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STANDARD HYDROPHONE WITH DIGITAL PREAMPLIFIER - USRD TYPE H76.(U)

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Standard Hydrophone with Digital Preamplifier USRD Type H76

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A standard hydrophone that incorporates an analog-to-digital conversion system has been developed. The 12-bit serial data from the hydrophone provides high reliability and accuracy of sound-pressure measurement over long distances. The errors due to the analog characteristics of long cables are eliminated. A reduced dynamic range due to the finite word size is the only penalty paid by the design.

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CONTENTS

STANDARD HYDROPHONE WITH DIGITAL PREAMPLIFIER
USRD TYPE H76

INTRODUCTION

The Underwater Sound Reference Detachment (USRD) of the Naval Research Laboratory is charged with the development of electroacoustic sensors that provide high-reliability measurements of underwater sound. These measurements often must be made under the most adverse conditions of environment. Ocean currents, wave motion, and stray electrostatic and electromagnetic fields are some of the disturbing factors that limit acquisition of useful acoustic data.

We developed a standard hydrophone with a digital preamplifier to solve the problem of making reliable acoustic measurements in areas where power-line electromagnetic fields or other electrical interference is encountered and where the acoustic information detected must be transmitted for long distances without loss of accuracy.

The digital output of the hydrophone provides high immunity to induced electromagnetic interference and retains a high order of reliability in data transmission quite independent of the length of the electrical cable. The attenuation and frequency response of a long cable do not affect the quality of acoustic data which have been digitally coded in binary form at the source. A hydrophone with an analog output is highly susceptable to errors in data transmission over long cables and in the presence of electric fields which may be superimposed on the analog electrical signal.

DESIGN

The digital hydrophone, shown in Figs. 1 and 2, is essentially an analog hydrophone in which an analog-to-digital (A/D) converter is incorporated in the hydrophone itself. The piezoelectric element is one which was designed for a standard noise-measuring hydrophone. The choice of sensor configuration is optional, and the sensor can be designed to fit a variety of measurement specifications. The design of hydrophone sensors is more thoroughly treated in other reports, some of which are listed in the bibliography. The emphasis of this report is on electronic design and on total-system evaluation.

A block diagram of the digital hydrophone electronics is shown in Fig. 3. A piezoelectric crystal (1) is coupled to the input terminals of a hybrid microcircuit preamplifier(2). This analog preamplifier provides an impedance transformation to match the crystal element to the remaining circuitry. It also provides approximately 12 dB of voltage gain.

The preamplifier output is connected to the input terminals of an eight-pole active Butterworth filter (3). This low-pass filter has a cutoff frequency of 10 kHz and 48-dB/ octave attenuation of higher frequencies, as required for antialiasing.

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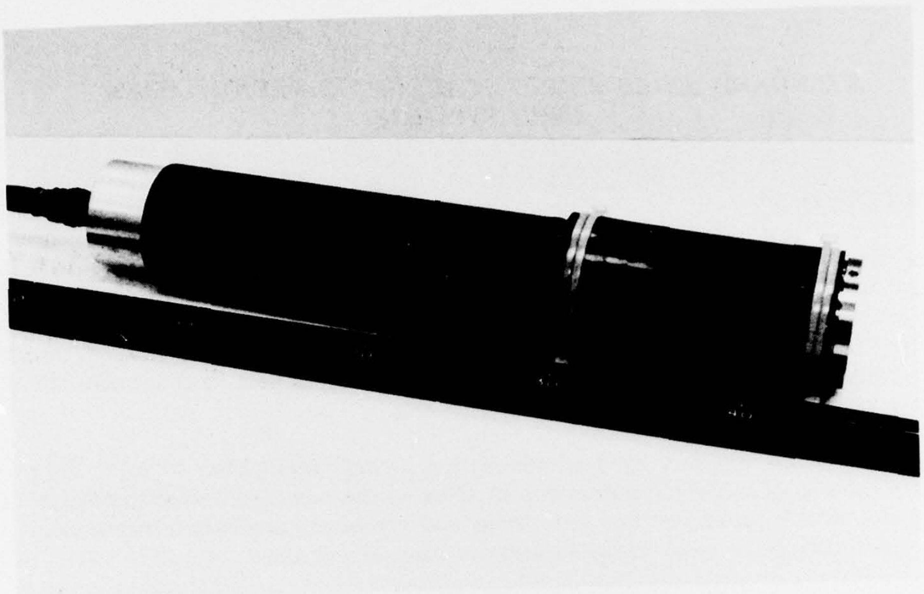

Fig. 1 — USRD Type H76 hydrophone

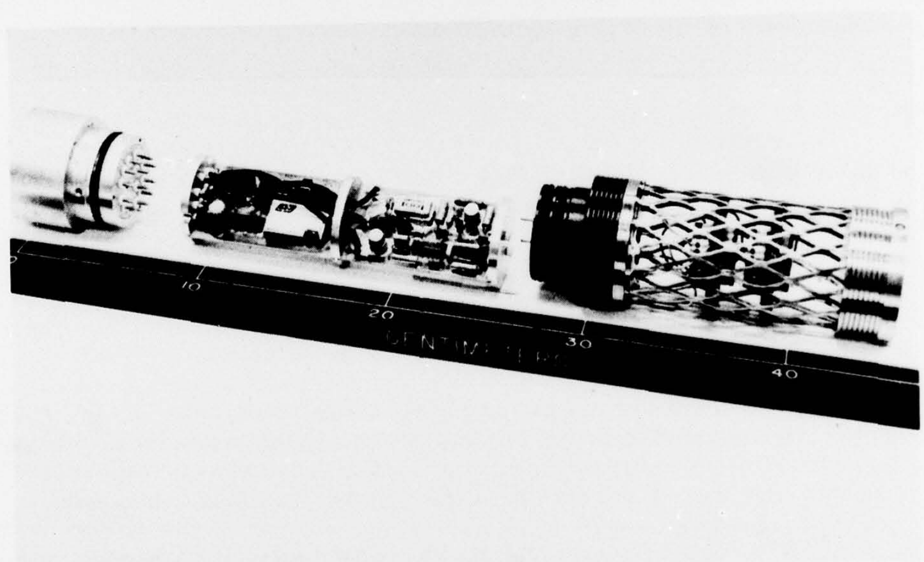

Fig. 2 — USRD Type H76 hydrophone, case removed

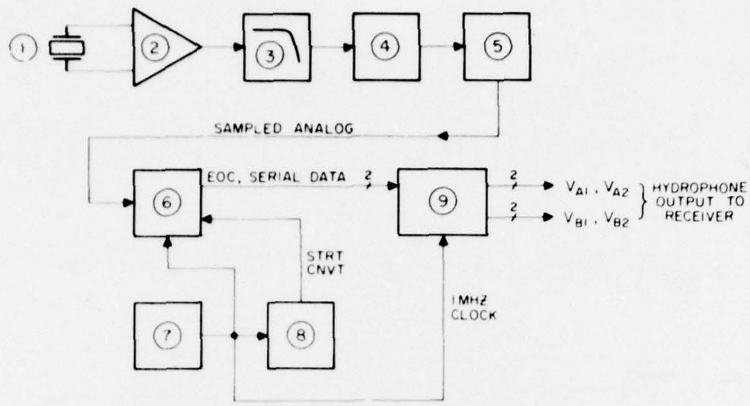

Fig. 3 — Block diagram of digital hydrophone electronics

The filtered output passes through a level-shifting network (4) to the input terminal of a miniaturized sample-and-hold circuit (5). This device tracks the filter output when it is in the "sample" mode and holds a sampled voltage value when it is in the "hold" mode. It is switched between these two modes at a 66-kHz rate.

A voltage regulator provides a stable ±15 V dc to the circuitry. The electronics described thus far are mounted together on a single printed-circuit board, the "analog" board, which is placed within a shielded housing.

A second printed-circuit board, the "digital" board, is also shielded and contains electronics to be described next. A voltage regulator provides a stable +5 V dc to this board.

The output of the sample-and-hold circuit (5) is applied to the input terminal of a miniature high-speed 12-bit A/D converter (6). This device changes the sampled voltage to a 12-bit binary number and outputs this data in serial NRZ form. A 1-MHz square-wave oscillator (7) clocks the A/D converter. Control logic (8) causes a new A/D conversion to begin every 15 clock pulses, or every 15 μs. The A/D converter produces an end-of-conversion (EOC) pulse at the end of each A/D conversion. This pulse and the serial data are applied to the input terminals of balanced line drivers (9).

The 1-MHz clock is also applied to these same line drivers. The resulting digital signals comprise the hydrophone output, and they are sent up twisted-shielded-pair transmission lines. By combining the clock with the serial data, phase shifts between clock and data are avoided. Therefore, clock and data arrive together at the end of the cable as a combined signal. The dc voltages are sent down the cable to the hydrophone electronics on separate conductors.

A timing diagram, showing both digital hydrophone and receiver waveforms, is given as Fig. 4. The receiver circuitry, shown in Fig. 5, is described next.

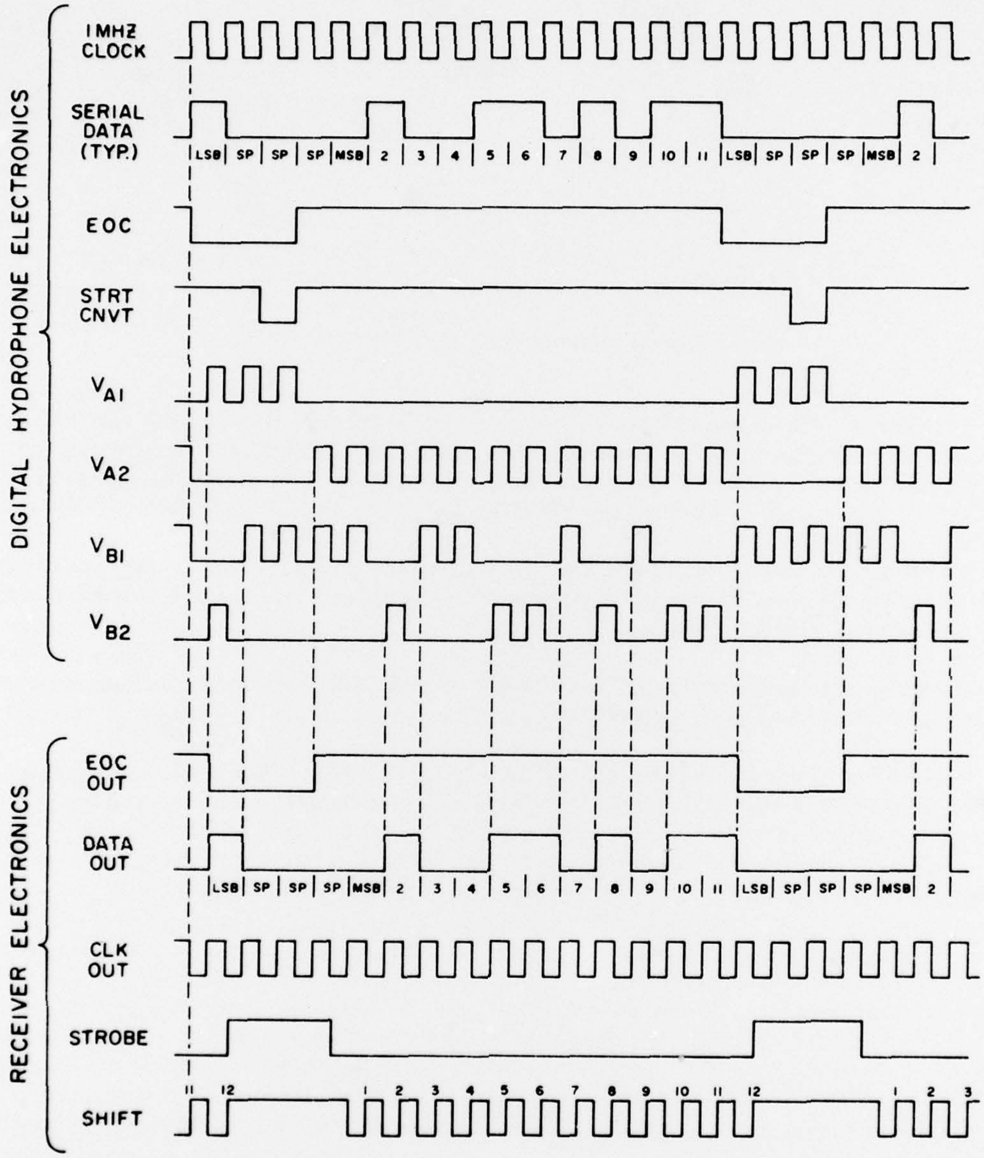

Fig. 4 — Digital hydrophone timing diagram

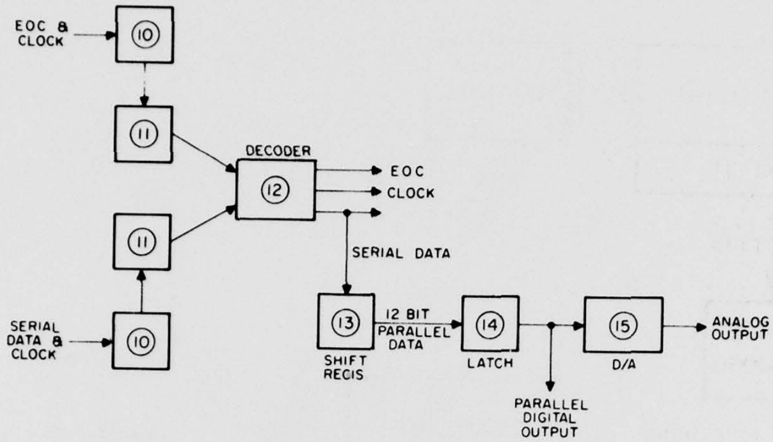

Fig. 5 — Receiver circuitry

The basic purpose of the receiver is to decode and reconstitute the received digital data. It acts as a termination for the hydrophone cable and provides a means of supplying dc power and a calibration signal to the hydrophone. Two twisted pairs in the cable carry the digital data. One pair carries the EOC signal combined with the clock. The other carries the serial data combined with the clock. Each twisted pair is terminated at the receiver with a balanced resistive load (10) and a balanced optical isolator circuit (11). This removes from the digital data any common-mode noise that might have been acquired coming up the cable. The digital data are also "squared-up" by the optoisolators.

The optoisolator outputs are applied to a decoder circuit (12). This circuit extracts the clock, serial data, and EOC pulses from the combined signals which were received.

These decoded signals are brought to BNC connectors for processing or monitoring. The serial data are also applied to the input terminal of a shift register (13).

The decoded clock and EOC pulses generate a "shift" input to this shift register. The serial data are therefore converted into 12-bit parallel binary numbers at the shift register output. This occurs every 15 μs. A "strobe" pulse is generated each time a parallel data word has been assembled. This strobes the data word into a 12-bit latch (14) which holds the word until a new word is strobed in 15 μs later. The output of this latch, together with the strobe pulse, is brought to a connector for interfacing to external circuitry (such as a computer). The output of the latch is also applied to the input of a 12-bit D/A converter (15) so that the digital data can be reconverted to analog form. This is primarily for monitoring purposes. The contents of the latch are also displayed on a 12-bit LED indicator.

Thus the receiver provides reconstituted received data in serial form, in parallel form, and also as an analog signal.

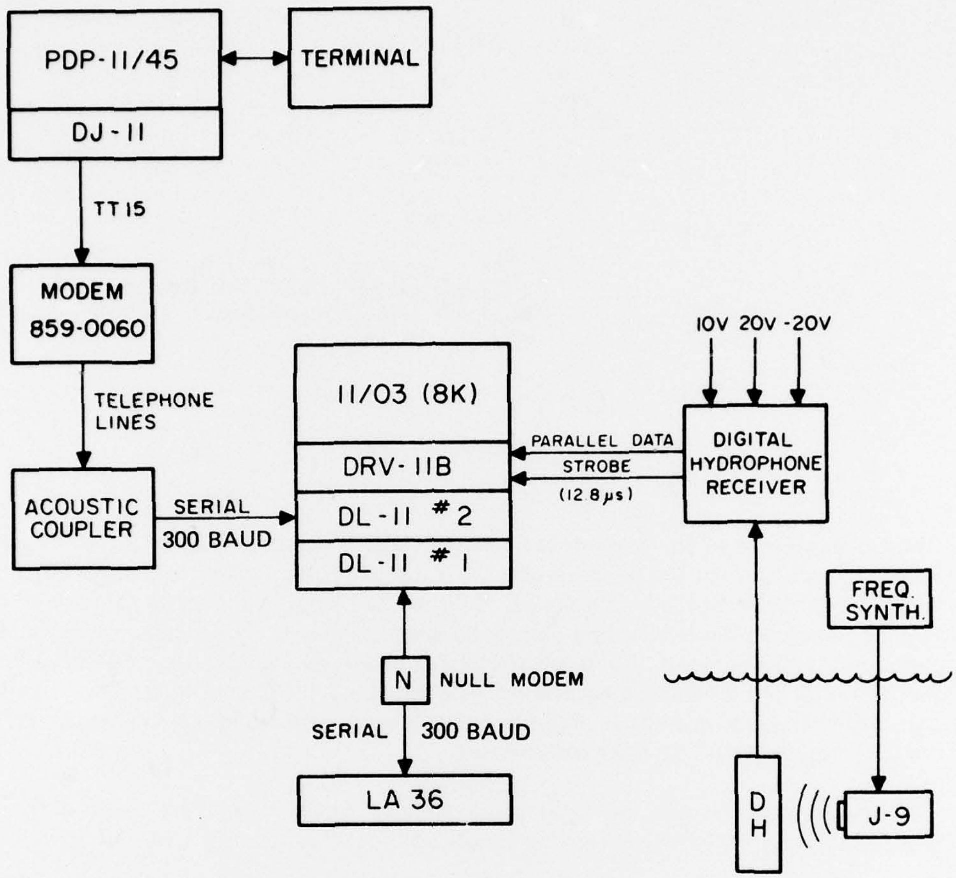

Fig. 6 — Digital calibration block diagram

ACOUSTIC CALIBRATION

The digital hydrophone was acoustically calibrated in the USRD Lake Facility. Two methods using the standard comparison technique were employed. The first method was a normal calibration using the analog output of the receiver applied to the normal analog-calibration system. The second method employed the parallel digital output of the hydrophone. The digital-calibration block diagram is shown in Fig. 6.

Calibration was controlled by a PDP-11/03 microcomputer. Programming was accomplished in FORTRAN and in machine language on the PDP-11/45 computer. The executable task image was downline-loaded into the PDP-11/03 by the serial input-output interfaces. From this point, the PDP-11/03 took complete control of the calibration process.

The parallel data from the digital hydrophone were received through a direct-memory-access (DMA) interface. The 250-kHz data-transfer rate of the DMA allowed sufficient data points to be obtained to calibrate at the higher frequencies. Calibration was performed only at discrete frequencies with an integral number of measurement points per cycle. The RMS voltages were computed from the reconstructed sinusoidal waveforms. From these voltages, the calibration was ultimately computed. The program proceeded through a predefined frequency table, requesting that a frequency be set and the sound-pressure level be entered. The DMA transfer was then initiated, the data processed, and the calibration at the preselected frequency printed on the terminal.

Figure 7 shows the comparison between the normal analog type of calibration and the digital calibration. There was good agreement over the frequency range 0.1 to 8 kHz.

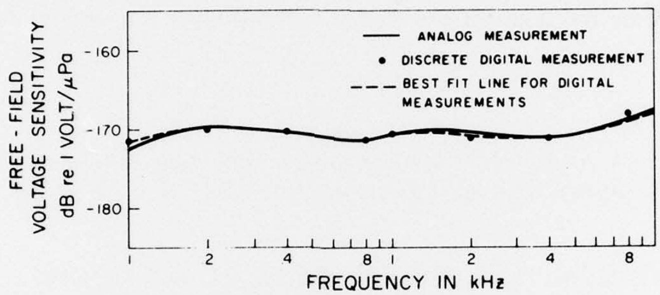

Fig. 7 — Comparison of normal analog calibration to digital calibration

NOISE AND DYNAMIC RANGE

The limitation in dynamic range and noise of the digital hydrophone is imposed by the 12-bit resolution of the A/D converter. The maximum voltage that can be accepted by the A/D converter is 3.54 V rms (or 11 dB re 1 V). The acoustic sound pressure needed to develop an 11 dB level is +181 dB re 1 μPa. This determines the upper limit of the dynamic range. The lower limit is determined by the resolution of the 12-bit word, which is 2^{-12}, or 2.44×10^{-4}, or -72.2 dB re 1 V. The minimum resolvable voltage level is then -61.2 dB, which is equivalent to a sound pressure level of 108 dB re 1 μPa.

CONCLUSION

The H76 digital hydrophone, although limited in frequency response and in dynamic range compared to analog-type hydrophones, has distinct advantages which make it a more desirable instrument for certain measurement problems. A specific application may be the use of digital output hydrophones in underwater acoustic ranges where it is common to use kilometers of cable to transmit analog acoustic data to shore-based computers. Another indicated use would be in monitoring the acoustic-source level of a high-power towed projector. In this application, analog-hydrophone cables are susceptable to induced electrical cross talk due to the high-voltage driving signal to the projector, which usually must be transmitted through the same cable bundle that carries the hydrophone signal.

The state of the art in digital components is advancing rapidly, and the limitations mentioned are constantly being reduced. Higher frequency ranges are now possible. Higher dynamic range can possibly be designed into future models with a minimum compromise to frequency range.

ACKNOWLEDGMENTS

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