UNPUBLISHED REPORT

AN INLAND WATERS ACOUSTIC ECHO
AMPLITUDE/DEPTH ANALYSIS SYSTEM
FOR MONITORING FISH POPULATION DISTRIBUTIONS

ES 505

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SECTION 1: INTRODUCTION

The response of animals to variations in the environment is an important subject for biologists at CCIW. To aid in the monitoring of the distribution of fish in inland waters relative to other environmental parameters, a development program was initiated at CCIW to produce an electroacoustic system for this purpose. This system was targetted to be capable of resolving fish in the water column and accumulating the depth and apparent size information. This development was initiated by successful experience with a simpler system in 1973. A literature search preceded the system design effort. A system target performance specification was evolved in cooperation with scientists of the Great Lakes Biolimnology Laboratory for the requirement of taking censuses of fish populations in inland waters.

The design, development, testing and field performance of the resultant systems are described in this unpublished report. An interim system was especially configured to allow field work to commence prior to completion of the first system. A second system was requested before final delivery of the first. To expedite the delivery of the second system, and to assist in assessing the design and performance of the two systems, a contract for field engineering services was placed with Canadian industry. Mr. J.S. Lawton, P. Eng., of C-Tech Limited was contributed to much of the work presented in Sections 7, 8, 10.

The references are listed in Section 12. Many of the articles referenced in the bibliographies of those listed have constituted the general data base for this work. In the interest of brevity only the most recent and directly related publications are included in the listing, with the addition of those contributing articles which would otherwise not be referenced indirectly.

SECTION 2: GENERAL SYSTEM DESCRIPTION

The design goal for the CCIW high resolution acoustic fish census system is summarized by the Initial Concept Sketch, Figure 1, the System Functional Block Diagram, Figure 2, and the system target performance specification (Section 3). The system components were specified, sourced and procured toward achieving this goal. These components are described in Sections 3 through 6. A photograph of the 1974 system (Aqua version) is shown in Figure 3.

Functionally, the system radiates a burst of acoustic energy into the water column below the electroacoustic transducer. This energy is scattered by variations in the local acoustic impedance (targets). The energy returned to the transducer is detected. The time of arrival of the reflected energy relative to the time of transmission determines the range of the target from the transducer assuming the propagation velocity is known. After compensating the returned signal for geometrical losses the amplitude is a measure of the apparent "target strength" of the reflector.

The system was configured as a rack mounted assembly suitable for deployment from CCIW scientific launches. It requires approximately 700 watt of 110 volt AC 60Hz power.

The 1973 system was built around hardware used earlier by Dowd at the Marine Ecology Laboratory. The goal of target classification into four ranges for the 1974 system was selected on the basis of previous successful experience by Dowd with a bottom referenced, 4-amplitude range system (Reference no. 8). The number of depth ranges was increased over that used by Dowd to provide greater vertical resolution in the water column.

SECTION 3: SYSTEM SPECIFICATION

3.1 SYSTEM TARGET PERFORMANCE SPECIFICATION

The system target performance specification is detailed on the following page. The characteristics are grouped into four categories: Amplitude, Depth, System Features, System Data Outputs. The specifics are discussed below.

The on-axis target strength range for the system is limited by the spatial resolution capabilities of the electroacoustic transducer. The side lobe suppression of the directivity characteristic of the transducer is the primary limitation in defining the sampled volume. The absolute range of target strength for the system is determined by the transmitted intensity and the receiver sensitivity. For this system the selected target strength range corresponds to estimates of target strength for fish in the size range of interest (2 cm to 20 cm ref. no. 2).

The sorting of the echo amplitude information is a problem with many implications. This is discussed at length in Section 9. For this system the target strength range was divided into four equal increments. The accuracy of the amplitude processing is targetted to be $\pm$ 1dB. This includes errors incurred in the electronic signal processing. The actual limitations imposed by the acoustical estimation of target strength may be much greater, however, and this is also discussed in Section 9.

The sorting of the echo depth information is largely a question of time measurement and knowledge of the acoustic propagation velocity in the water column. This system assumes a constant phase velocity of 1500 $m\ s^{-1}$ in its depth measurements. (The accepted value for fresh water at 20^{o}C is $1.48 \times 10^{3}\ m\ s^{-1}$). No echo processing occurs for returns corresponding to the first 3 metre below the transducer. This limitation is imposed by the requirement that the electroacoustic subsystems require a finite time interval to recover from the transmission function and attain the state of controlled receiver gain for the receive function. A further limitation is imposed by the reverberation characteristics of the acoustic volume surrounding the transducer. Under normal operating

TARGET PERFORMANCE SPECIFICATION FOR 1974 CCIW ACOUSTIC FISH CENSUSING SYSTEM

On-axis Target Strength	:	-25dB to -45dB re 2 m radius sphere
No. of Amplitude Sorting Increments	:	4 bins; of 5dB range each
Accuracy of Amplitude Thresholds	:	± 1dB
Depth Measurement Range	:	3 to 100 m (Shallow water)
No. of Depth Sorting Increments	:	6, with lower 6 depth thresholds adjustable
Accuracy of Depth Thresholds	:	± 0.1m, resolution 1m
Resolvable No. of Targets/Metre	:	10 maximum (Pulse width limited)
No. of Target Data Channels	:	24 (4 amplitude x 6 depth)
No. of Ancillary Channels	:	4 (no. transmissions; Extended echos; total depth; time
Counting Range; per channel; per interval	:	1 to 9999 echo counts
Transmission Rate	:	Fixed 4 Hz
Transmission Acoustic Pulse	:	80 kHz; 100 μs; (15 cm insonification)
Sub-bottom Counting Inhibit	:	Provided by bottom tracking feature (± 0.5 m window)
System Mode of Operation	:	Semi-automatic (Run and Halt)

System Outputs

Digital Recording of Data	:	Magtape; half-inch, 7 track, 556 BPI recording. (Capacity: 12,000 independent fish census samples)
Hard Copy Printout of Data	:	Digital Printout of Independent Counts. (10 column printer; 400 census samples)
Digital Display of Data	:	Display of 4 accumulating counts in one selected depth layer, or status data.
Analog (Intensity) Display of Data	:	Fibre-optics recorder, showing time history of targets in the vertical water column. (Photosensitive paper display) (Dynamic range and range resolution targeted to match above system parameters.)

conditions the reverberation time of this volume is considerably less than the time corresponding to 3 metre (4ms) range. However, in conditions of high surface turbulence and aeration, the reverberation field has been observed to cause returns after 4 ms.

The water column may be divided in up to 6 depth ranges. The lowest depth range may overlap the bottom. The servo-locked bottom detection feature inhibits the counting of bottom returns as fish targets. This servo loop allows the bottom to change by ± 0.5 metre from one transmission to the next. For operation over very irregular bottoms, the servo feature may be inhibited, allowing the bottom to be rejected on amplitude of the echo alone. In the field experience to date, this phenomenon has not occurred.

3.2 SOLUTION OF THE SONAR EQUATION

The sonar equation is a convenient representation of the relationship of the physical phenomena which determine the performance of a sonar system. It is written with all terms expressed in deciBells, hence attention must be paid to units and reference parameters to ensure that the physics is not misconstrued. The following table lists the parameters, their abbreviations and target values.

$$\text{Received signal dBv}_{rms} = SL - TL + TS + 2D(\theta,\emptyset) + RR + G$$

$$= SL - \left(40 \log R + \frac{2\alpha R}{10^3}\right) + TS + 2D(\theta,\emptyset) + RR + G_o + 40 \log \frac{R}{3}$$

$$= SL + TS + RR + G_o + 2D(\theta,\emptyset) - 40 \log 3 - \frac{2\alpha R}{10^3}$$

$$\therefore \text{Received Signal} = \left(SL + RR + G_o - 40 \log 3 - \frac{2\alpha R}{10^3}\right) + TS + 2D(\theta,\emptyset)$$

Hence, to achieve some reasonable signal level at the output of the receiver for a given target strength reflector on-axis, one adjusts SL and G_o as necessary.

To give an output from the receiver of 0.2 v rms (-14dBv) for a target of strength - 45dB on axis, the initial receiver gain, Go can be found by substituting the target values as

$$Go = -14 - 217 + 180 + 19.1 + 45$$
$$Go = 13.1 \text{ dB.}$$

A-25 dB target would then give an output of +6dBv (2vrms) from the receiver. The receiver gain would track the transmission losses to a maximum value of 13.1 + 60.9 = 74dB. The error margin for the time varied gain was targetted to be ± 1dB throughout the range.

TERMS USEFUL IN THE SONAR EQUATION

PARAMETER	SYMBOL	DEFINITION	TARGET VALUES (dB)
Source Level	SL	$=20 \log_{10} \frac{P_{rms}}{1 \mu Pa}$ @ 1 metre from the transducer face on the acoustic axis. $=(TR/V)_{(0,0)} + 20 \log V_{rms}$. Prms= root mean square pressure in units of μPa	217
Transmitting Response	$(TR/V)_{(\theta,\emptyset)}$	=dB re 1 μPa_{rms} per V_{rms} applied to transducer measured at 1 metre from the transducer face at $\angle(\theta,\emptyset)$ from the acoustic axis	Matched in this case to give SL with power input up to 1KW rms.
Receiving Response	$(RR)_{(\theta,\emptyset)}$	=dB re 1 Vrms per μPa rms	-180
Directivity	$D_T(\theta,\emptyset)$	$=(TR/V)_{(\theta,\emptyset)} - (TR/V)_{(0,0)} = D_R$ for a reciprocal transducer operated	0 on-axis $-3dB$ @ $\theta,\emptyset = 3.25^{\circ}$
	$D_R(\theta,\emptyset)$	$=(RR)_{(\theta,\emptyset)} - (RR)_{(0,0)}$ in its linear regime	< -20dB for θ,∅ outside main lobe
Target Strength	$TS_{(\theta',\emptyset')}$	$=20 \log \frac{P_{rms} \text{ reflected}}{P_{rms} \text{ incident}}$ measured at 1 metre from the centre of the target with the principal axes of the body at $\angle(\theta',\emptyset',\cdots)$ to the incident wavefront. A perfectly reflecting sphere of radius 2 metre has TS= 0dB*	-45 to -25
Propagation Loss	TL	$=40 \log \frac{R}{1} + 2 \alpha \frac{R}{10^3}$ R= range in metre α= attenuation coefficient in dB per 10^3 m.	2
Receiver Gain	G	$=Go + G \left(\frac{R}{Ro}\right)$ Go= voltage gain when R=Ro $Ro \leq R \leq Rmax$ $=20 \log \frac{V_{rms} \text{ out}}{V_{rms} \text{ in}}$	13.1 3 metre to 100 metre.

(*Where measurements appear to be unrealistic the intent is the value corrected for TL to 1 metre.)

SECTION 4: ELECTROACOUSTIC SUBSYSTEMS

4.1 INTRODUCTION

The transmitter/receiver and the transducer comprise the two electroacoustic subsystems. They must be compatible in frequency response, impedance, sensitivities - both transmitting and receiving. The characteristics of a transceiver are readily adjusted to those required within realistic limitations. The transducer, however, is formed from discrete elements with a relatively small range over which the resulting characteristics are useful. Hence, to avoid excessive first time engineering costs, the transducer must be selected as close as is feasible to an available commercial model.

The high resolution desired in this system requires short transmitted pulse length and controlled directional characteristics. Both of these parameters argue for increasing the operating frequency. The upper bound is determined by the increase of attenuation with frequency for sound in water, and the difficulty of electroacoustic/electronic engineering at high frequencies. The practical limit is the band around 100 kHz. The scattering of acoustic energy by targets is determined largely by the size of the target as compared to the wavelength of the energy i.e. it is a diffraction phenomenon.

Objects much smaller than a wavelength give rise to Rayleigh Scattering, where the acoustic target strength is proportional to the fourth power of the object dimension. Objects much larger than a wavelength are observed to produce specular reflection, wherein the acoustic target strength is proportional to the square of the dimension (i.e. area). The transition region between these two phenomena is the Mie Scattering region. This type of scattering is characterised by a non-monotonic behaviour of target strength with dimension. The size of the fish of interest, together with the practical electroacoustic technology conspire to force operation of the system in this region of complex scattering.

4.2 TRANSDUCER

The transducer (Figure 6) was selected following an extensive market survey of commercially available, medium power, narrow beamwidth, 100 kHz transducers. The transducer is a modified version of a standard product of Edo Western. The resonance frequency is 80 kHz, which is at the low end of the acoustic spectrum suited for this system. The modifications by the manufacturer were directed to increasing the slide lobe suppression and fabricating a faired housing and support suitable for over the side mounting on a small vessel.

The key characteristics are:	Edo Western Model 4042	
	S/N 101	S/N102
frequency:	80kHz	80kHz
transmitting response:	173.8 dB	173.4 dB re 1μPa/V @ 1m
receiving response:	-175.9 dB	-173.9 dB re 1v/μPa
-3dB beamwidth:	7.5^{o}	7.5^{o}
sidelobe suppression:	20 dB	26dB
impedance:	175Ω	175 + j38 Ω
maximum power:	1 kW	1 kW

(Manufacturer acceptance test data - 1974).

The improved directional characteristics of S/N 102 were the result of the manufacturer's refinement of the array shading. More details of the transducers performance are given in Section 7.

4.3 TRANSCEIVER

The transceiver (Figure 5) was selected following a market survey. The characteristics of the device were specified in keeping with the system requirements. The implementation of a precision time varied gain characteristic designed for shallow water application is the primary technological difficulty in the receiver portion of the transceiver. This subject is discussed further in Section 10. The selected transceiver is a modification of a standard product of Edo Western.

The salient characteristics are: Edo Western.

Model	248C-15	248C-15A
S/N	535	539
frequency	80kHz	80kHz
max. power output	1kW	1kW
impedance	175Ω	175Ω
receiver gain minimum	0dB	0dB
maximum	104.6dB	104.6dB
maximum error in TVG to 40 log R	+3 -5dB	+4 -2dB
-3dB bandwidth	10.7kHz	10.7kHz
-60dB bandwidth	20.9kHz	22.4kHz

The second transceiver incorporated a redesigned TVG in attempt to improve over the first transceiver's performance. The TVG in these receivers was implemented using three fixed gain stages with three series FET's acting as potentiometric gain controllers. The control signal for the FET set was derived from a diode voltage function generator. The modification consisted largely of expanding the function generator to provide more control in the shaping of the TVG characteristic.

This series FET technique has been judged unsuccessful. The non-linearity of the FET transfer function, its temperature dependence, and evidence of feed through of the received signal to the gain control signal all contribute to this judgement. To attain a useful TVG characteristic from the second transceiver it was necessary to operate the TVG receiver at a high absolute gain to obtain the appropriate control. This required signal attenuation upstream of the TVG receiver greater than was possible with the existing preamplifier. The EDO WESTERN preamplifier was disconnected and an instrumentation preamplifier (Scientific-Atlanta Model 1116) was used.

SECTION 5: ECHO ANALYSIS/CONTROL SUBSYSTEM (EACS)

5.1 INTRODUCTION

The Echo Analysis/Control Subsystem (Figure 4) is the heart of this fish census system. It provides the supervisory control functions to operate the data acquisition, display, and data logging devices. EACS accepts the received echos from the receiver and applies amplitude and depth sorting. It accumulates digital counts over a number of successive transmissions corresponding to the four amplitude ranges for each of six depth ranges. EACS actively discriminates against the bottom echo, and applies a "Bottom Lock" technique to provide security in this discrimination.

The EACS was specified around the system requirements. It was configured as a hard wired, digital data acquisition subsystem. EACS is a single CCIW standard rack mountable assembly. The contractor for the design and fabrication was EDA Electronics. The device is comprised of 2 printed circuit board cards and 12 wire-wrap cards. The circuitry is composed largely of MSI,CMOS integrated circuit devices.

The alternative to the hard wired EACS is a minicomputer based data acquisition system. The small number of systems planned, and the requirement of minimizing the size of the system overall, both argue in favour of the hard wired approach. The flexibility inherent with the minicomputer based system is attainable only with the appropriate investment in software. Further, the minicomputer requires the development of the appropriate interfaces which duplicate much of the functions of EACS.

5.2 INTERFACING

Functionally, EACS was designed to be compatible with a variety of 100 kHz transceiver/transducer systems. It offers input signal conditioning to match signal levels, and the selection of synchronous or asynchronous triggering to be compatible with a variety of graphic recorders. It also offers selection of one of three pulse lengths (100,200,500 μs).

5.3 ECHO PROCESSING

The signal derived from the receiver is buffered into the EACS circuitry through an amplifier with selectable gain (± 20dB, 5dB increments). This signal is envelope detected (rectified, filtered) to produce a "DC" signal containing the information bandwidth of the system. This signal is summed with other status data and is fed to the graphic recorder. The detected signal is compared to five reference voltages. An echo event is defined from the time the detected signal exceeds the lowest threshold. One transmission burst length later, the EACS determines which amplitude interval the echo is classed as by recognizing the highest of the four reference voltages exceeded. The word in the memory corresponding to the range and amplitude classification of the echo is incremented. A dead time (preset on the rear panel) of up to 0.8 times the transmit burst duration is incorporated in echo processing to allow for "echo stretching" by the target. After the dead time interval, the echo processing is again enabled.

To recognize the case when the target density is so great as to render the system incapable of resolving the targets individually, an extended echo event counter is included. This counter accumulates the number of occasions when the echo envelope continuously exceeds the lowest threshold for a selectable number of transmission burst durations (1-8).

5.4 BOTTOM ECHO PROCESSING

The bottom echo is recognized as a signal which exceeds the fifth and highest threshold (6 $dB_V \equiv -25$ dB TS). With the arrival of the bottom echo, target echo processing terminates even though the lowest depth margin may be set below the bottom. To prevent the termination of processing with a large echo (associated with a large fish, or a closely packed school of fish, or a noise spike) and to ensure termination with a weak bottom return, a bottom lock servo loop is incorporated. This loop, when locked onto the bottom echo allows a variation of ± 0.5 metre of the depth for the bottom return from one transmission to the next. If no bottom return is identified in this depth window, the servo loop generates a logical bottom signal to terminate the echo processing. A missing bottom echo counter is incremented. After a selectable number of missing bottom returns (1-9) the servo loop unlocks and accepts the first echo which exceeds the fifth threshold as the bottom and locks on it.

For a vessel speed of 4 knot (2 $m.s^{-1}$) and a transmission rate of 4 Hz, the 0.5 m window will track apparent bottom slopes of less than 45°. The apparent slope may be due to excessive vessel roll rather than actual bottom topography. In the case of rougher topography than the above, the servo loop would cause loss of possible data by tracking above the real bottom and extraneous target counts by tracking below the bottom. This effect can be minimized by decreasing the number of missing bottom returns required to unlock the loop, with the increased risk of the bottom detection circuitry identifying the returns from high localized target densities as the bottom and prematurely terminating echo processing.

5.5 ECHO AMPLITUDE DETECTION - THRESHOLDING

Some discussion of the actual means of echo amplitude detection is required. The detection circuitry in the EACS uses a full wave rectifier followed by a low-pass filter (integrator). Ideally, one would want to measure the energy corresponding to the returned echo. Assuming that the preceding analog circuitry does not produce more distortion than is tolerable, the energy would be proportional to the mean square voltage, and thesholding could be performed with the rms voltage signal. The rectifier-filter scheme above can be adjusted to match the rms voltage for a burst of sinusoidal signal with a defined envelope (eg. boxcar). However, the echo returns have complex envelope shapes 9, and hence, this scheme will not measure the true rms voltage of a 100 μsec duration burst signal with 100 kHz centre frequency [6].

The echo is longer than the transmitted acoustic burst due to the finite size of the reflector. A further restriction on measuring the total energy reflected by the target is the requirement of summing over the total echo. The scheme used in this system integrates only over one burst duration, and rejects the later arriving energy. One may consider that the system imposes a bias on the range extent of the reflector in the estimation of target strength.

In summary, the amplitude detection scheme used in this system is a practical solution, far from the ideal one. The error introduced by this scheme has not been determined, and this would seem to be an area where mathematical modelling techniques could make a distinct contribution in the estimation of the error and the evaluation of the improvement possible with alternative schemes.

SECTION 6: DATA DISPLAY AND RECORDING SUBSYSTEMS

6.1 GRAPHIC RECORDER

The graphic record of the acoustic data presents the best opportunity for the operator to assess the performance of the system and the characteristics of the local environment under study. This display records the time history of the samples taken, showing the nature of the bottom, the distribution of targets in the water column, and the extent of surface reverberation, boat roll and other interference. The EACS incorporates status data into the display, indicating the depth sorting ranges and event marks which identify the data logging intervals.

Commensurate with the above mission, the graphic recorder was specified and selected. This resulted in the use of a Fibre Optic Cathode Ray Tube (FO-CRT) recorder (Honeywell 1856) which is illustrated in Figure 7. Conventional graphic recorders used in depth sounding applications use moving stylii which electrochemically mark the recording paper. The FO-CRT recorder uses an electron beam which stimulates a phosphor. The emitted light is coupled by the fibre optic face of the cathode ray tube to a photosensitive recording medium. The advantage with the latter approach is that the sweep speed for this recording technique can be orders of magnitude greater than is possible with electromechanical technology. A further advantage is that the electronic scan can be triggered synchronously, whereas the mechanical recorders must be operated in a continuous mode to achieve high sweep speeds.

The primary limitation of the FO-CRT recorder is the performance of the photosensitive media available. Photochemical products which require post-exposure wet chemistry or heat processing are available to produce high resolution, wide tonal range recordings. However, the requirements of this system require real time presentation of the display. A compromise is possible with the utilization of photo developed papers. The medium selected for this system is KODAK LINAGRAPH

DIRECT PRINT PAPER TYPE 1895. It offers rapid light developing characteristics, moderate tonal range, and moderate image stability. The tonal dynamic range is less than the dynamic range of the signals for which the system is designed (12dB as against 20dB). This limitation has not proved to be severe as no attempt is made to determine target strength quantitatively from the graphic record. The stability of the record is adequate provided it is not exposed more than necessary to ambient light. Reproductions of samples of the graphic records are shown in Figures 8 and 14.

6.2 DIGITAL PRINTER

The digital printer used in this system is a standard commercial unit. The Hewlett-Packard 5055A is used in a number of systems at CCIW and has been found to be satisfactory for line powered applications. It is configured to print 10 columns on pressure sensitive paper. The device operates at 11 lines per second. To ensure that the paper does not jam in high humidity environments it has been found to be necessary to store the paper in sealed plastic bags. The data logging format is shown in Figure 8(b).

6.3 INCREMENTAL MAGNETIC TAPE RECORDER

To minimize the post experiment data handling effort required, the systems offers the facility to record industry standard, 7-track, computer compatible magnetic tape records. The recorder for which the EACS was made compatible is a Kennedy Model 1600/360. Unfortunately, the numerical data is written backwards on the tape (LSC first rather than MSC first). A special handling routine will be written to reformat the data for the CDC 3000 computer facility at CCIW. Figure 8(c) shows the tape format, and Figure 8(d) illustrates a processed record as printed on the line printer.

SECTION 7: SUMMARY OF SYSTEM PERFORMANCE TEST DATA

7.1 INTRODUCTION

In order to assess the capabilities of the system it is necessary to test each of the subsystems with regard to their functional characteristics, and compare the test with the specified performance. After defining the system parameters, it is desirable to execute as realistically as is feasible a complete system test to verify the predicted performance. A test program was undertaken for this system. A number of problems were discovered, not all of which have been resolved to date. However, work is continuing to better define the parameters in question, and to improve the performance of the limiting system components.

7.2 ELECTROACOUSTIC TRANSDUCER

The electroacoustic transducers were tested by the manufacturer prior to delivery. The directivity patterns for the devices are shown in Figure 9 (a) and (b). The second transducer (S/N 102) shows improved shaping of the main lobe. When installed, the second transducer was observed to be mismatched to the transmitter. Its apparent impedence was approximately 100 ohm rather than the 175 ± 35(1±j) ohm specified.

Following the field season, the transducers were taken to C-Tech Ltd. for recalibration. This additional data showed some change in sensitivities (a function both of aging and temperature):

	Edo Western*	C-Tech Ltd.
On-axis transmitting response		
S/N 101	173.8	175 dB re μPa/V @ 1m
S/N 102	173.4	174

	Edo Western*	C-Tech Ltd.
On-axis receiving response		
S/N 101	-175.9	-172 dB re V/μPa
S/N 102	-173.9	-178
Impedance		
S/N 101	175+j0 Ω	200-j35 Ω
S/N 102	175+j38 Ω	40+j90 Ω

*S/N 101 20 March, 1974 7.8°C
S/N 102 15 July, 1974 22.8°C
All C-Tech measurements 2, 3 April, 1975 4°C.

More extensive directivity measurements were made at C-Tech to determine more fully the characteristics of the transducers. These are shown in Figures 9 (c) and (d). For S/N 101 they show that the side lobe suppression is somewhat poorer than the Edo Western data suggests (16dB rather than 21dB). For S/N 102 there is little significant difference except for the side lobe suppression which is 21dB rather than 26dB (meets the specified requirement).

At the time of this writing S/N 102 has been sent to Edo Western for inspection. The anomalous impedance has been ascribed by the manufacturer to the selection of unstable components for the shading network. This fault is being corrected and it is hoped that the solution will result in improved transducer performance.

7.3 ELECTROACOUSTIC TRANSCEIVERS

The transceivers have been the subject of extensive testing due to their critical function in the system and the number of problems that have arisen out of these tests. The transmitter portion of the transceiver has not caused any concern to date. The transmitted pulse in water is shown in Figure 10. Coherent switching would improve the pulse shape. The receiver has been carefully studied due to its failure to meet the time varied gain specification. The receivers show nonlinear characteristics (Figure 10(b)).

The definition of gain for these amplifiers is not possible in the strict sense of the word, however, an approximation to the actual signal processing occuring can be made. The measured performance depends upon the measurement technique. Two sets of gain measurements are shown for the receivers in Figure 11 (burst and continuous wave). The gain measured for a signal burst is the better assessment of actual receiver performance in the field. However, the gain of the receiver is modulated to some degree by the strength of the signal integrated over a time constant. This mild "AGC" characteristic would depress the gain at times equivalent to short ranges due to the large signals passed by the receiver at the time of transmission and the ensuing reverberation.

It should be noted that the results of our gain measurements are markedly different from those obtained by the manufacturer in their acceptance test data (Section 4.3). This is due to an improper measurement technique utilized by the manufacturer. Our measurements were achieved using a matched attenuator feeding the input of the receiver across a dummy load. The signal input was determined which gave a fixed output from the receiver for each range value.

The effective on-axis target classification characteristic as determined from the burst gain measurement and other system parameters is given in Figure 12 for both systems. With the above comments in mind this provides the best estimate of the system performance capability.

The TVG characteristic of the second system transceiver was measured again in the spring of 1975. The result (Figure 11 (b)) showed an increase in gain of approximately 8dB and change in the gain slope characteristic. Efforts to determine if this difference is attributable to any systematic error in the measurement have proved fruitless.

The apparently self-consistent results obtained by Lawton would suggest that the earlier gain measurements were adequate at that time. The more recent measurements would seem to indicate a severe aging characteristic in the TVG receiver.

7.4 COMPLETE SYSTEM TEST

A series of experiments were conducted with the second system in Lake Erie. A set of spherical targets, shown in Figure 13 were systematically lowered below the transducer. The response of the system was observed both in the form of the graphic record and the digital counts in the appropriate depth range. This data is presented in Figure 14. The effect of boat roll on the position of the targets relative to the acoustic axis of the transducer is very evident. One may observe that a given target will appear to have a range of target strengths with the relative maximum corresponding to the return for which the target was closest to the acoustic axis. Upon examination of the data it is evident that qualitatively the system classifies the target echos in the manner which is expected.

The returned echos were observed with an oscilloscope. The largest amplitude echo observed from a series of transmissions was noted. This data is plotted in Figure 14(f). One would expect that a target would be underestimated in size by such a system. For large targets at short ranges, the estimate is uncertain as the assumptions of plane wave geometry are not justified. For small targets, one would expect that the supporting apparatus may contribute to raise the observed target strength over the nominal value.[10]

The digital data has been reduced to the form shown in Figures 14 (g) (i-v). The expected number of returns from the target, summed over all 4 amplitudes was calculated based on the size of the target (dimension along the acoustic axis) and the "dead time" (Section 5.3) in effect. No attempt was made to correct for the possibility that the target may have swung out of the beam (boat roll) or that the supporting apparatus may have contributed returns.

SECTION 8: INITIAL FIELD EXPERIENCE

The first of the two systems was installed on the CSL Aqua. The interim system was used from April through June at Nanticoke in Lake Erie. The complete system was installed at Red Rock, Lake Superior in Mid-July. It was used intensively through August. The system saw further application at Nanticoke in the fall. It participated in a workshop at Picton (Lake Ontario) in late November. Apart from a few design faults uncovered at the time of installation, the equipment functioned well for most of the field season. The EACS suffered a few problems attributed to random IC failures. The FO-CRT graphic recorder (both systems) started failing after a few months of use. The repeated problems experienced were eventually discovered to be basic design faults. Honeywell has modified these instruments to include as much as practicable the improvements made in the redesign of the problem prone areas of the device. (new model 1856A). These equipment failures are summarized in the following table.

The second system, apart from the recorder problems mentioned above, functioned without incident after installation. The installation aboard the Keenosay was made at Wheatly (Lake Erie) in early August. The system was used extensively by J.S. Lawton for the testing and evaluation program through the fall. A limited amount of fish census data was collected by biologists of the Ontario Ministry of Natural Resources.

The performance of the system to date has been judged by the scientist as largely successful. Numberous comparisons have been made with the classical abundance measurement method, mid-water trawls and the derived performance has been consistent.

SECTION 9: SYSTEM SAMPLING CHARACTERISTICS

9.1 SUMMARY

The fish census system described in this report resolves and ennumerates single targets in the water column in the target strength range of -50 dB and greater (on axis) with the limitations imposed by the receiver performance as described in Section 7. The amplitude sampling characteristics are complex due to the very nature of the measurement.

In the design of such a system, the trade-offs to be faced are: target strength for a given reflector increases with frequency (to a limited extent); the technological difficulty and cost of electroacoustic systems increases dramatically above a few hundred kiloHertz; range resolution and directional control improve as frequency increases. The selection of 80 kHz rather than 100 kHz or 200 kHz for the operating frequency has the following results: reduces the target strength for the reflectors of interest; reduces slightly the potential range resolution; eases the technological difficulty in the electroacoustic subsystems and offers the possibility of reduced cost.

9.2 CALIBRATIONS

The calibrations of the individual and combined electronic assemblies is feasible to within 1dB of "actual" values. The calibration of an electroacoustic transducer is repeatable to within 1dB under controlled conditions at a calibration facility.[7] Comparison of results between different facilities is usually within 2 or 3dB.

If one examines the sonar equations in Section 3.2 one can observe that there are a minimum of three independent measurements (SL, RR, G) required to determine the on-axis performance of the system at a given range. Alternatively, one can operate with a standard target as in Section 7, and determine the performance within the limitations of the experiment. Here again, as discussed in Section 7, the difficulty of the experiment reduces the accuracy of the estimate.

Hence, the amplitude performance of a sonar system under controlled conditions may be readily defined to within 3 or 4dB with useful certainty.

Calibration in the field, as recommended in some circles [1], may be considered a useful operational guide, but hardly an absolute measure of system sensitivity. Field conditions may involve complex thermal structures and significant aeration in the water. Alignment of the calibration transducer with the acoustic axis of the transducer system under test is critical and may be extremely difficult under field conditions. The stability of the sensitivity of the reference transducer is also important. It is common practice in military work to provide a special shipboard facility for calibration of reference transducers. Finally, the distance from the transducer to the reference is also critical. It must be great enough to ensure that measurements are made out of the near field of the transducer, unless special effort is made to ensure a repeatable near field measurement. The distance must be well known to ensure proper correction for geometric losses.

9.3 DIRECTIONAL CHARACTERISTICS

In Section 3, the directional problem was reduced by considering the target to be on the acoustic axis. In reality, a natural reflector would rarely be on the axis per se. The directional characteristics presented in Figure 9 give a representation of $D(\theta)$. Only one angle is given, however, for a transducer with a symmetric array of elements, the deformation with the angle associated with rotation about the acoustic axis should not be excessive. When the target is off-axis, the energy of the incident acoustic field is reduced due to the directional radiating properties of the transducer. The reflected energy is detected with the directional receiving response. These processes combine to reduce the estimate of the target strength of the reflector.

9.4 THE NEED FOR MODELLING

The target strength of any object other than a sphere is a complex function of the orientation with respect to the incident acoustic field. This is the case for fish, hence the position of the fish "in the beam" and its orientation relative to the beam determine the target strength measured. No attempt has been made to date to study the system amplitude sampling characteristics with a mathematical model, however it is possible to formulate an intuitive feel for the processes at hand.

Consider first that the system sampled a uniform ensemble of identical resolvable targets whose spatial density was sufficiently low that coincident returns from more than one target did not occur. If the system were adjusted to estimate the on-axis target strength of the target set as the highest amplitude interval, then the system would accumulate counts in all four amplitude intervals as the number of samples increased. If the target density was constant with depth, then the number of returns per unit depth would scale with the square of the depth due to the volume associated with the solid angle corresponding to the beam and the depth increment. This portion of the problem should be amenable to modelling.

Consider now, that the system samples a uniform ensemble of reflectors with a distributed set of target strengths. Retaining the assumptions above one can see that the data collected by the system represents a convolution of the system sampling characteristic with the target strength distribution. This implies that the target strength distribution must be known in order to extract it from the data collected. In practice, one would expect that it would be sufficient to have an ap roximation to the actual target strength distribution to allow the extraction from the data of information with useful significance. It would appear that mathematical modelling would be extremely valuable in determining the limitations of such an approach and in estimating the tolerances necessary in the definition of the approximate target strength distribution for the data reduction.

A further result desired from such modelling would be the requirement for the definition of the system performance characteristics necessary to support the scientific utility of the data. Given the problems associated with field calibration it may be possible to design an experiment suitable for field conditions with a target set array with selected statistics. The goal would be to produce a field measurement suitable for comparison with defined values consistent with the system model. In terms of the conventional calibration of subsystems, it would be desireable to obtain from the system model confidence requirements for the estimates of subsystem parameters. This would support the design of efficient and sufficient calibration programs.

SECTION 10: IMPROVEMENT PROGRAM

An improvement program is underway at the time of this writing to remedy the major shortcomings of the systems and to make minor improvements where feasible. The greatest concern is that of the Time Varied Gain receiver subsystem. Work is progressing on having the necessary development and design performed by industry toward producing the improved receive channel. Further refinement of the signal processing is not anticipated until such time as the system is well modelled and the effect of errors and system changes can be effectively studied.

Some modifications to the EACS have been implemented to improve the utility of the graphic display. These have been to reduce the dynamic range of the signals fed to the graphic recorder and thus prevent "blooming" of the trace, and to incorporate a small dot in the display to identify targets counted by the EACS. The latter is especially useful in that it confirms the presence of the small targets even if the sensitivity of the recorder should drift sufficiently so that they would otherwise not be represented.

The systems will receive burn-in testing prior to re-deployment with the intent of reducing the occurrence of failures in the field. Re-calibration of all other subsystems is complete. Effort will continue towards making the two systems identical and interchangeable.

SECTION 11: CONCLUSIONS

The CCIW Acoustic Fish Censuring Systems represent significant progress toward filling the requirements of CCIW biologists in the study of fish behaviour in inland waters. The shallow water operating mission has pressed the need for some innovations over conventional echo sounder technology. The problems associated with the receiver characteristics have prevented the first system from collecting useful amplitude data regarding the target strength distributions sampled. With the improvement of this aspect of the system, it is hoped that the data collected in the next field season will contribute to a better assessment of the system performance.

Such systems have much to offer to biologists in terms of resolving and enumerating the fish targets sampled in inland waters. System and experiment method modelling are required to define the sampling characteristics with the goal of determining the overall sensitivity to variations in the size and population distribution of the targets under study. As was the case with the single target, on-axis sensitivity, it would be desireable to verify the modelled performance with a known target ensemble. Hopefully, the support will continue for this work toward producing a more useful and better understood tool for the biologists.

SECTION 12: REFERENCES

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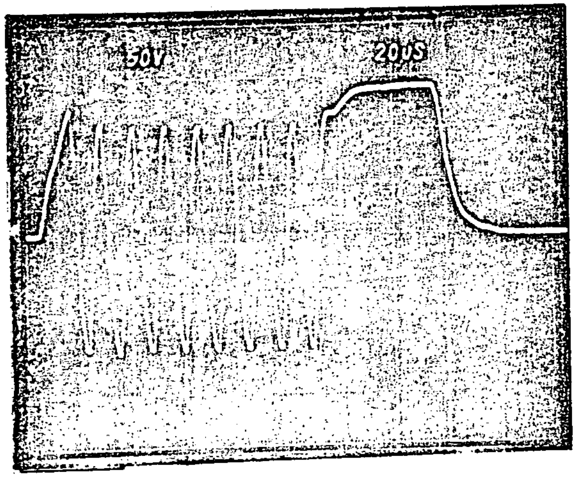
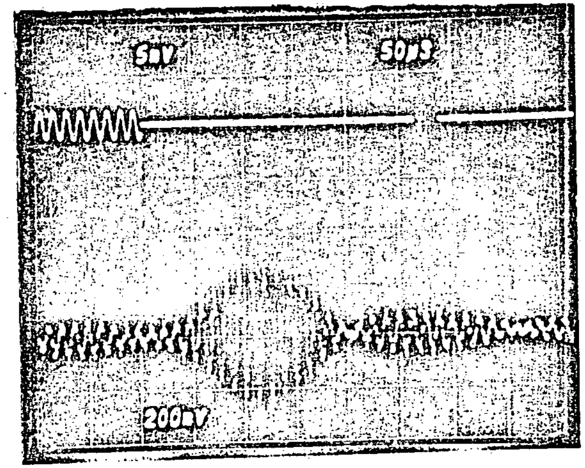
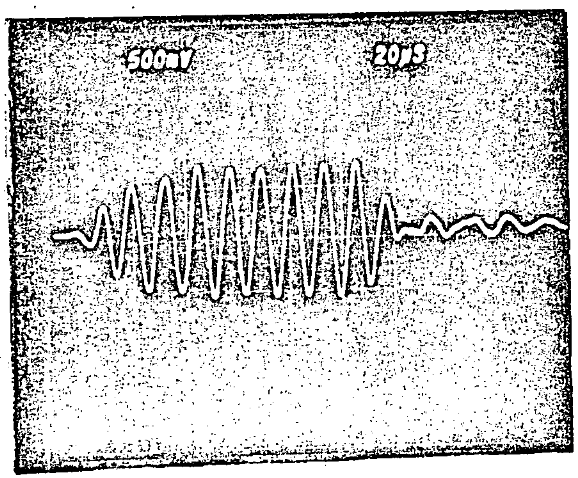


Transmitter output into 170 OHM
Dummy resistive load at TP=2

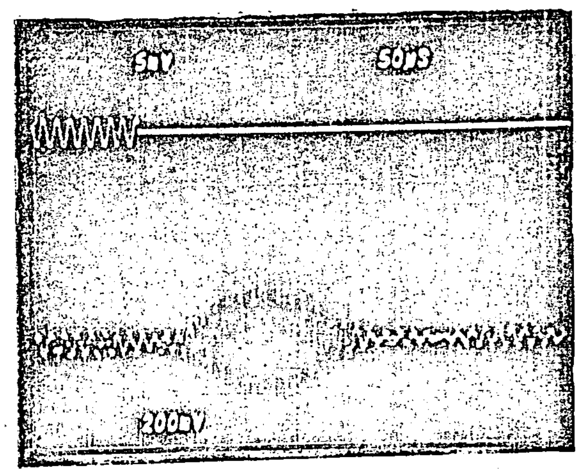


Input signal and receiver
Output at 3 metre



In water acoustic pulse for transducer S/N 101 measured with F33 transducer on-axis

(a)



Input signal and receiver
Output at 100 metre
(Input signal before attention)

(b)

FIGURE 10

CCIW FISH CENSUS SYSTEM -- SIGNAL WAVEFORMS

TABLE OF FAULT HISTORY

DATE	SYSTEM NUMBER	SYMPTOM	DEFECTIVE UNIT	DIAGNOSIS
7/6/74	1	Graphic recorder unstable with temperature.	Sweep Generator	Sent to Honeywell for modification. Report No. 61-05141
22/8/74	1	EACS - Data log when switched from run to hold.	EACS	Contact bounce eliminator update added.
10/9/74	1	EACS - Memory not resetting, printout only first six lines.	EACS Board 4	C3 (CD4011) of A4 holding internal clock line high - replaced.
24/9/74	1	Graphic recorder 3 meter line not writing.	EACS Board 14	3 Meter line (differentiated rising edge) too short in duration for graphic recorder-Changed capacitor to 500 pf.
8/10/74	2	Graphic recorder failed. (Fuses blown.)	Graphic Recorder	Returned to Honeywell for repair.
11/10/74	2	Graphic recorder from first system failed.	Graphic Recorder	Returned to Honeywell for repair.
24/10/74	1	Graphic recorder from second system failed.	Graphic Recorder	Readjusted in the field to operate.
4/11/74		Second graphic recorder to Honeywell for modification.		
23/11/74	1	First graphic recorder failed in lab.		Returned both units to Honeywell for modification.
22/1/75	1	Up to 9 record gaps on magtape recorder after datalog.	EACS Board 7	D4 (CD4023) of A7 Defective.
25/2/75	1, 2	Drift in sensitivity of graphic recorder such that small amplitude returns not recorded reliably.	Graphic Recorder	Modify EACS to add A "Confirmation Pulse" that identifies counted echoes-A14.
26/2/75	1, 2	Range 6 line on graphic recorder too wide.	EACS--Front Panel	Pull down resistors on switches changed from 100K to 22K.
26/2/75	1, 2	Blooming of graphic recorder trace during data logging.	EACS Board 8	Logic fault enabled range line marking circuitry to write on graphic recorder during data logging - A8 modified.
23/4/75	1	First field trial-graphic recorder blooming.	EACS	Dynamic range of signal to graphic recorder limited A14 both systems, drive signal terminated at graphic recorder to prevent oscillation.
24/4/75	1	Field trial -- 3 metre and range lines missing.	EACS	Bottom track servo locked on 3 metre line -- Modify A14 to prevent status signals from coupling into threshold detectors.