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MICROCOMPUTER-CONTROLLED TRANSDUCER CALIBRATION FACILITIES AT THE DEFENCE RESEARCH ESTABLISHMENT ATLANTIC

G W McMahon (1), C V Sheffer (1) and D R Chang(2)

(1) Defence Research Establishment Atlantic, Dartmouth, Nova Scotia, Canada
(2) Evans Computer Applications, Halifax, Nova Scotia, Canada

1. INTRODUCTION

Since its origination during World War II, the Defence Research Establishment Atlantic (DREA) has maintained acoustic calibration facilities to support its underwater acoustic research programmes and to assist the Canadian Forces in sonar development and evaluation. Over the years the facilities have been upgraded periodically to embrace new technology, and the latest of these improvements has been the installation of microcomputer-controlled measurement systems.

This paper will present an overview of the acoustic calibration facilities now available at DREA. We will first describe briefly the two major sites, the Acoustic Barge and the Acoustic Tank, and their mechanical equipment. The electronic equipment and computer systems will then be described. Finally, we will outline the computer programmes that have been developed to carry out the transducer calibration tasks.

2. ACOUSTIC BARGE

The acoustic barge is a 300-tonne welded steel vessel 36 m long by 17 m wide. It is moored in a sheltered cove 5 km by water from DREA, where the water depth is about 42 m (see Figure 1). The hull contains a rectangular well, 9 m by 18 m that is open to the sea. The main work area, including the well is covered by a deckhouse. A 10-tonne electro-hydraulic crane on the outer deck

Fig. 1. The DREA Acoustic Barge in Bedford Basin.

can swing loads from a boat or ship into the deckhouse through a large doorway.

Five-tonne loads can be moved anywhere within the deckhouse by an electric bridge crane. It is used to handle the stations on which transducers or other devices are mounted.

Transducers can be mounted and rotated at depths from 2 to 40 m on a number of different stations. Light stations, capable of 200 kg loads, are used on trolleys to suspend devices anywhere within the well. Heavy stations, capable of loads up to 7 tonnes, can be fixed to the ends of the well or on the outer deck within reach of the deck crane. On some of the stations, digital shaft encoders provide digital readout of the rotation angle.

The barge is supplied with 3-phase electrical power via a cable to shore 500 m away. Emergency power for essential services is provided by a diesel generator.

3. ACOUSTIC TANK

The acoustic tank is a circular redwood tank 7.3 m diameter by 4.5 m deep. It is housed in a concrete "cable tank" in a building formerly used to service transatlantic communications cables. Figure 2 is a view from below, showing the top of the wood tank, and the work bridge resting on the lip of the cable tank. Both the work bridge and the tank itself are mounted on rubber pads to isolate them from ground vibrations for frequencies above about 10 Hz.

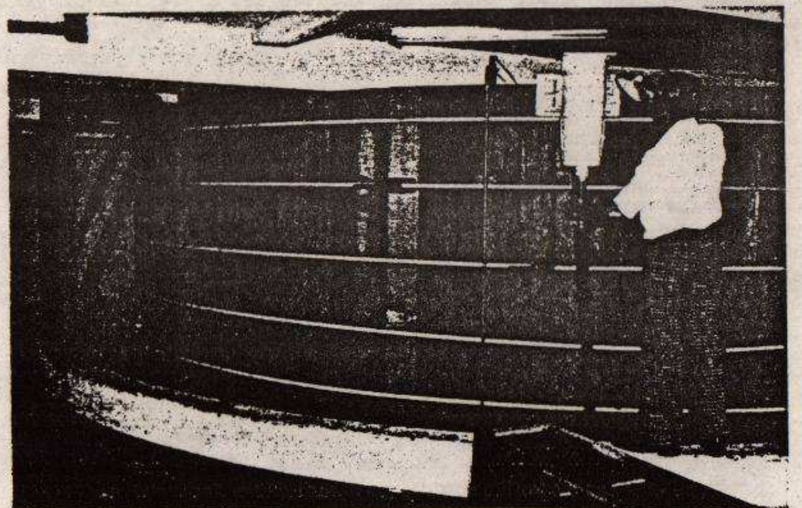

Fig. 2. The DREA Acoustic Tank showing one end of the work bridge, and some of the water filtration equipment.

Two moveable platforms rest on the bridge and there is no direct mechanical connection between the platforms and the floor, again to provide acoustic isolation from floor vibrations. Two identical transducer mounting stations attach to the two platforms. The stations' shafts are rotatable under remote control and incorporate digital encoders for readout of the shaft rotation angle.

Wedge-shaped blocks of "insulkrete" sound absorbing material [1] line the walls and part of the floor of the tank. These greatly reduce the reverberation time of the tank for frequencies above 4 kHz.

4. CALIBRATION TRANSDUCERS

Because of their broad bandwidth, the sound sources most useful in our calibrations are the J-series of moving coil projectors [2], designed by the Underwater Sound Reference Detachment (USRD) of NRL in Orlando, Florida. The frequency range from about 10 Hz to 20 kHz is adequately covered by these units. Piezoceramic transducers such as the USRD Type F33 [3], are used when higher frequencies are required.

Our standard hydrophones are piezoceramic units, either commercially manufactured or built in our transducer laboratory. Absolute calibrations of the standards are carried out periodically by the reciprocity method [4], one of the tasks performed with the aid of the microcomputer.

5. ELECTRONIC FACILITIES

The electronic equipment for the tank is fairly conventional and includes low-noise differential preamplifiers, programmable filters, programmable synthesizer, wideband power amplifier, and the usual monitoring equipment such as oscilloscopes and meters. The barge equipment is essentially the same, but additionally includes a 7.5 kVA high power amplifier.

Figure 3 is a composite block diagram of the computer-controlled calibration system. All of the items shown in the large block on the left are housed in the microcomputer drawer. The connections shown are those that might be used in a projector response measurement or part of a reciprocity calibration. The digital shaft encoder is used for recording directivity patterns. The digital-to-analog converter (D/A) and programmable low pass filter are used for pseudo-random noise generation in a hydrophone calibration procedure. The analog-to-digital converter (A/D) is used for all signal sampling. It has eight multiplex channels, although in most of our calibration procedures only one channel is used.

6. CALIBRATION PROCEDURES

A complete calibration of an underwater sound transducer will normally include free-field receiving and/or transmitting response over a frequency band, far-field directivity patterns at selected frequencies, and electrical admittance or impedance over a frequency band. Detailed descriptions of the basic procedures and their limitations are beyond the scope of this paper, and the reader is referred to a text by Bobber [5] for a thorough discussion of the subject.

Our present software package controls six calibration procedures:

1. Hydrophone receiving sensitivity by the comparison method;
2. Projector transmitting response by reference to a standard hydrophone;

3. Absolute receiving and/or transmitting responses by the reciprocity method;
4. Electrical admittance or impedance measurement;
5. Directivity pattern measurement; and
6. Hydrophone comparison calibration with pseudo random noise signals.

The first five of these procedures use the tone burst technique which is outlined in the following section.

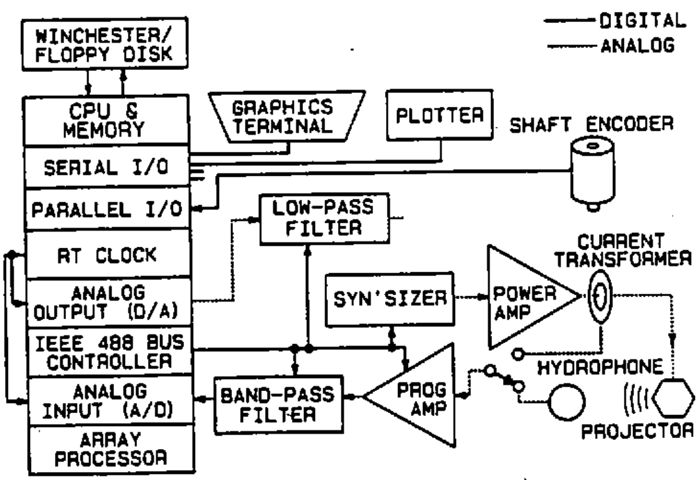

Fig. 3. Composite block diagram of the computer-controlled calibration system.

6.1 Tone Burst Signals

The tone burst or pulsed sound technique is commonly used to achieve effective free-field conditions in a confined medium such as in a tank or shallow pond. It is easily implemented under computer control using a programmable synthesizer for signal generation and an A/D converter for signal recovery. The time window available for sampling of the received waveform extends from the initial arrival of the direct signal to the arrival of the first interfering signal from a boundary or object. We normally apply discrete Fourier transform (DFT) processing to a sequence of samples taken as late as possible in the time window when the signal has reached nearly "steady state" conditions. The primary frequency component is extracted by the DFT process and used in the subsequent computations for that frequency.

Continuous sinusoidal (CW) signals are used only when the time window is not long enough to contain a useable tone burst. This results in a sacrifice of accuracy when good free-field conditions cannot be realized.

The maximum frequency available for tone burst or CW measurements is limited arbitrarily to 450 kHz.

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6.2 Computer Programmes

The computer programmes are written in FORTRAN except for a few short routines which are written in the MACRO assembler language. Extensive use is made of the subroutine libraries supplied with the various peripheral devices.

The programmes are highly user-interactive. The operator is guided through each step of the procedure by statements on the display screen, and is prompted for parameter input or other action as required. Figure 4 shows a typical display sequence, obtained during a projector calibration: The operator selects a step from the menu at top; step one, initialization, calls for new parameter input. A default or existing value is printed and may be chosen; or a new value may be typed, as, for example in Figure 4, a new upper frequency and depth were selected.

Many error checks are performed and appropriate messages to the operator are displayed if an error is detected. Some are generated by peripheral devices and signify a hardware fault or an attempt to clock events too rapidly. Others are programme-generated and arise from inappropriate parameter selection and/or software timing problems.

During tone burst or CW calibrations, the synthesizer frequency is stepped through the band from the upper to the lower frequency. The stepping can be interrupted at any point to cause a repetitive loop at that frequency or to restart the procedure. Up to 1024 separate frequency points can be processed. The received signal is passed through a programmable bandpass filter that is stepped to follow the synthesizer frequency. System gain is adjusted automatically to keep the signal at a suitable level for sampling by the 12-bit A/D converter.

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1. INITIALIZE FOR NEW CALIBRATION.
2. NEW CALIBRATION, SAME PARAMETERS.
3. REPEAT FINAL PASS.
4. NEW CALIBRATION FACTOR.
5. NEW PLOT PARAMETERS, PLOT RESULTS.
6. SAME PLOT PARAMETERS, PLOT RESULTS.
7. QUIT.

WHICH STEP? 1

LOWER FREQUENCY (KHZ):                              1.000  ??
UPPER FREQUENCY (KHZ):                             10.000  ??  20
DFT FREQUENCY DECREMENT (MAX. 0.997):               0.990  ??
FILTER HALF-BANDWIDTH (KHZ):                        1.000  ??
TRANSDUCER DEPTH (METRES):                          1.000  ??  1.83
DISTANCE, PROJECTOR TO STANDARD (METRES):           1.000  ??
AVAILABLE TIME WINDOW (MSEC):                       1.888
TIME WINDOW (MSEC; MINIMUM   0.100):                1.888  ??
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Fig. 4. Example of the message display to the operator, obtained during a projector calibration.

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Graphic results are plotted in prescribed formats on the display screen, and the operator can make scale changes. Hard copy results can be made directly from the display, or they can be plotted on a multiple-pen x-y plotter. The results can also be saved on a disk file for later plotting, and multiple plots can be placed on the same graph.

6.2.1 Hydrophone Comparison Calibration

This procedure determines the voltage sensitivity of a hydrophone by comparison of its open circuit output voltage with that of a standard hydrophone placed in an identical sound field. Figure 5 shows a typical graph of results plotted on the digital x-y plotter. A number of unknown hydrophones may be calibrated without repeating the standard measurements every time. Since only the ratio of two voltages is important, the measuring system need not be calibrated but it must, of course, be linear.

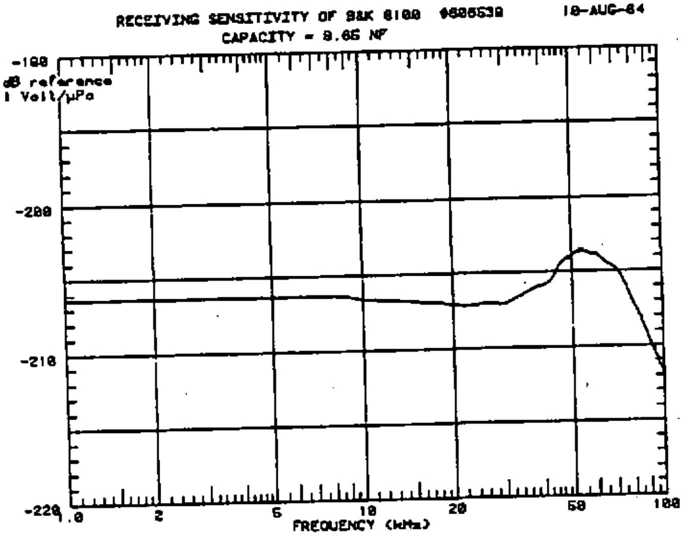

Fig. 5. Typical graph of receiving sensitivity of a hydrophone.

6.2.2 Projector Calibration

The transmitting current (or voltage) response of a projector is determined by measuring its driving current (or voltage) and, using a standard hydrophone, measuring the intensity of the resulting sound field at a specified free-field location. A graph of results for a typical projector calibration is shown in Figure 6. Again, the same measurement system is used for both projector drive level and the standard hydrophone output, so the system must be linear but need not be calibrated.

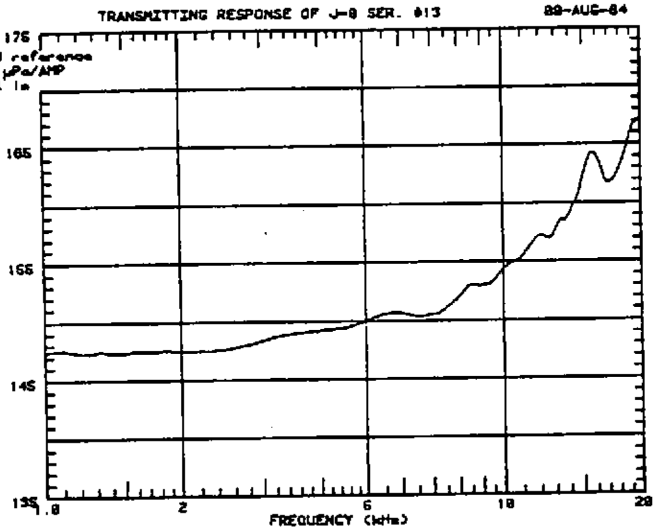

Fig. 6. Typical graph of transmitting response of a projector.

6.2.3 Reciprocity Calibration

The reciprocity procedure allows the absolute calibration of three transducers, none of which is required to have a known electroacoustic response. At least one of the transducers must be reciprocal, one must be a hydrophone and the third is a projector. The standards on which the reciprocity calibration is based are: a frequency standard (the synthesizer), an accurate length measure, and an electrical standard, in our case the current transformer. The density of the medium, either fresh water or sea water, enters into the computation of the reciprocity parameter [6]. As in 6.2.1 and 6.2.2, the measuring system must be linear over the range of voltages to be measured. Graphic results are plotted in the same form as in Figures 5 and 6.

6.2.4 Admittance/Impedance Measurement

The electrical admittance or impedance of a transducer is determined by measuring the complex voltage and current at the transducer terminals, using two multiplex channels of the A/D converter. The measurement may be made at selected single frequencies or stepped through a specified frequency range. In the latter case, real and imaginary components are computed, and plotted against frequency. Alternatively, the imaginary component can be plotted against the real component. Also, the blocked admittance (impedance) [8] can be specified by the operator and subtracted from the components before plotting. This common technique allows more precise observation of the motional admittance (impedance) of a resonant transducer.

6.2.5 Directivity Patterns

A directivity response pattern [7] of a transducer is obtained by rotating the transducer about an axis and periodically measuring its response, using an auxilliary transducer placed at a suitable far-field location. The auxilliary transducer is either a projector or a hydrophone depending on whether the test transducer is a hydrophone or a projector, respectively.

The rotation angle is tracked by the computer using a digital shaft encoder attached to the transducer rotating station. The encoder emits a pulse every 0.1 degree that is used to trigger a sample sequence. Most transducer directivity measurements do not require such fine resolution, so the programme allows simultaneous directivity measurements of up to eight elements in a transducer array, or simultaneous measurements at up to five frequencies. Also, a number of adjacent samples may be averaged for smoothing of the plotted results. Naturally, the transducer must be rotated slowly enough to allow the 3600 sample sequences; typically 50 to 200 seconds are required.

Preliminary directivity patterns like that shown in Figure 7 are displayed on the graphics terminal allowing the operator to adjust plot parameters. Hard copy results may be plotted on the multiple pen x-y plotter. Either cartesian or polar coordinates can be chosen and an example of the former is shown in Figure 8, where the directivity is plotted for two frequencies obtained during the same rotation. The response amplitude is plotted in decibels relative to

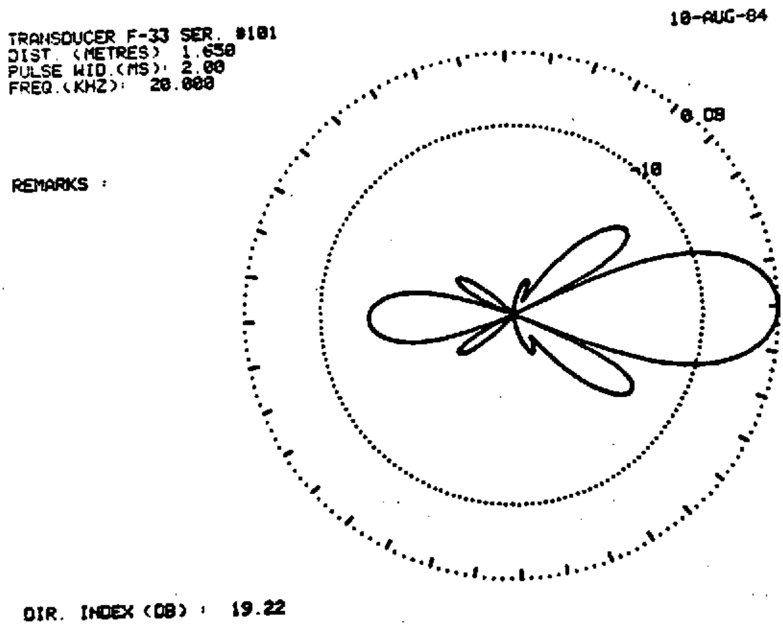

Fig. 7. Directivity pattern as displayed on the graphics terminal.

the maximum response, and the angle of maximum response is chosen as the nominal acoustic axis or zero degree position. Any other angle may be chosen by the operator as the zero degree position.

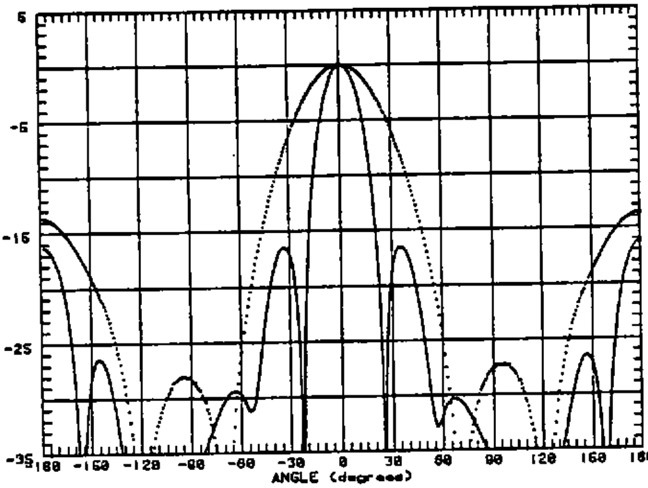

Fig. 8. Cartesian coordinate plot of directivity patterns taken at 10 kHz (dotted) and 20 kHz (solid) during one rotation of a type F33 transducer.

The directivity index (DI) is computed for each pattern, assuming a symmetry axis, as specified by the operator, to be either coincident with, or at right angles to the acoustic axis. The DI is automatically printed on the display terminal pattern (Figure 7).

6.2.6 Hydrophone Noise Calibration

The sixth programmed procedure is the comparison calibration of a hydrophone using pseudo-random noise signals generated by the D/A converter [9]. The frequency band is defined by the A/D sampling rate, which is also the D/A signal generation rate. Up to 1024 voltage samples are taken in each of two passes, one for the standard hydrophone and the other for the unknown hydrophone placed at the same location in an identical sound field. The array processor uses the FFT method to compute the power spectrum for each hydrophone from the received signal, and the unknown sensitivity is calculated in each frequency bin. Plotted results for noise calibrations are in the same format as in Figure 5 but with the abscissa labelled in Hz rather than kHz.

The noise method is used predominantly at lower frequencies in a reverberant environment such as the tank, where the available time window is too short for tone burst measurements. The noise burst is then started well before sampling is begun so as to allow the noise field to become more-or-less stationary. Alternatively, at higher frequencies, the complete FFT sample sequence may be contained within the free-field time window, allowing a wideband, free-field calibration with noise-like signals. The highest A/D sampling rate available with our present hardware is 125 kHz, limiting the upper frequency for noise calibrations to about 50 kHz. The method can be used down to 5 Hz or lower, depending on the available sound source.

7. FUTURE DEVELOPMENTS

We have briefly described the underwater acoustic calibration facilities at DREA and have outlined the computer programmes that were developed to control the common transducer calibration tasks. Improvements to these programmes will be added in the future; for example, a modified Prony method [10,11] is being implemented to extend the low frequency range of tone burst measurements to time windows that are only one-half period long. A task being considered for future development is the determination of far-field directivity of a transducer from near-field measurements [12].

Besides the calibration tasks, there are many other acoustic experiments that are facilitated by the microcomputer: A programme is presently being written to automatically record ambient noise spectrum level and directionality at the two calibration sites. Another programme nearing completion will simulate a sonar echo ranging scenario so that a military sonar set or a depth sounder can be exercised at the tank or barge.

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