electronic subsystems
Size:	5.6 mL X 2.44 mW X 2.87 mH
Weight:	5455 kg
Power:	460 VAC, 16 kVA, 3 phase, 60 Hz

B. Maintenance Van

Contains:	Electrical-mechanical repair facility, system spares
Size:	3.66 mL X 2.44 mW X 2.44 mH
Weight:	3182 kg
Power:	120/208 VAC, 6 kVA, Single phase, 60 Hz

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