A BEDLOAD TRANSPORT ACOUSTIC MONITOR FOR USE IN RIVER SYSTEM STUDIES

UNPUBLISHED REPORT ES-504

B. White

B. White,
Electronic Engineering Unit,
Engineering Services Section,
CANADA CENTRE for INLAND WATERS
Burlington, Ontario, Canada.

November, 1974
Revised:- June, 1975.

TABLE OF CONTENTS

FIGURES

1. INTRODUCTION

A number of techniques have been applied to the monitoring of bedload transport in the lakes and rivers of Canada. The primary objective of this project was to provide a broadband, wide dynamic range, acoustic sensing and recording system targetted to collecting data which would offer an opportunity to better assess the potential for underwater acoustic measurements in the study of bedload transport. Although this was not the first such passive acoustic monitoring system to be deployed in fast flowing rivers, the performance objectives selected for this CCIW system were generally those of significantly increased frequency coverage; improved dynamic range; reduced self resonances; reduced hydrophone flow noise; and uniform spatial directivity in the total system bandwidth.

The system was developed in a limited engineering program from components of current technology. A target performance specification was prepared in conjunction with CCIW hydraulics specialists. To this end system components were specified, selected and obtained. A program of bench tests and underwater tests was undertaken to confirm the performance characteristics of the complete system. To date the system has seen use in monitoring spring flood conditions in rivers of lower mainland British Columbia.

The unpublished report following describes system design characteristics and its measured electroacoustic performance.

2. GENERAL SYSTEM DESCRIPTION

The design goal for the system was developed largely on the data base generated by the W.S.C. System (Appendix 1). The earlier data had shown spectra with broad spectral density peaks at low audio frequencies. This is consistent with the reverberation characteristics of the cross section of the river. Simplistic analysis of the possible resonant modes of the gravel material suggests that radiated acoustic energy should be observable well into the ultrasonic regime. This concern spurred interest in extending the system bandwidth as far as feasible.

The goal of attempting to sample the acoustic field in flooding rivers constrains the design of the experiment in a number of important areas. The turbulent flow of the rivers advects debris as well as bottom material. This requires the underwater assembly to be rugged and of minimal cross-section. The flow past the body and hydrophone produces both acoustic (radiating) and non-acoustic (non-radiating) pressure fluctuations. Skudrzyk (5) has shown that increasing the size of hydrophone sensor decreases its response to non-acoustic self flow noise (correlation decreases with length scale). The flow noise produced by turbulence associated with body hydrodynamics is not the sole acoustic limitation. The turbulence associated with the river flow itself also features radiating and non-radiating pressure fields. The latter is formed from a spectrum of length scales associated with the river flow and not constrained by the scales of flow past the sensor. This turbulence field is advected past the sensor. A final concern is the flow debris which may produce impact noise on the sensor assembly, and which may carry small air bubbles. The air bubbles act as efficient radiators at resonance.

2. <u>GENERAL SYSTEM DESCRIPTION</u> (Cont'd)

The only controllable aspects of the experiment are the site and the design of the equipment. The preferred site would be distant from waterfalls, rapids and hydraulic jumps. The equipment must be rugged, low drag, stabilized and suitable for deployment under field conditions. The system was designed for river deployment from a platform with a suitable winch (cable car, bridge, boat). The system was to be field transportable and capable of operation from portable power sources. The system is represented with the Functional Block Diagram, Figure 1, a sketch of the physical configuration for deployment, Figure 2, and the system photograph, Figure 3.

The space sampling, or directional characteristics of the system are important for the following reason. The objective of the measurement at hand is to monitor the acoustic energy radiated by events occuring on the river bed. To properly assess the spectral density it is necessary to have this directivity invariant with frequency and constant over the period of the measurement. Thus, the optimum hydrophone would be omnidirectional over the system bandwidth.

These general design goals translated into the quantitative system target performance specification are shown on the following page.

TARGET PERFORMANCE SPECIFICATION

CCIW ACOUSTIC MONITORING SYSTEM FOR FLUVIAL BEDLOAD TRANSPORT

Data Acquisition Mode

Monitored Frequency Band	:	10 Hz to 30 KHz
System Spatial Response	:	Omnidirectional, in above band.
System Dynamic Range	:	40 db or better.
Field Recording Technique	:	Half inch Magtape; 60 ips; FM recording DC to 30 KHz on 216 KHz IRIG carrier.
No. Frequency Bands Recorded	:	2 (see block diagram)
Band (1) Recording	:	Full Bandwidth (10 Hz to 30 KHz) 125 dB to + 165 dB re 1 μPa rms
Band (2) Recording	:	2 KHz to 30 KHz (hipass-filtered) 117 dB to 157 dB re 1 μPa rms
System Data (Tape) Capacity	:	10 minutes/pass (2 tracks) 3 passes/tape (6 tracks)
Range of Water Speeds	:	Zero to 3 m/s (stable body)
Body Effective Drag Coefficient	:	0.08
System Size and Weight	:	Body/200 cm x 20 cm/160 kg (350 lb.) Cable/ 30 m Electronics/ 80 kg
Pressure Rating	:	3450 kPa (500 psi)

Data-Reduction Mode

1. TRANSCRIBE DATA TO WIND/WAVE FLUME INSTRUMENTATION TAPE FACILITY FOR SECURITY.
2. PLAYBACK INTO BANDPASS FILTER / LOGARITHMIC DETECTOR SYSTEM AS IN 1973 SYSTEM.
3. PLAYBACK INTO REAL TIME SPECTRAL ANALYSIS FACILITY IF AVAILABLE.

3. DESIGN CHARACTERISTICS OF SYSTEM COMPONENTS

- Hydrophone (Electroacoustic Characteristics)

The hydrophone sensor is composed of a commercial spherical shell polarized ferro-electric ceramic transducer element and preamplifier. It features omnidirectional acoustic sensitivity, low sensitivity to vibration and low sensitivity to the non-acoustic pressure fields associated with turbulent flow. The preamplifier (+30dB gain) selects the system dynamic range and provides a low impedance drive for the cabling and system interconnection. The requirement that the hydrophone sensor be as free as possible from refraction, diffraction, resonance, and flow disturbance effects arising from the supporting structure was addressed by mounting the sensor upstream of the structure. This effort to achieve free field sensor performance had to be balanced against the requirement to protect the fragile sensor element from minor collisions with flow debris. A rod cage of minimal acoustic and flow interference effects was added.

Figure 5 shows the design configuration of this hydrophone/pre amp subassembly, and Figure 6 shows both external and internal (x-ray) construction. The unit was designed, manufactured, and calibrated by International Transducer Corporation, Goleta, California.

3. DESIGN CHARACTERISTICS OF SYSTEM COMPONENTS (Cont'd.)

- Hydrophone Sensor - (Hydrodynamic Characteristics)

The hydrophone was especially configured by the manufacturer to mate with the mechanical structure developed at CCIW to support it in the flow. As illustrated in Figure 5 the hydrophone has a hemi-spherical nose which covers the sensor element and a body of cylindrical cross-section which is tapered to the diameter of the support tube. The sensor element is supported by the rho-c urethane which, is in turn, bonded to the stainless steel preamplifier housing/hydrophone support. It was intended that flow separation be moved as far as possible downstream from the element. The final shape was constrained by molding technology.

The protective rod cage was formed with faired sections to reduce turbulence and drag. The ungainly requirement of supporting the hydrophone upstream of the support structure increases the drag. To maintain a reasonable wire angle in high flow velocity deployment, a large depressive force is required. This was achieved statically with a large dead weight support structure rather than dynamically, due to flow noise and turbulence considerations. The total weight of the streamlined structure is 350 pounds in air. It is formed from a centre support frame and two half-body ballast pieces cast from lead. The structure (Figure 9) can be disassembled for transport. The tail of the body is fitted with closely coupled, rugged fins. These serve to align the body with the mean flow and to damp inertial oscillations. The body is supported by a faired tow bar which is pivoted at the centre line of the body. The fairing is free to rotate to minimize side lift forces. The signal cable is routed through the support tubing and up through the tow bar.

3. DESIGN CHARACTERISTICS OF SYSTEM COMPONENTS (Cont'd.)

- Data Recording Subsystem

  The preamplifier of the hydrophone is connected with the surface power supply and data recording subsystem by the signal cable. The signal is fed through a matched 8.9 dB attenuator to one input channel of a portable instrumentation recorder. The recorder is configured as a 3 x 2 channel, wideband FM system operating at 60 ips from 24 VDC with 1/2 inch tape. (IRIG WB GROUP I FM, 216 kHz cf, 40 kHz BW, >40 dB SNR). The second input channel is fed via a unity gain, 2 kHz hi-pass active filter. This second channel was recorded to expand the dynamic range of the system in the potentially most significant part of the total signal band, and to guard against saturation, due to low frequency noise sources. The voice track was used to reinforce data identification. The tapes are protected in magnetically shielded storage cans.

- Data Replay Subsystem

  The same recorder was used to replay the field tapes for data analysis. The data was analysed using 1/3 octave filtering and a logarithmic detector. The data has been re recorded on an in house laboratory. instrumentation recorder with present plans for FFT analysis.

The interconnection schematics for both record and replay modes are illustrated in Figure 4 (a and b).

4. SYSTEM PERFORMANCE TESTS AND CALIBRATIONS

- Hydrophone Assembly

The individual hydrophone subassemblies, including preamplifiers were calibrated by the supplier prior to delivery at frequencies from 2 kHz to 30 kHz. This data for device S/N01 is presented in Figure 7. The hydrophone acoustic sensitivity is frequency independent below 5 kHz. At very low frequencies, of the order of 10 Hz, the capacitance of the sensing element and the finite input impedance of the preamplifier limit the response. The hydrophone subassembly was demonstrated to be omnidirectional ± 6 dB up to 30 kHz. The element self resonance is about 40 kHz.

The complete hydrophone assembly including the streamlined body (Figure 9) was calibrated as a unit by C-Tech in Cornwall. These results were obtained using an improved mounting jig necessary for the calibration and a low frequency calibration transducer (J11 series). The frequency sweep, Figure 8(a), shows an 9 dB discrepancy in sensitivity between the measurements made with the two calibration reference transducers at 10 kHz. The trend of the data suggests that this hydrophone assembly has an essentially flat response from below 500 Hz to 30 kHz. The cause for the measurement discrepancy is thought to be due to the deviation of the particular J11 transducer used from their generic sensitivity characteristic and possible alignment errors in the calibration arrangement. The latter would, when coupled with the increasing directivity of the reference transducer with frequency, give rise to the sloping sensitivity characteristic measured.

4. SYSTEM PERFORMANCE TESTS AND CALIBRATIONS

- Hydrophone Assembly (Cont'd)

The directional characteristics of the complete assembly are presented in Figure 8(b) - (j). A point of special interest is indicated in Figure 8(e) - horizontal pattern at 2 kHz. At this frequency when the acoustic field propagates along the axis of the body, energy reflected from the mass of the body destructively interferes with the field at the hydrophone. This produces an apparent loss of sensitivity of 6.5 dB in the narrow band associated with this phenomenon. At the harmonics of this frequency, the phenomenon would repeat. One would also anticipate that there would exist frequencies for which constructive interference would occur. These sensitivity measurements are made in a tone burst mode to avoid extraneous reflections from the boundaries of the calibration facility and other hardware. Since one has control over the length of the tone burst, and the portion of the tone burst used for measurement at the receiving equipment, it is possible to produce a variety of estimates of the system sensitivity. The selection of the preferred estimate is best made after defining the nature of the measurement to which the system is to be applied.

Throughout the directivity measurements there are features of small angular extent but indicating large fluctuations in received energy. These are associated with the background acoustic noise in the calibration facility - in most cases noise caused by ice cracking. Up to 10 kHz, the assembly response is omidirecitonal +1, -6dB. There appears to be some influence of the rode cage in the horizontal measurements. Figures 8(i), and 8(j), show

4. SYSTEM PERFORMANCE TESTS AND CALIBRATIONS

- Hydrophone Assembly (Cont'd)

that the support structure causes significant deformations of the directional response. Reflections from the structure, diffraction and refraction by the structure all contribute to this deformation. Another potential source of deformation is that of air bubbles trapped in or attached to the structure. This hazard could be reduced by improving the finishing of the body -- filling voids and surface irregularities.

These hydrophone assembly tests demonstrated that the primary acoustic limitation of the system was the loss of omnidirectionality above 10 kHz due to the support platform. (Figure 8). The hydrophone rod cage produced no detectable deformation of the hydrophone response. The hydrodynamic characteristics of the assembly were determined in the CCIW Tow Tank facility. The assembly was demonstrated to tow stably to speeds in excess of 3 $msec^{-1}$. (Figure 10).

Attempts to date at measuring the self flow noise of the hydrophone assembly were thwarted by the high acoustic background produced by the towing carriage and the reverberant characteristics of the tow tank. The traditional absolute measurements of flow noise have been made for buoyant bodies modelled after torpedoes. For these measurements [5], the velocities are greater than 10 meter per second. In attempting to scale these results in order to obtain an estimate of flow noise effects for this system there are several points worth noting.

4. SYSTEM PERFORMANCE TESTS AND CALIBRATIONS

- Hydrophone Assembly (Cont'd)

First, the Reynolds' number for this system is of the order of 30 times smaller than for the buoyant body studies referenced. This implies that those aspects of the turbulence as determined by the Reynolds' number will not be largely comparable. Second, the construction of the hydrophone and the hydrophone assembly differ widely from the construction of the buoyant bodies. The effect of wall vibrations, especially in the case of the hydrophone, and those of the shape and surface imperfections of the assembly are essentially unknown for this system.

With the above reservations, it is possible to formulate an estimate of the broad band sound pressure level equivalent for this system deployed in a 3 ms^{-1} flow of +40 dB re 1μPa rms. The broad band noise for seastate zero is approximately +80 dB re 1μPa rms. Both these values are far below the system noise threshold and are outside of the possible dynamic range. Thus it would appear that the system self flow noise is below the minimum detectable signal. It should be remembered, however, that the recorded signal will include acoustic sources other than the collisions of the bed material.

- Data Recording

The recording electronics were set up and tested as detailed by the manufacturer. Efforts were made to record noise signals similar to those anticipated in the field to familiarize the users with the equipment and its operation.

4. SYSTEM PERFORMANCE TESTS AND CALIBRATIONS

- Data Recording (Cont'd)

The record and replay electronics were checked following the field exercise and were found to be satisfactory. On the broadband channel (10 Hz to 30 kHz) these electronics limit system dynamic range. On the midband channel the active filter cut-off at 2 kHz was checked to be 48 db/octave slope.

5. SUMMARY OF INITIAL FIELD & LABORATORY EXPERIENCE WITH THE SYSTEM:

The complete system has seen considerable use during the 1974 field season, deployed at sites on the Fraser and Vedder rivers of lower mainland British Columbia. Significant amounts of acoustic data were recorded. The system was operated from a cable car on the Vedder river and from a catamaran on the Fraser.

Difficulty was experienced in handling the complete hydrophone assembly as a unit, due to the weight and lack of suitable equipment in the field. The weight was judged to be excessive for the requirements of operating in the Vedder river but was necessary for the Fraser. Care was taken to avoid collisions with major debris in the flow in the case of the Vedder river. The greater depth of the Fraser and the conditions of operating from a catamaran in the flow eliminated any possibility of such manoeuvers.

The Honeywell Instrumentation recorder suffered an electronic fault in the field which was diagnosed and repaired by a Honeywell representative. Subsequent faults -- both mechanical and electronic appeared when the recorder was used to transcribe the data back at CCIW. It does not appear that the faults affected the recorded data. It would have been preferable to have recorded the data under "tape servo" rather than the reference internal to the machine as the last reported fault affects the internal reference.

The shield/ground problem in the hydrophone preamplifier was observed not to be a problem in the field, due to the remote nature of the experimental sites.

6. CONCLUSION

This limited engineering program has produced a useful system for monitoring the audio and near ultrasonic acoustic environment in fast flowing rivers, utilising the low drag deadweight depressed towbody which has been developed. Other applications for the wideband omnidirectional acoustic receiving system are also anticipated, both passive listening and transponding.

The electroacoustic characteristics of the hydrophone assembly are essentially flat up to 10 kHz, and have been determined to within ± 3 dB up to 30 kHz. The rugged hydrophone cage, necessary for protection in this severe operating environment, has been shown to be adequately transparent acoustically.
At the time of writing some effort continues, to round off the VLF testing and calibration phase, to recalibrate following successful correction of a shielding/ground problem, and as far as possible to reduce any residual uncertainties in system measured performance. Following that, if resources are available, the system can be further improved if necessary, by optimising the exterior shape and finish of the towbody structure to further reduce drag and flow noise, and to eliminate any residual directional limitations imposed by trapped air bubbles.

Hopefully, the system will see extensive use in river regimes where significant fluxes of bedload material have to be measured, so that, should a data base develop showing specific acoustic frequency bands associated with bedload transport, a system tailored to the selective monitoring of these signals could be readily developed in a more optimum form.

7. REFERENCES:

1. "Observation of the Noise of Bed Load" Bedeus, K. and Ivicsics, L. Publication 65, L'Association Internationale d'Hydrologie Scientifique. (1964). pp. 384-390.

2. "On the Noise of Waterfalls" Arabadzhi, V.I., Soviet Physics (Acoustics), 13, 1, 1967, pp. 102-103.

3. "Acoustic Detection of Bed Load Transport" Tywoniuk, N. and Warnock, R.G. Proceedings of 9th Canadian Hydrology Symposium. University of Alberta. May, 1973.

4. "Acoustic Detection of Sediment Movement" Johnson, P. and Muir, T.C. Journal of Hydraulic Research, 7, 4, 1969, pp. 519-539.

5. "The Physics of Flow Noise" Haddle, G.P. and Skudrzyk, E.J. Journal of the Acoustical Society of America, 46, 1, pp. 130-157.

APPENDIX I

WATER SURVEY OF CANADA

W.S.C. BEDLOAD MONITORING SYSTEM

PERFORMANCE SUMMARY:-

SYSTEM BANDWIDTH (DATA ACQUISITION):	100 Hz - 3 kHz (approx.)
DIRECTIONAL RESPONSE:	OMNI BELOW 1 kHz
DYNAMIC RANGE:	35 db (140 TO 175 dB μPa rms)
SPECTRAL ANALYSIS:	1 OR 1/3 OCTAVE FILTERING; LOGARITHMIC DETECTION.

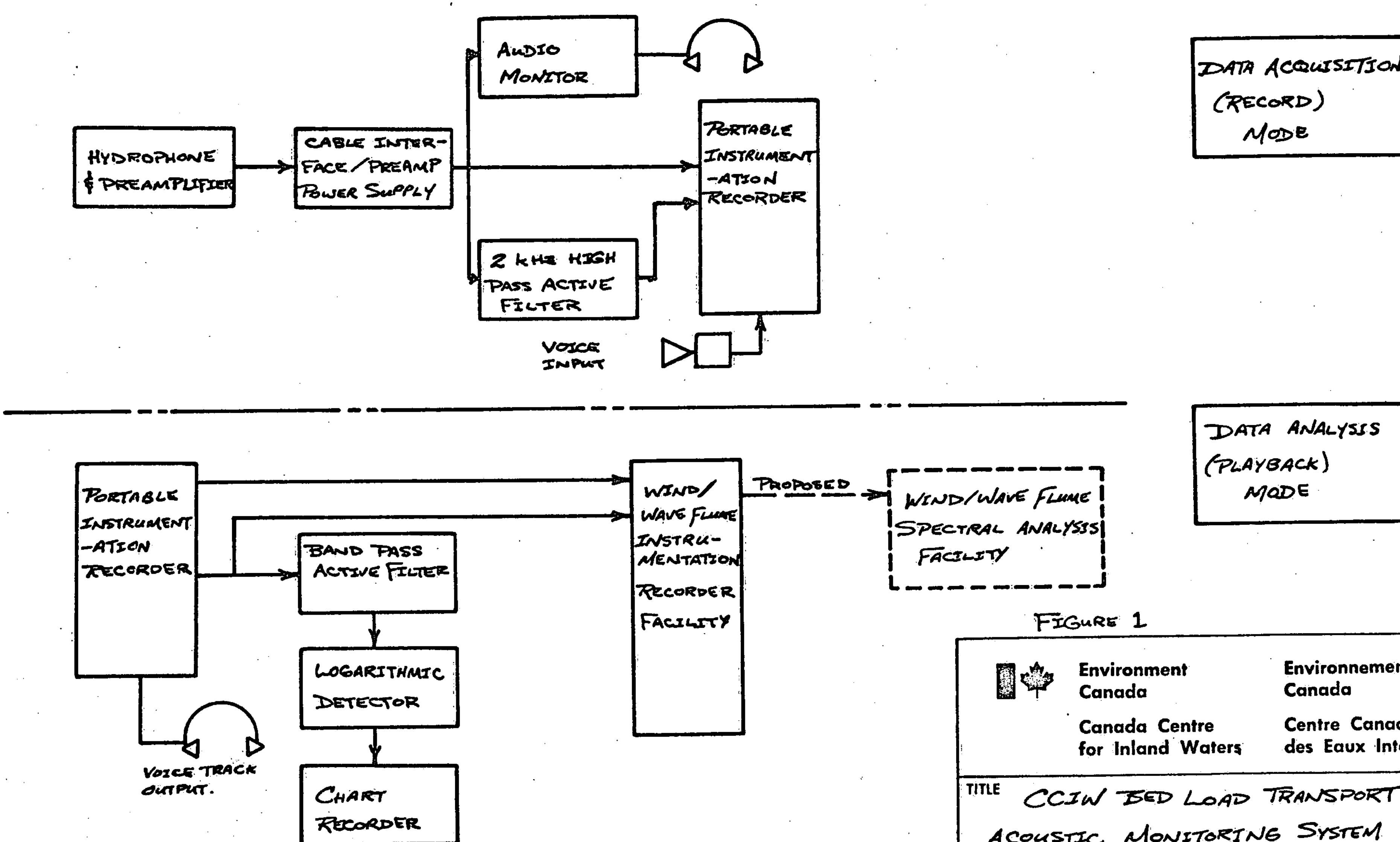


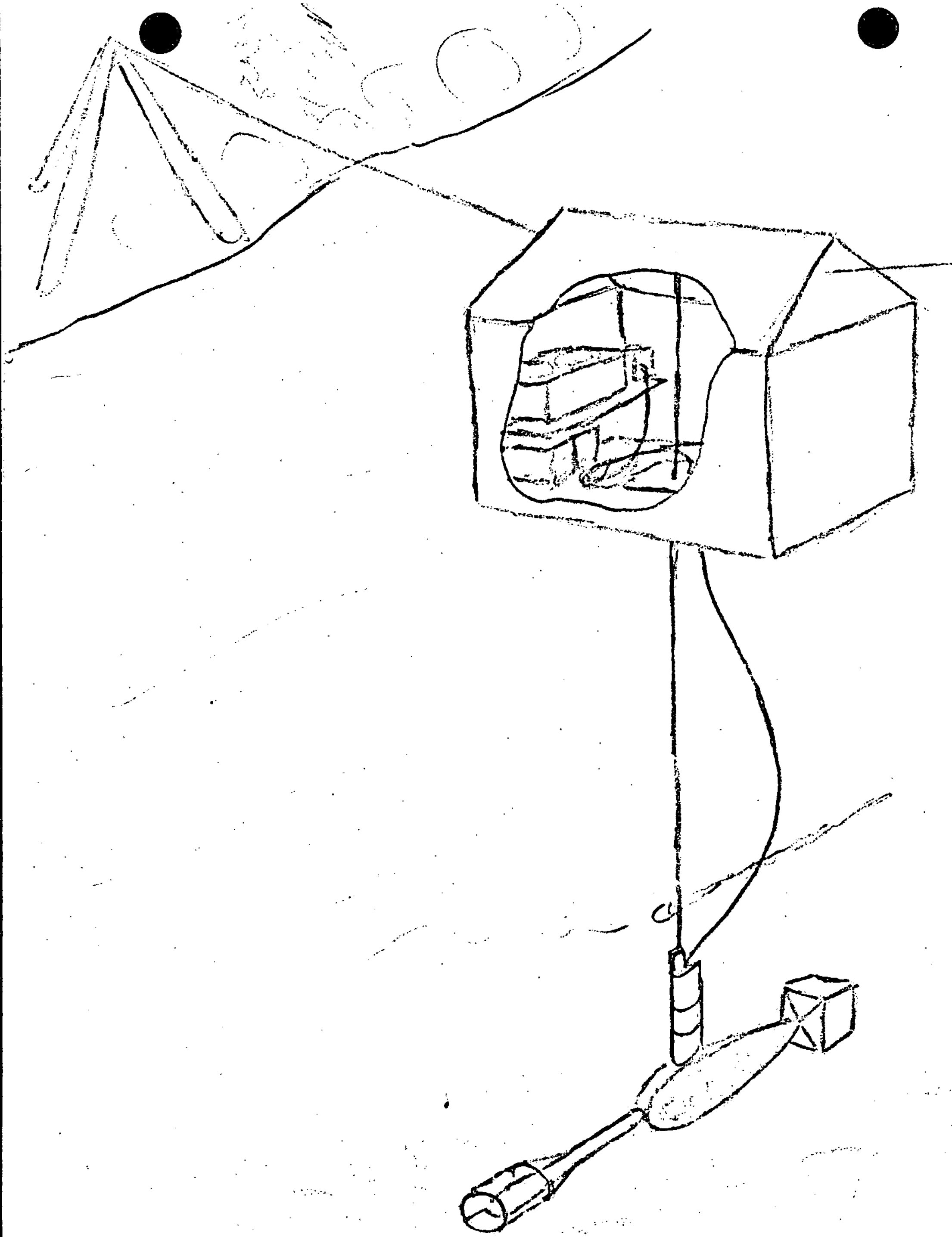
FIGURE 1

Environment Canada / Canada Centre for Inland Waters	Environnement Canada / Centre Canadien des Eaux Interieures

TITLE: CCIW BED LOAD TRANSPORT ACOUSTIC MONITORING SYSTEM FUNCTIONAL BLOCK DIAGRAM

DESIGNED BY	CHECKED BY	APPROVED BY
DRAWN BY BFW.	CHECKED BY	DRAWING NO.
SCALE	DATE Nov. 4/74.	SHEET OF

R.B.P.



NOT TO SCALE.

FIGURE 2

Environment Canada	Environnement Canada
Canada Centre for Inland Waters	Centre Canadien des Eaux Interieures

TITLE SKETCH OF BEDLOAD TRANSPORT ACOUSTIC MONITORING SYSTEM -- DEPLOYED AT VEDDER RIVER

DESIGNED BY	CHECKED BY	APPROVED BY
DRAWN BY B.W.	CHECKED BY	DRAWING NO.
SCALE NTS	DATE 4/11/74	SHEET OF

R.B.P.

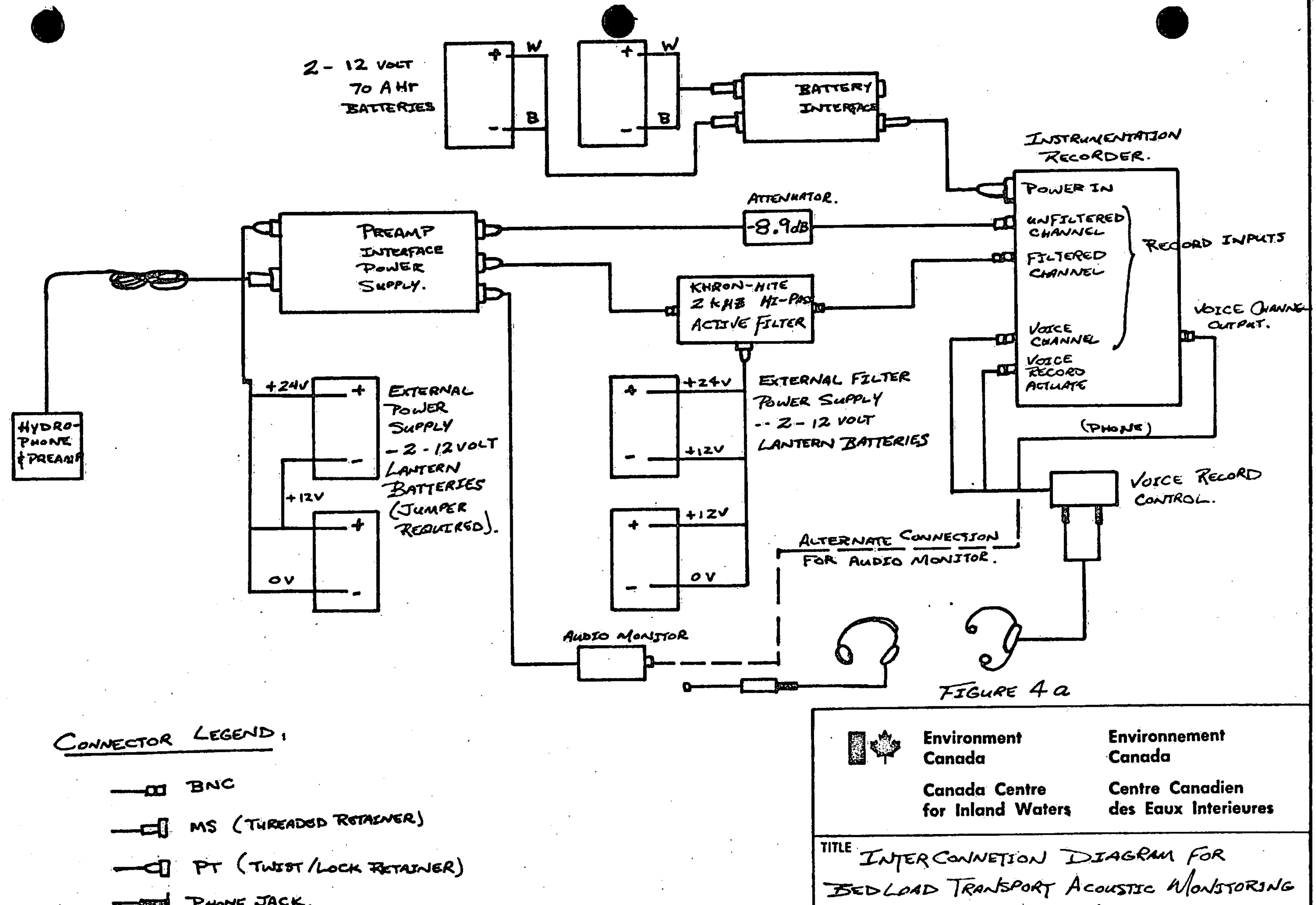


FIGURE 4a

Environment Canada — Environnement Canada

Canada Centre for Inland Waters — Centre Canadien des Eaux Interieures

TITLE INTERCONNECTION DIAGRAM FOR BEDLOAD TRANSPORT ACOUSTIC MONITORING SYSTEM -- RECORD MODE		
DESIGNED BY	CHECKED BY	APPROVED BY
DRAWN BY EFW	CHECKED BY	DRAWING NO.
SCALE ___	DATE 9/5/74.	SHEET OF

R.B.P.-72

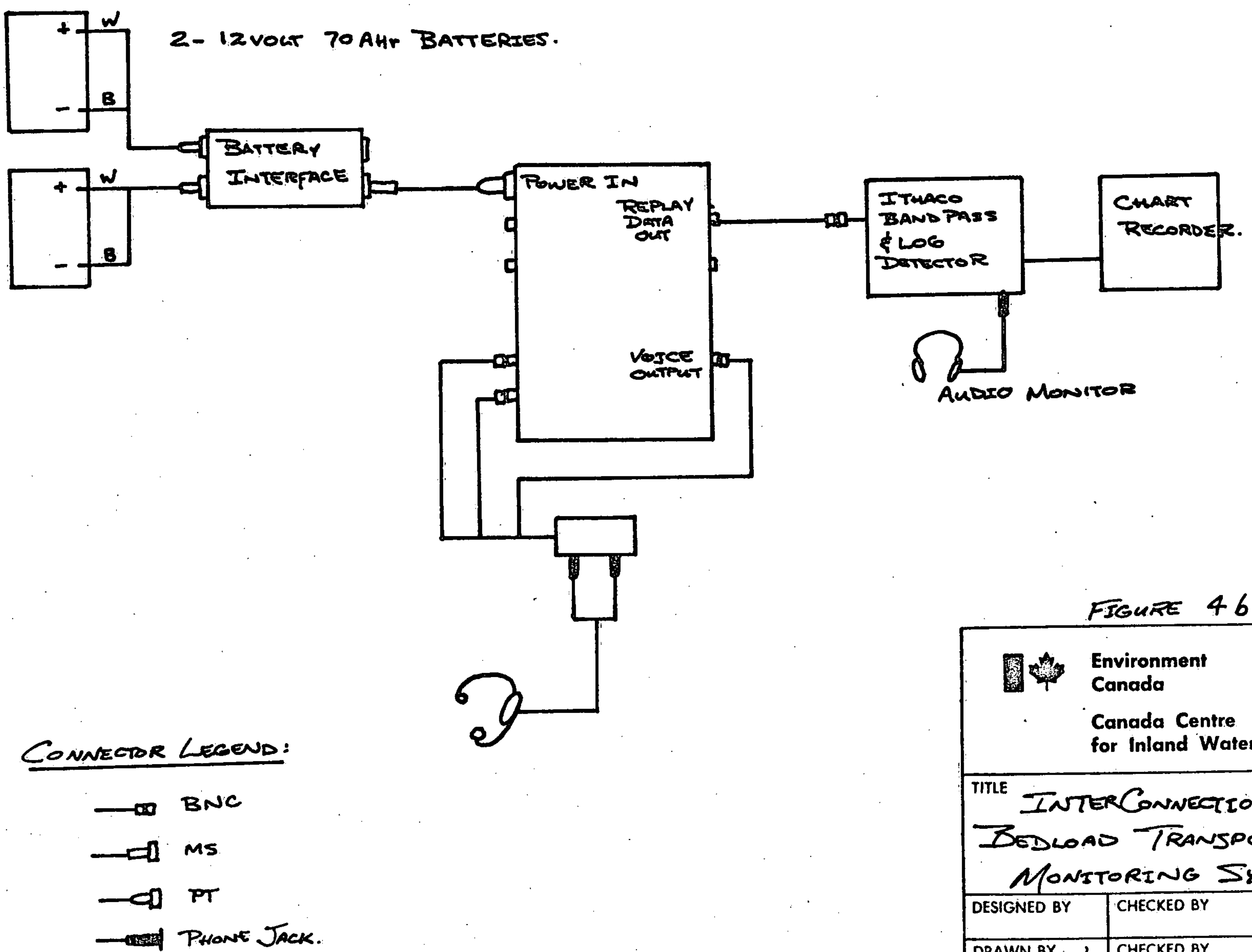


FIGURE 46

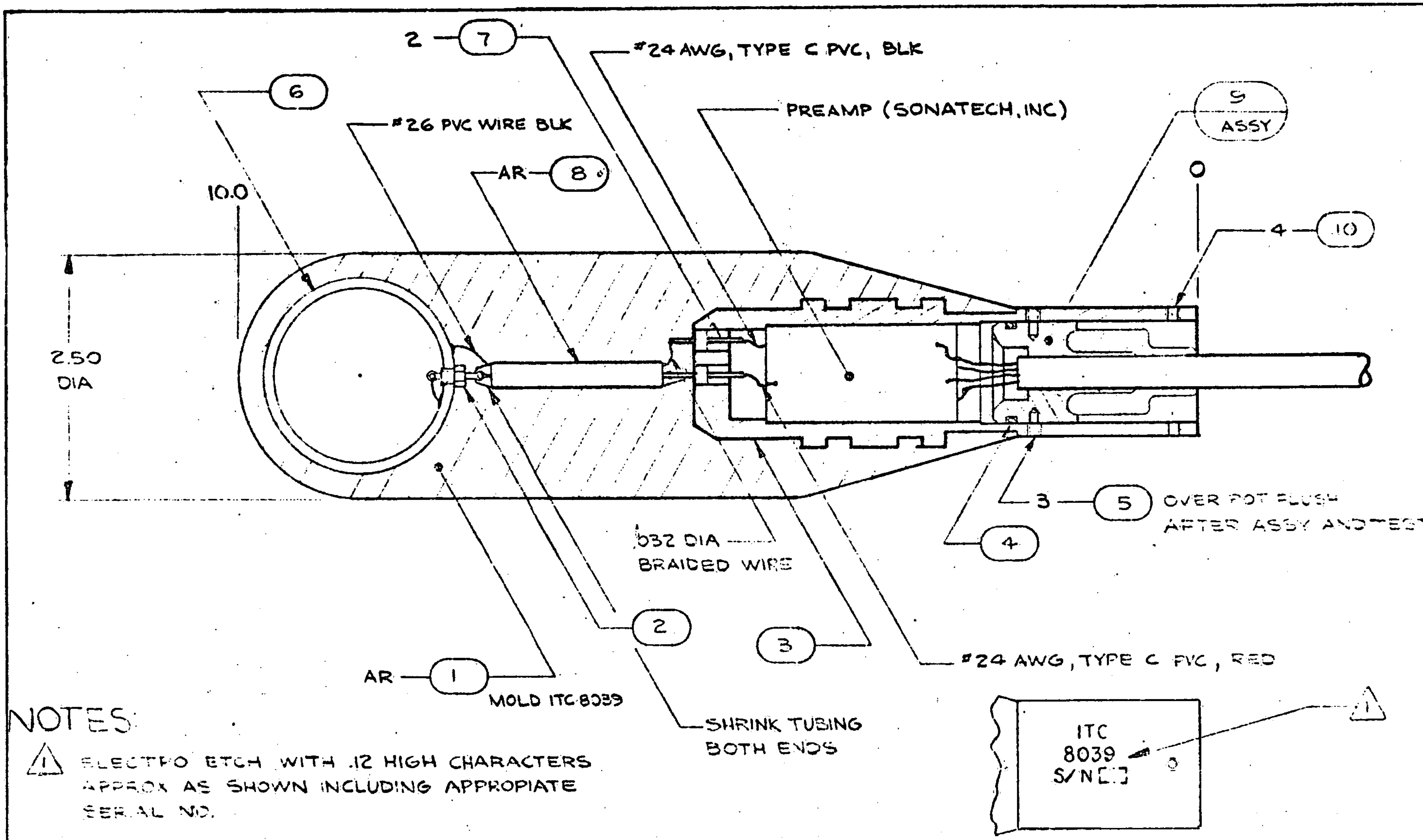
Environment Canada | Environnement Canada

Canada Centre for Inland Waters | Centre Canadien des Eaux Interieures

TITLE INTERCONNECTION DIAGRAM FOR BEDLOAD TRANSPORT ACOUSTIC MONITORING SYSTEM -- REPLAY MODE

DESIGNED BY	CHECKED BY	APPROVED BY
DRAWN BY EFW	CHECKED BY	DRAWING NO.
SCALE —	DATE 9/5/94	SHEET OF

R.B.P.



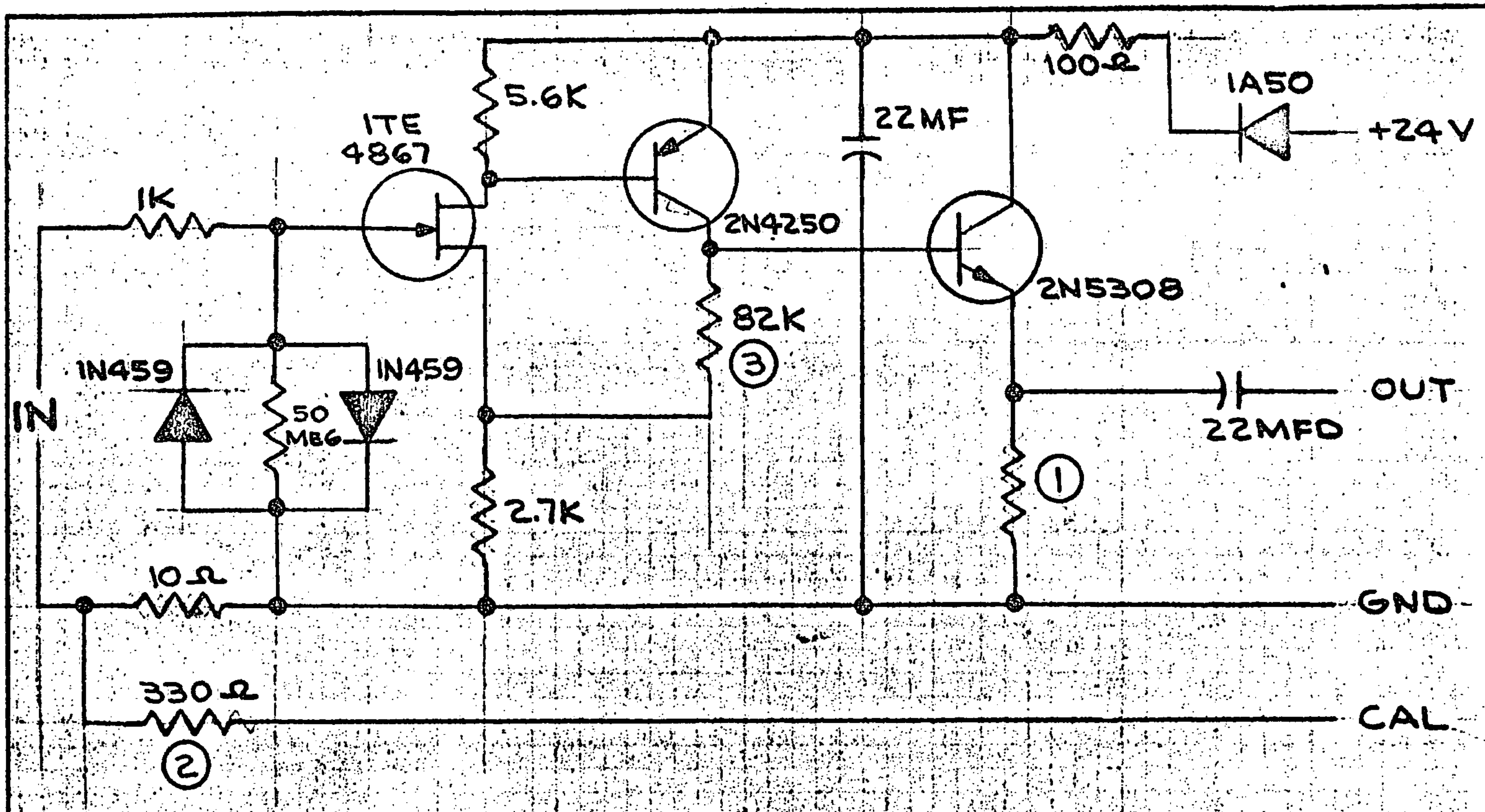
NOTES:

1. ELECTRO ETCH WITH .12 HIGH CHARACTERS APPROX AS SHOWN INCLUDING APPROPIATE SERIAL NO.

ISSUE	REVISIONS	DATE	ITC8039

HYDROPHONE SUBASSEMBLY

FIGURE 5a



① T & C for 8 Ma

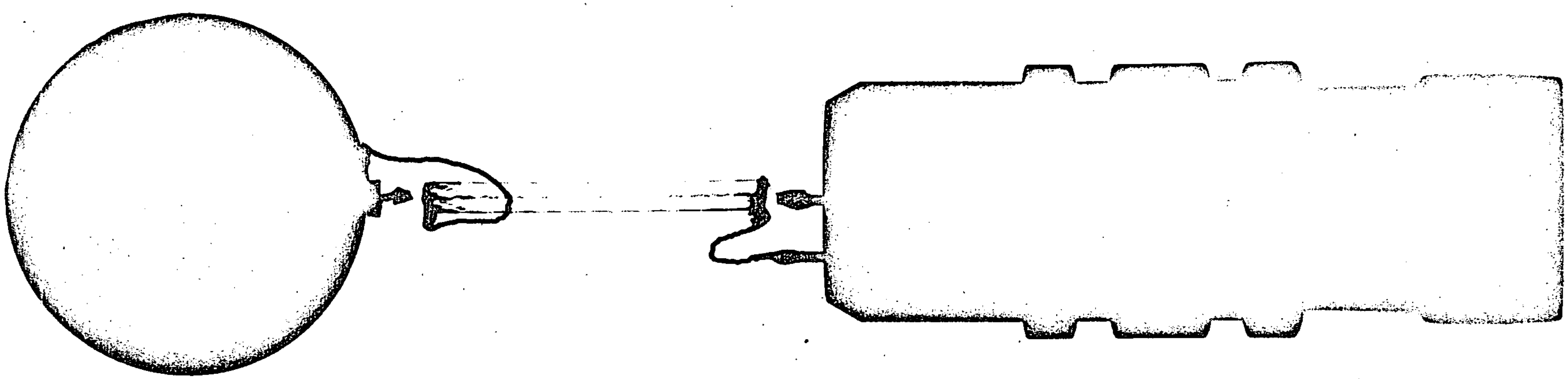
② T & C for 30 db pad

③ T & C for 30 db gain at 1 kHz

PREAMPLIFIER SCHEMATIC

FIGURE 5b

INTERNATIONAL TRANSDUCER CORP. SANTA BARBARA, CALIFORNIA	DWG. NO.
TITLE SCHEMATIC PRE-AMP(ITC-9029)	
DRAWING NO. 1566	
DRAWN G.B.H. 9APR74 · SCALE ~	



Environment Canada
Canada Centre for Inland Waters

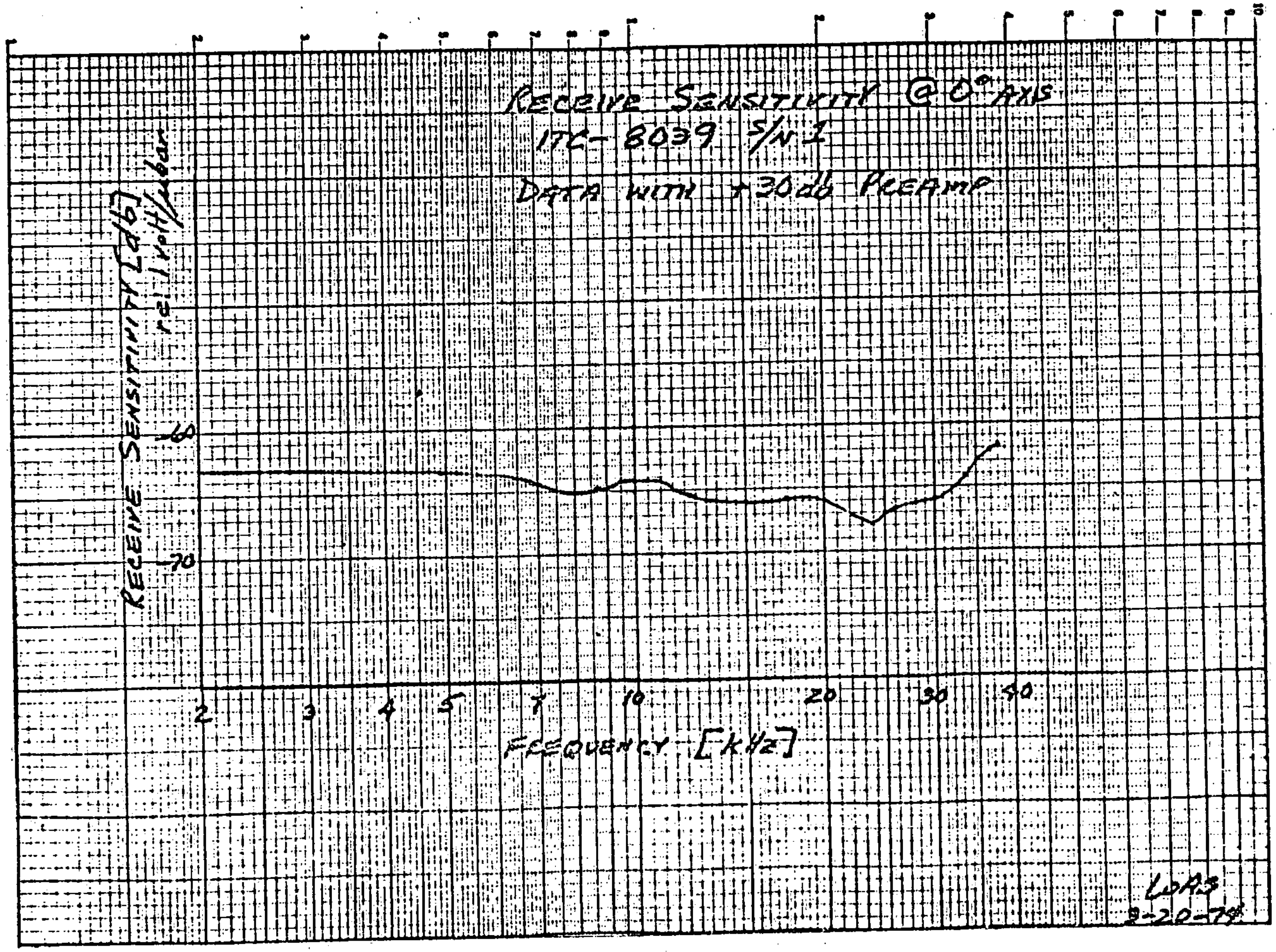
Environnement Canada
Centre Canadien des Eaux Interieures

TI

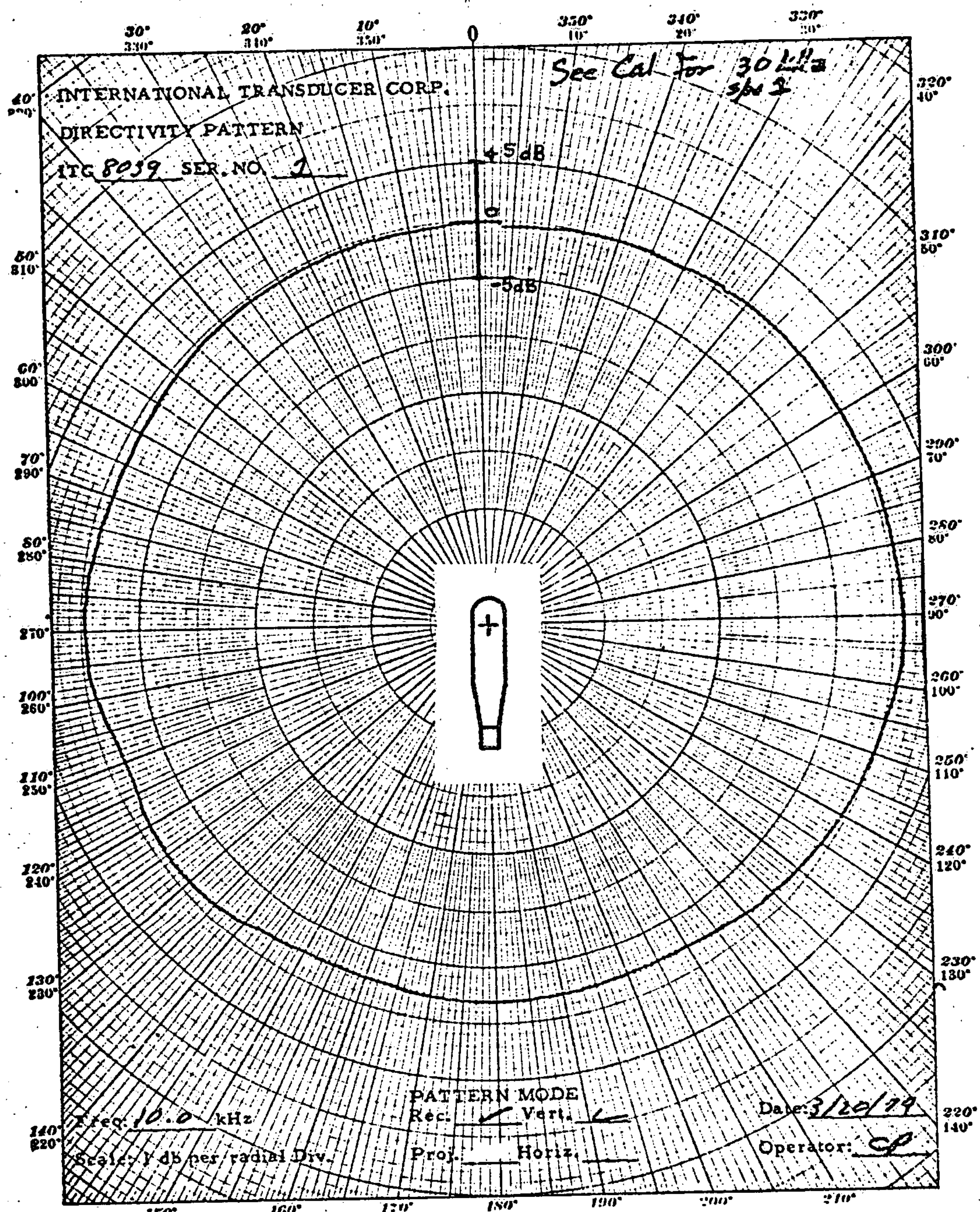
X-RAY IMAGE OF HYDROPHONE SUBASSEMBLY
FIGURE 6(b)

DESIGNED BY	CHECKED BY	APPROVED BY
DRAWN BY	CHECKED BY	DRAWING NO.
SCALE	DATE	SHEET OF

R.B.P.

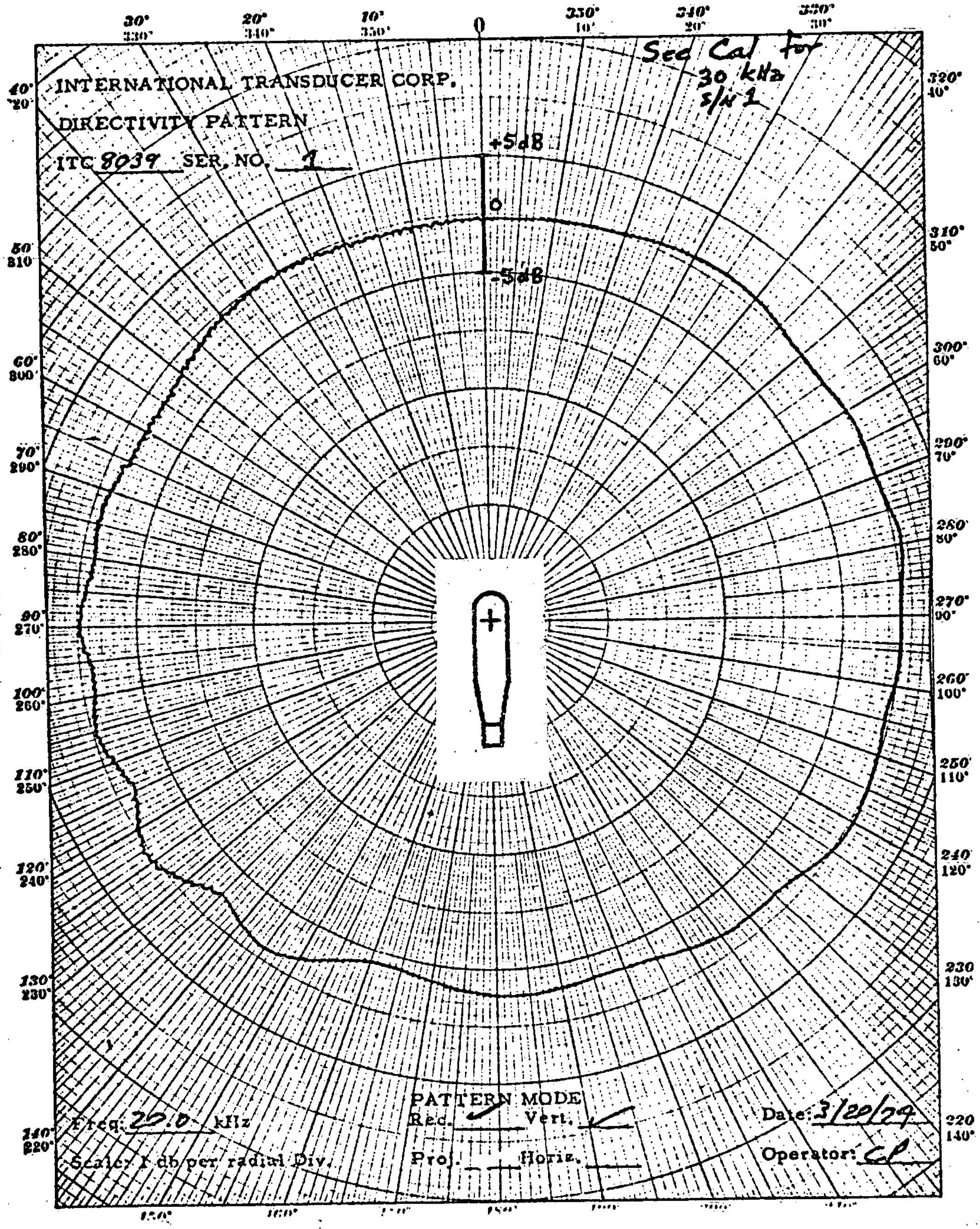


ACOUSTIC SENSITIVITY RESPONSE OF HYDROPHONE SUBASSEMBLY (ITC)
FREQUENCY SWEEP
Figure 7(a)



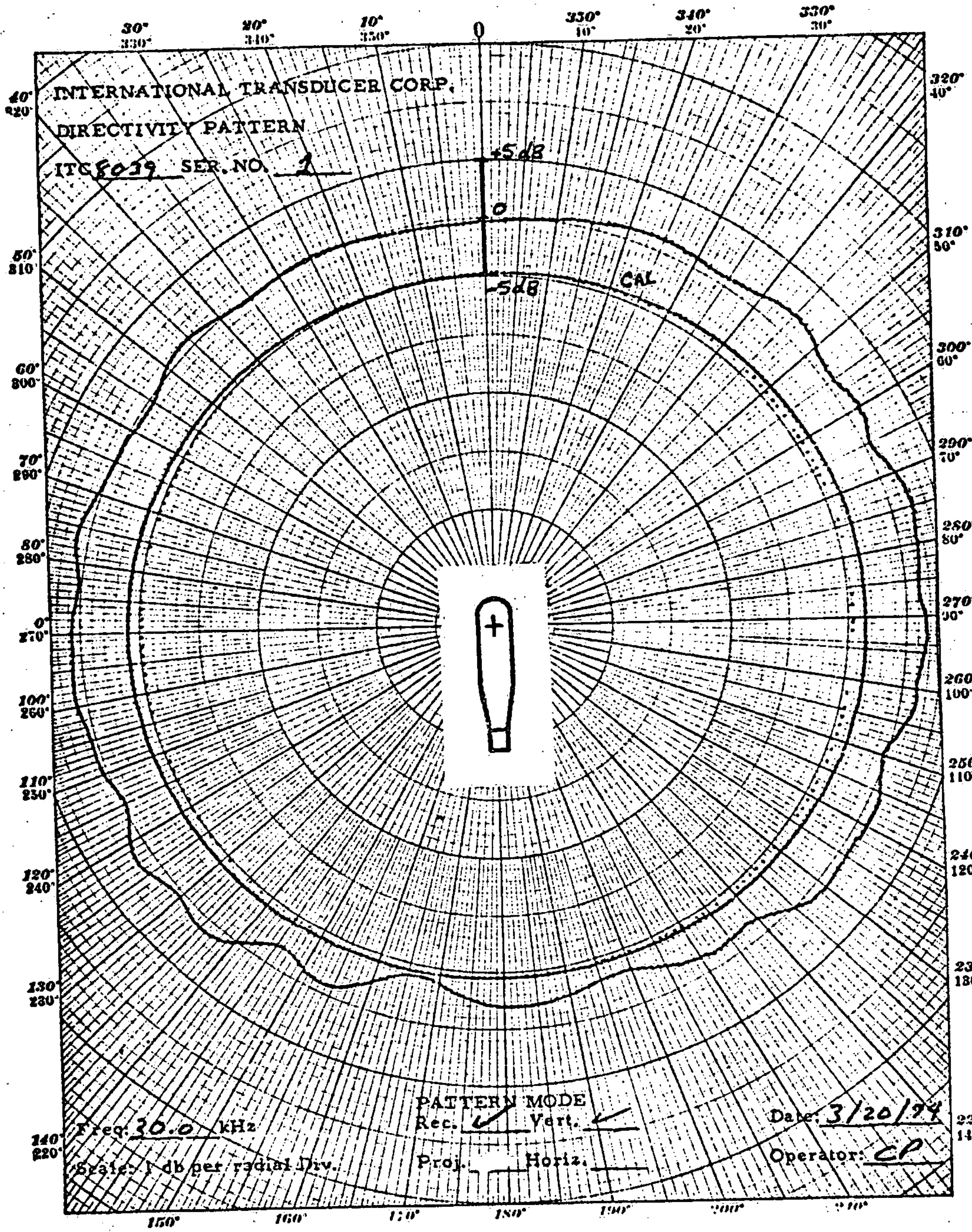
DIRECTIONAL RESPONSE – 10 kHz

Figure 7(b)



DIRECTIONAL RESPONSE – 20 kHz

Figure 7(c)



DIRECTIONAL RESPONSE – 30 kHz

Figure 7(d)

C-TECH UNDERWATER TEST SITE FEBRUARY 6 1975

Receiving Sensitivity, Mounted Vertical

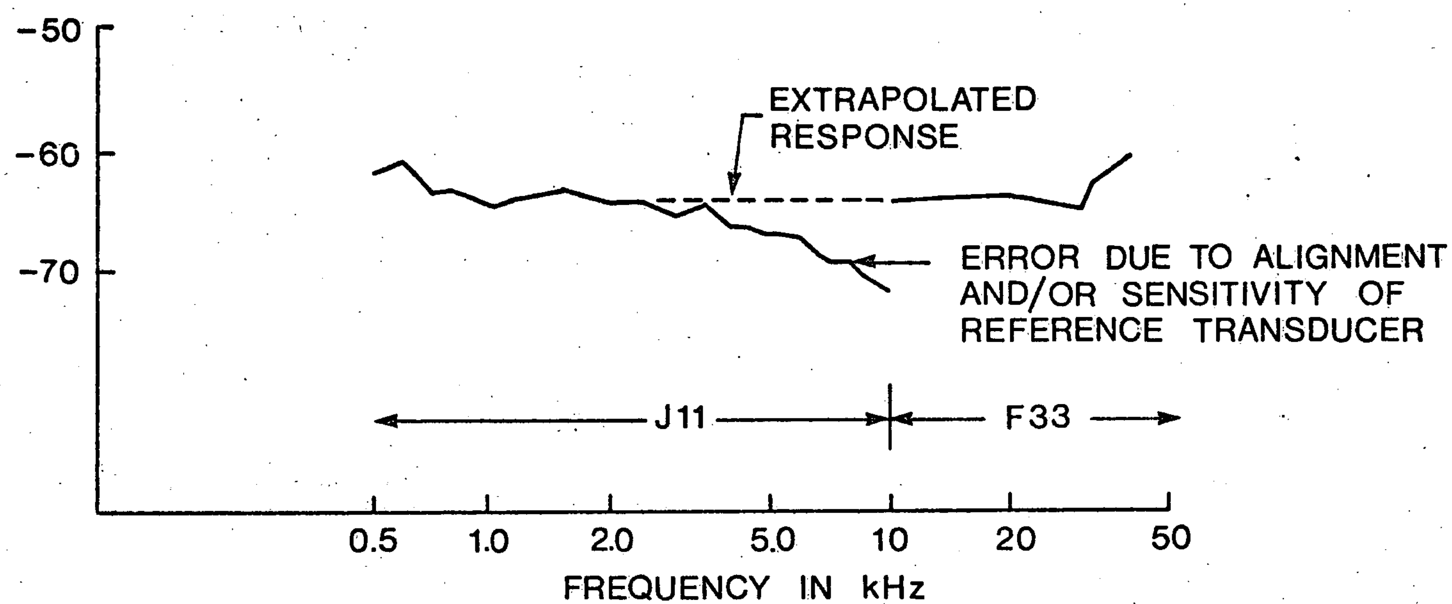
ITC 8039 Serial 1, c/w Towed Body

Data with 30 dB Preamp

Transmitting Projector 500 to 10,000 Hz J11 – 10 kHz to 40 kHz F33

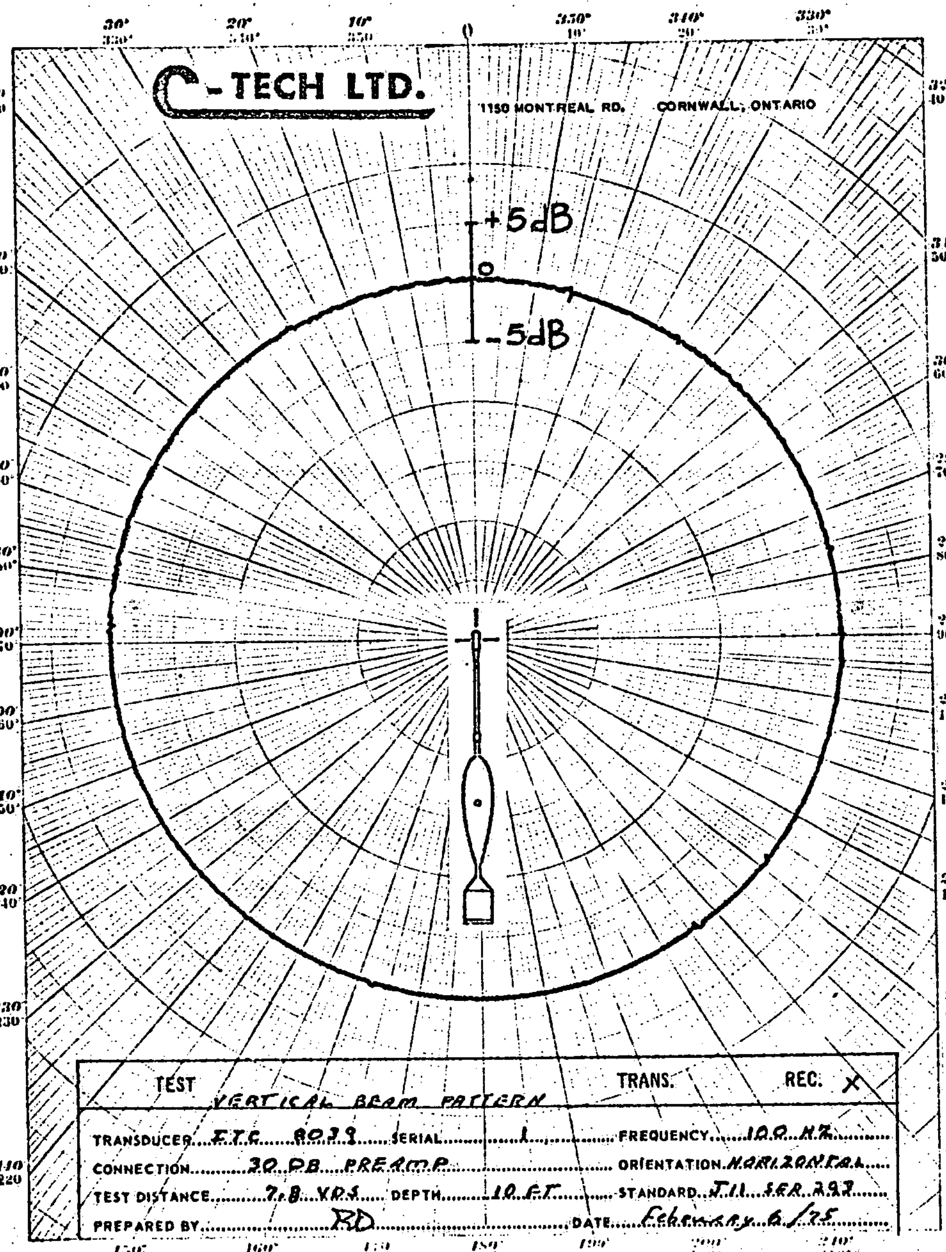
Test Distance J11 23.5 ft
F33 16.0 ft

Water Temp. 3.3 °C



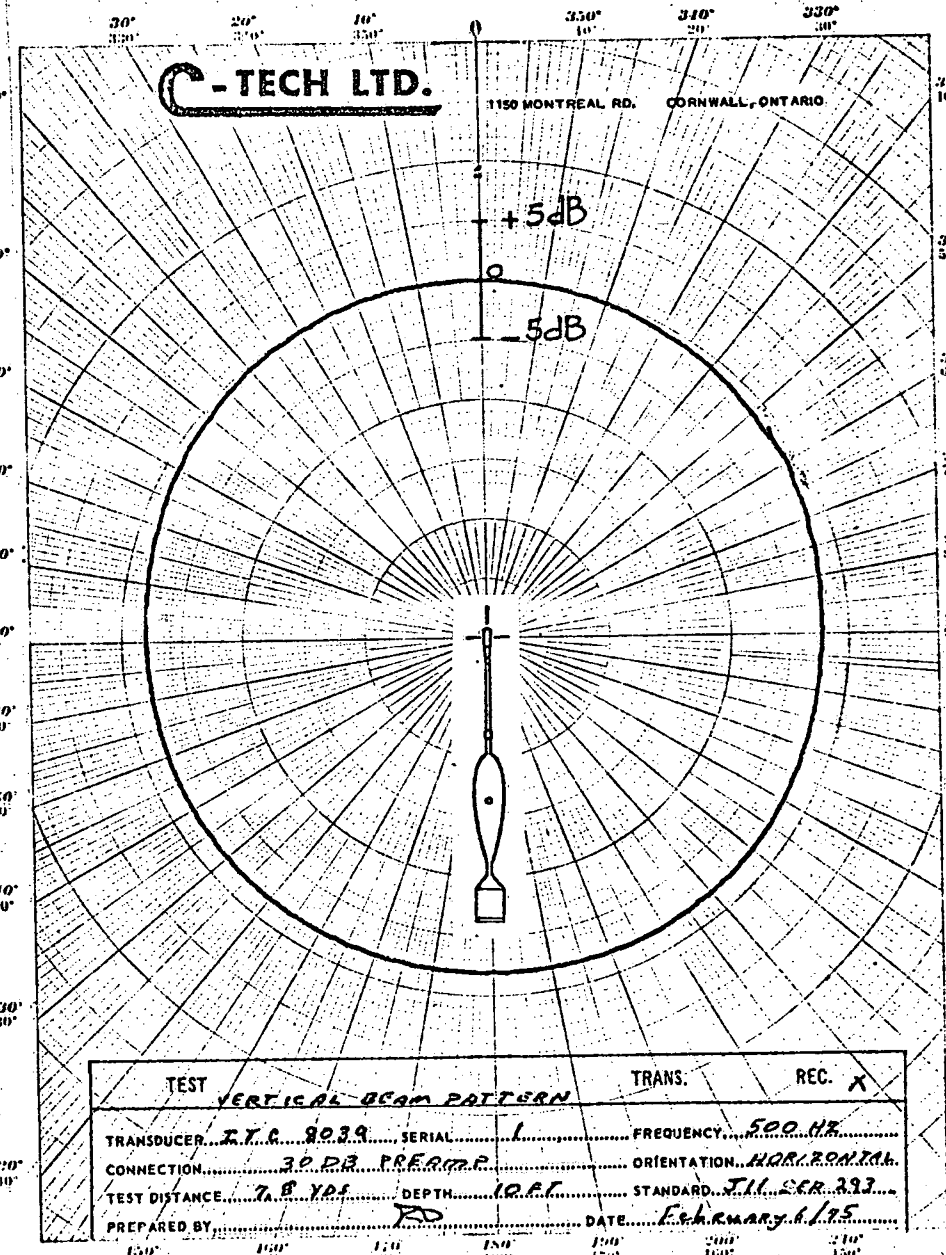
ACOUSTIC SENSITIVITY RESPONSE OF HYDROPHONE ASSEMBLY FREQUENCY SWEEP

Figure 8 (a)



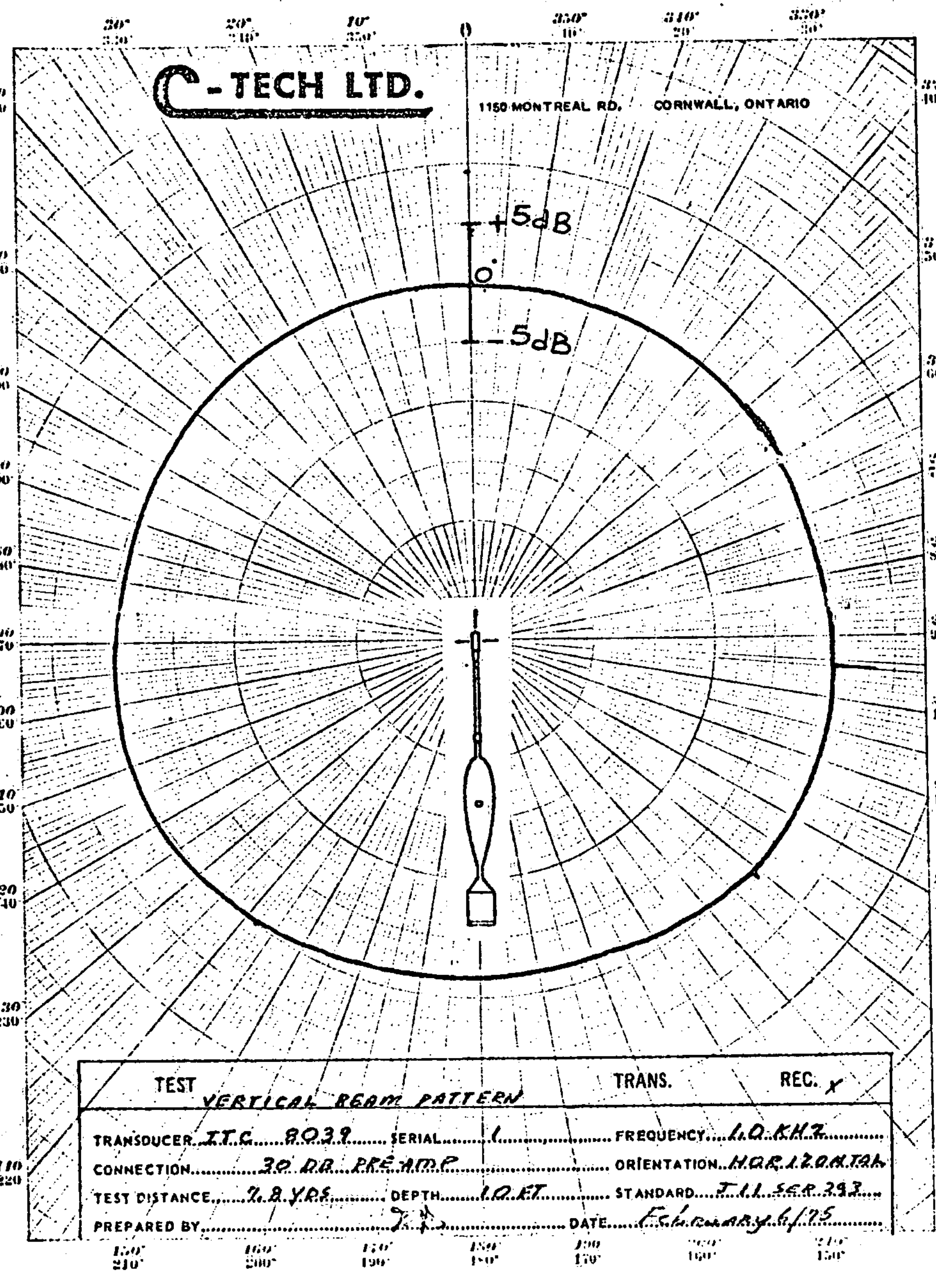
DIRECTIONAL RESPONSE - 100 Hz

Figure 8(b)



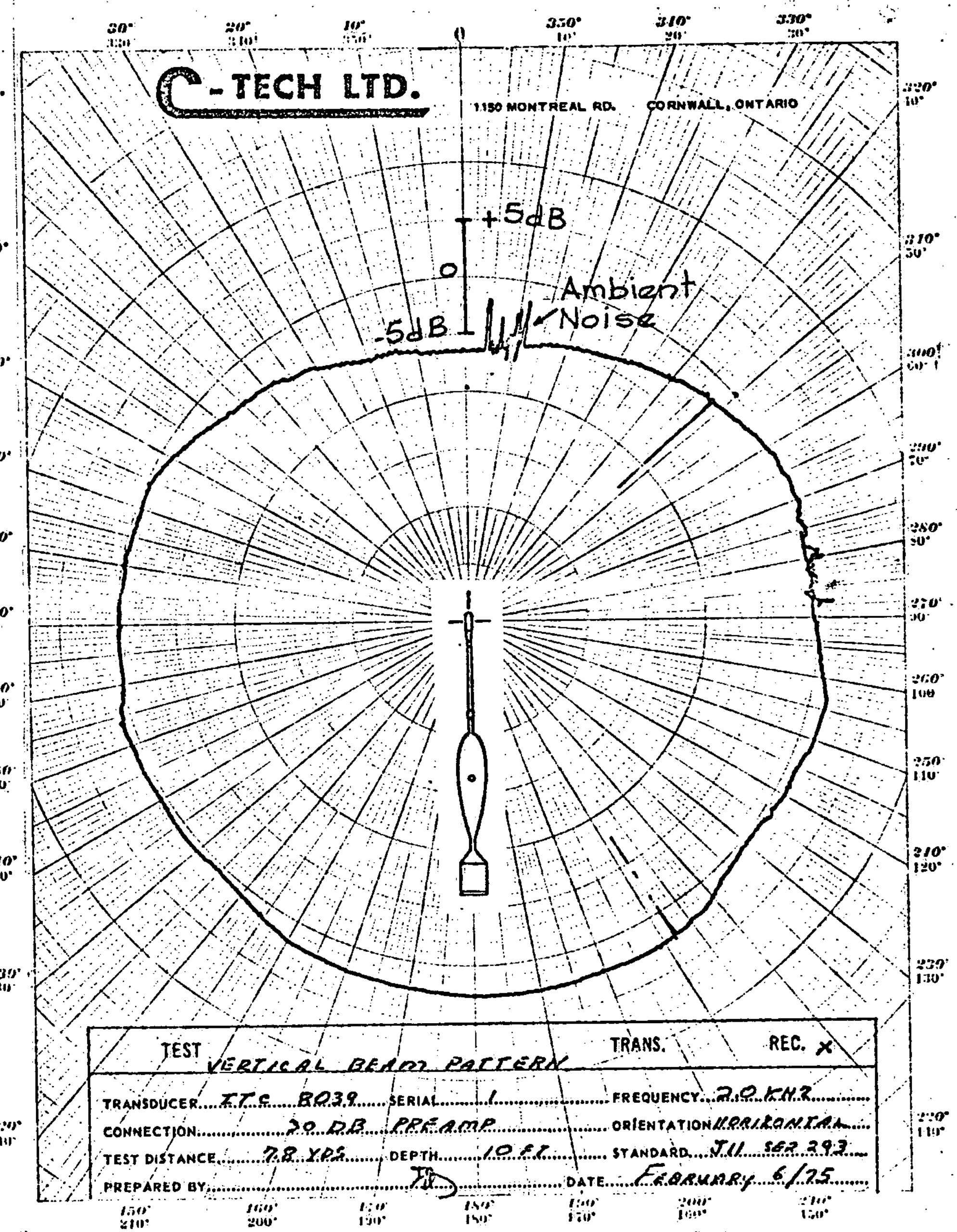
DIRECTIONAL RESPONSE - 500 Hz

Figure 8(c)



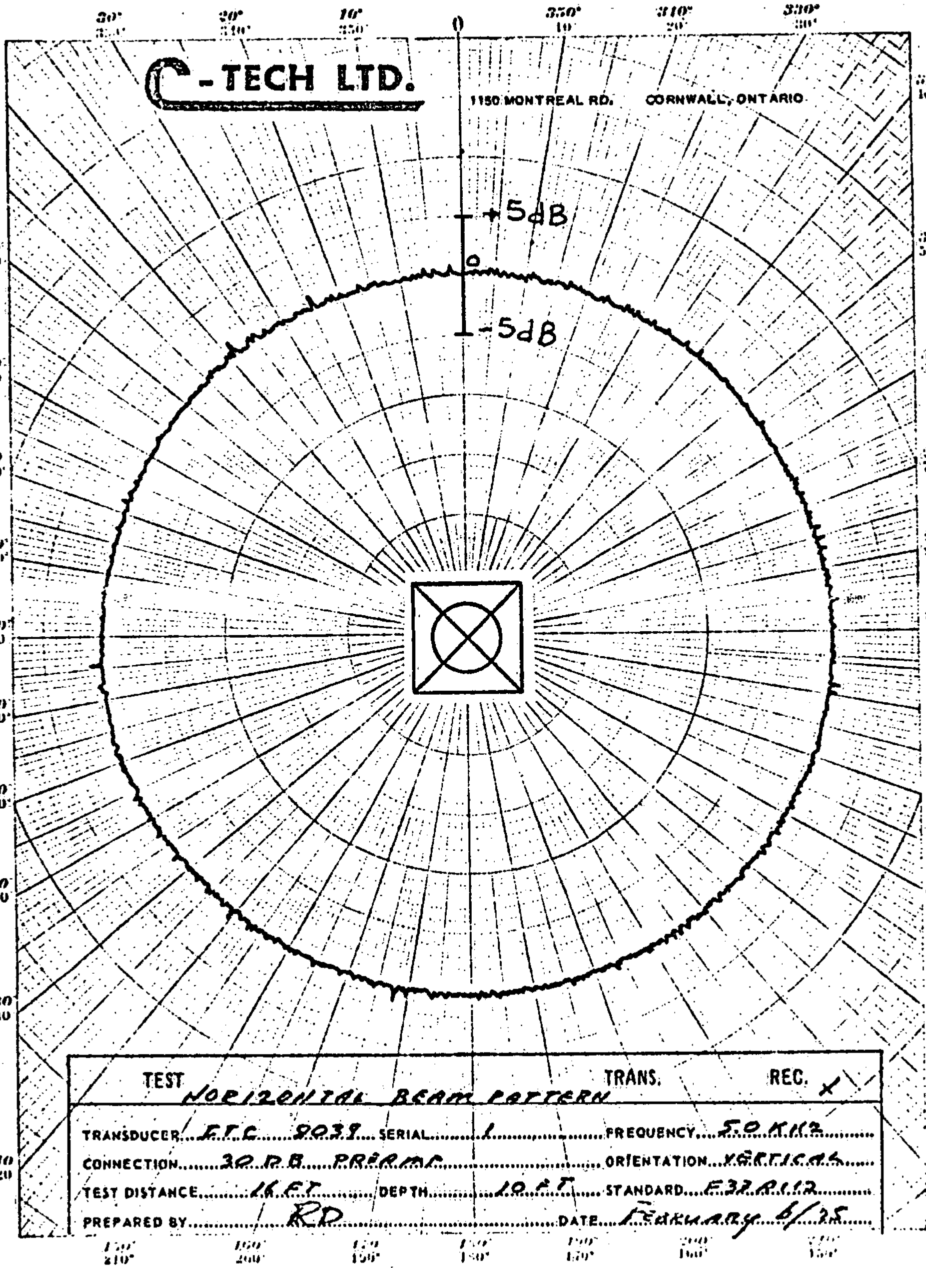
DIRECTIONAL RESPONSE - 1kHz

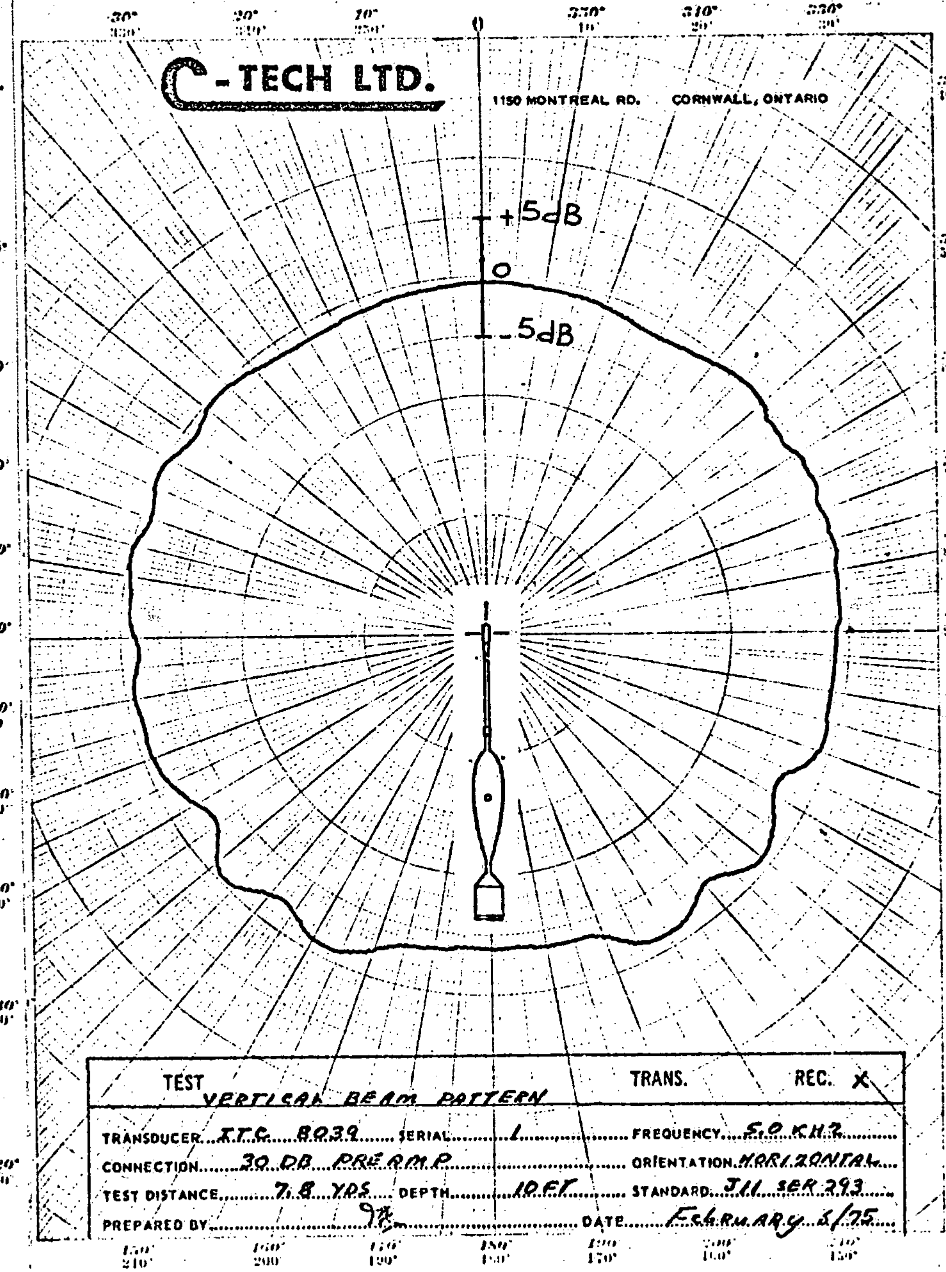
Figure 8 (d)



DIRECTIONAL RESPONSE - 2 kHz
WORST CASE FOR REFLECTED WAVE

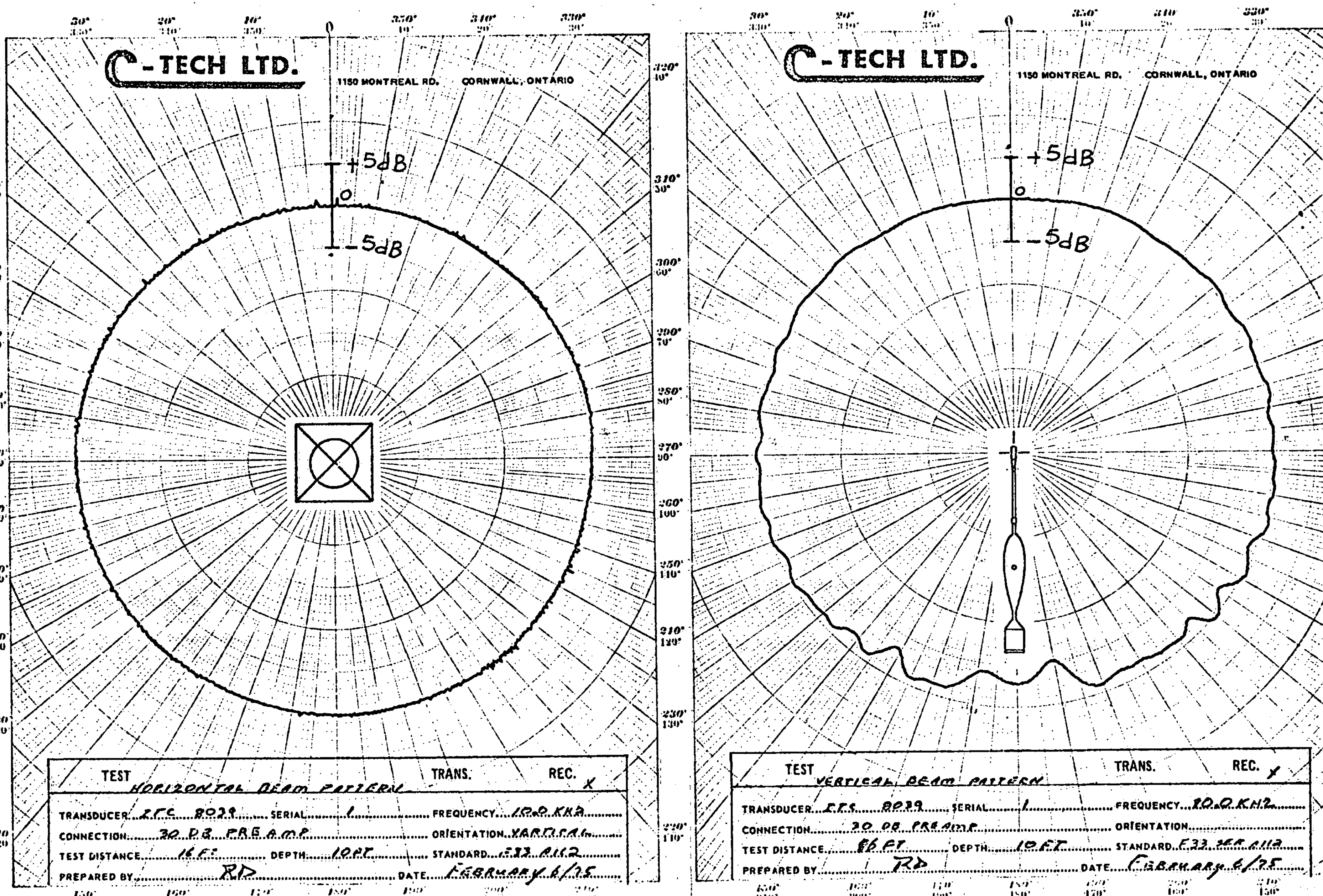
Figure 8 (e)





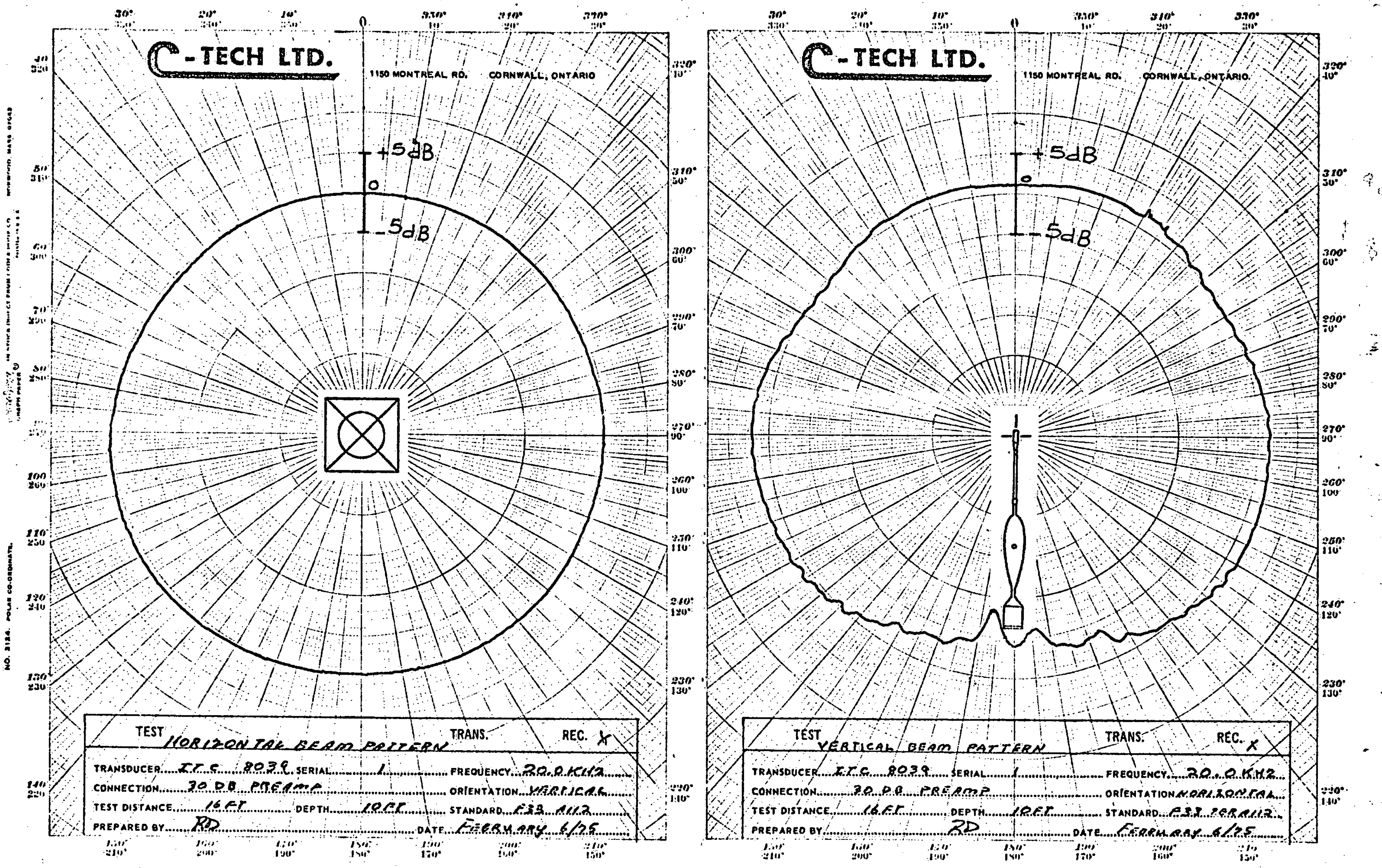
DIRECTIONAL RESPONSE – 5 kHz

Figure 8(f)



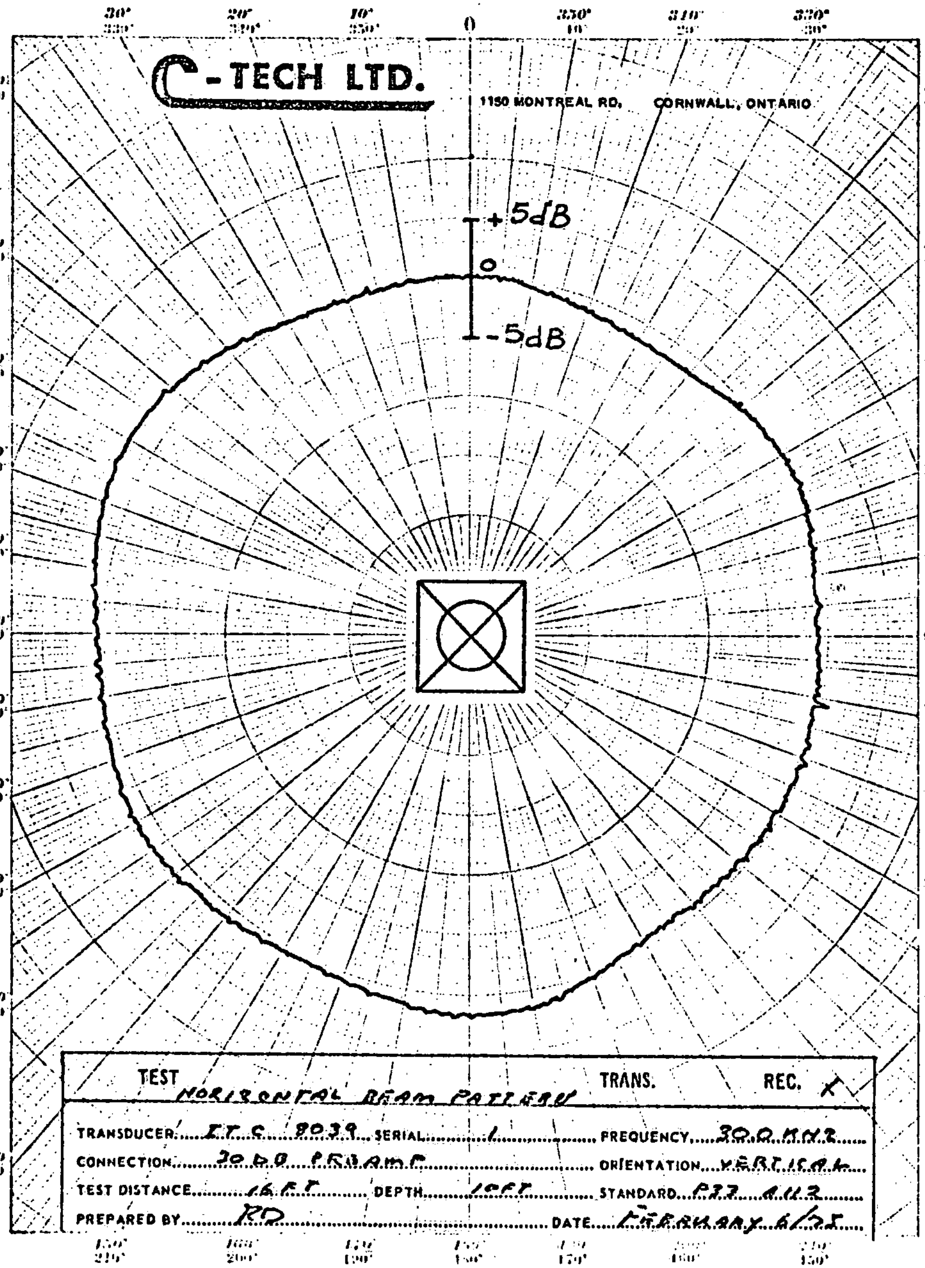
DIRECTIONAL RESPONSE – 10 kHz

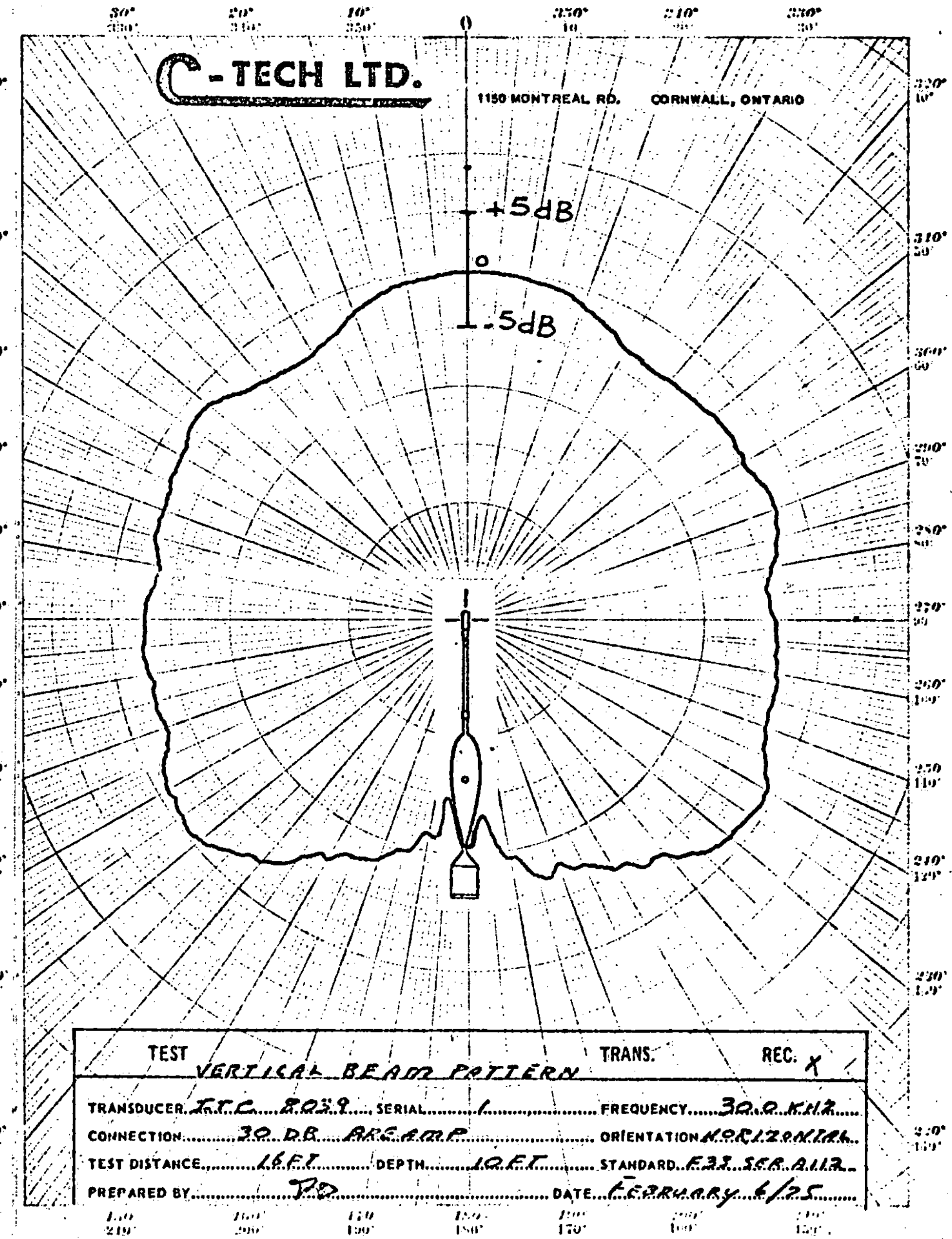
Figure 8 (g)



DIRECTIONAL RESPONSE - 20 kHz

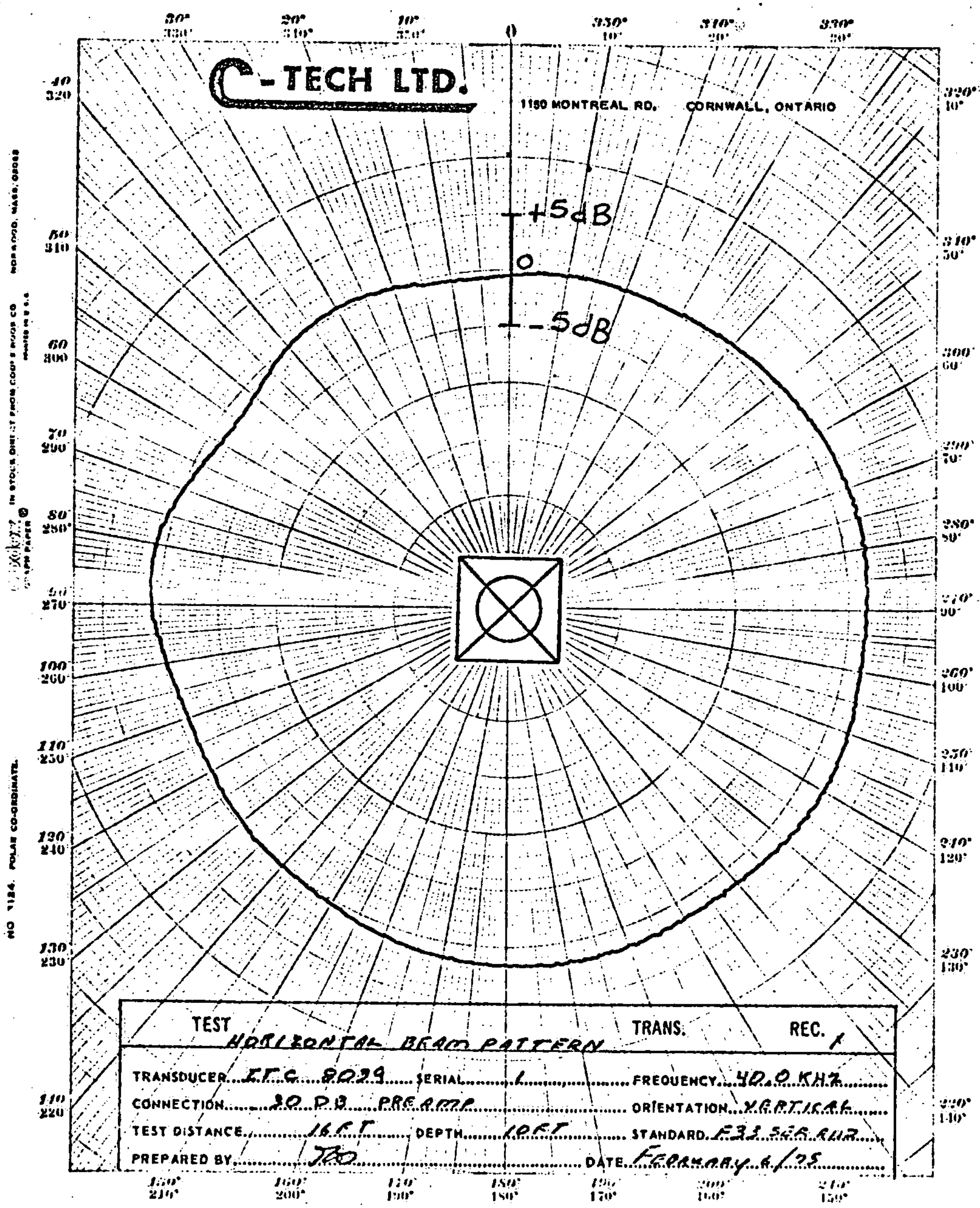
Figure 8(h)

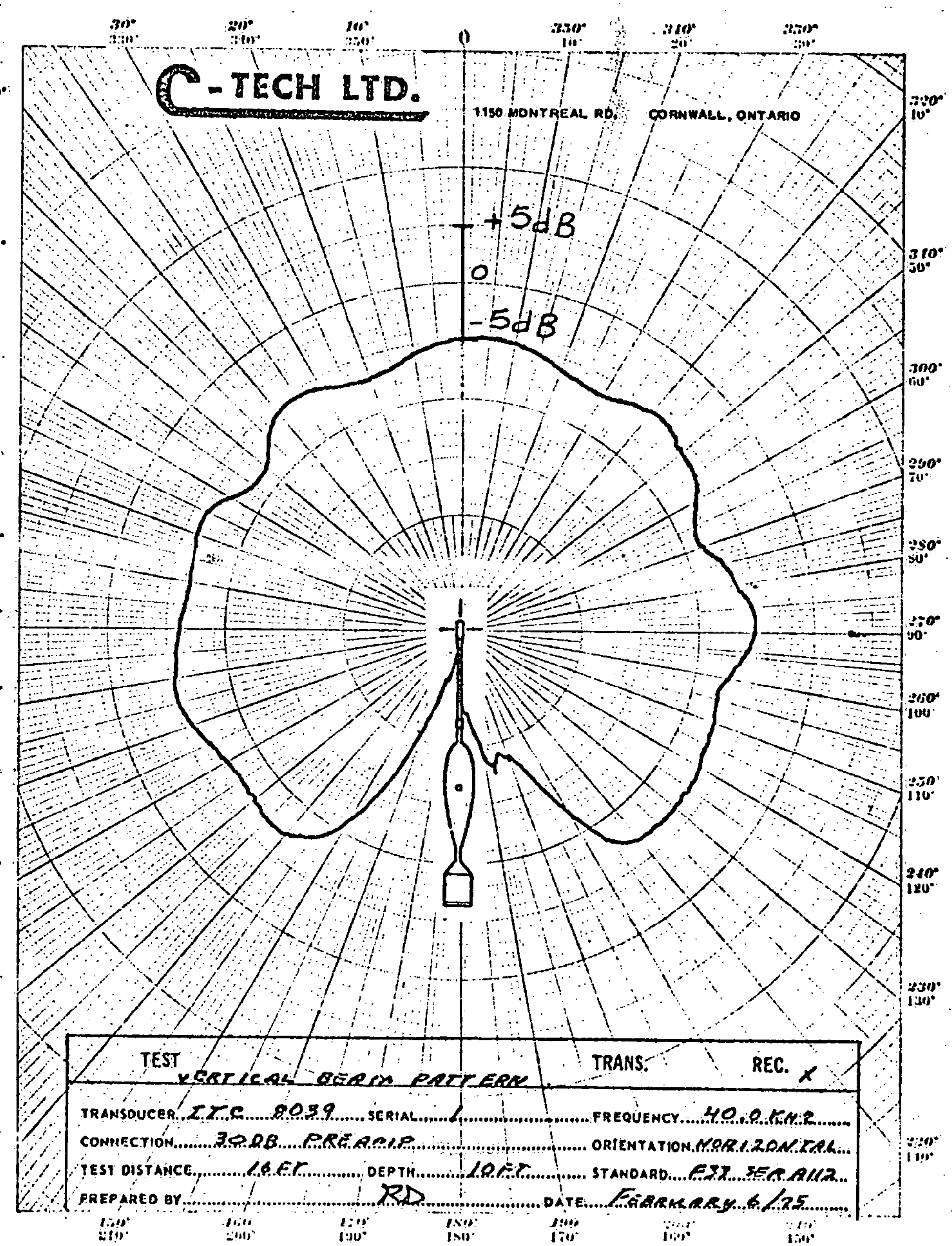




DIRECTIONAL RESPONSE – 30 kHz

Figure. 8 (i)



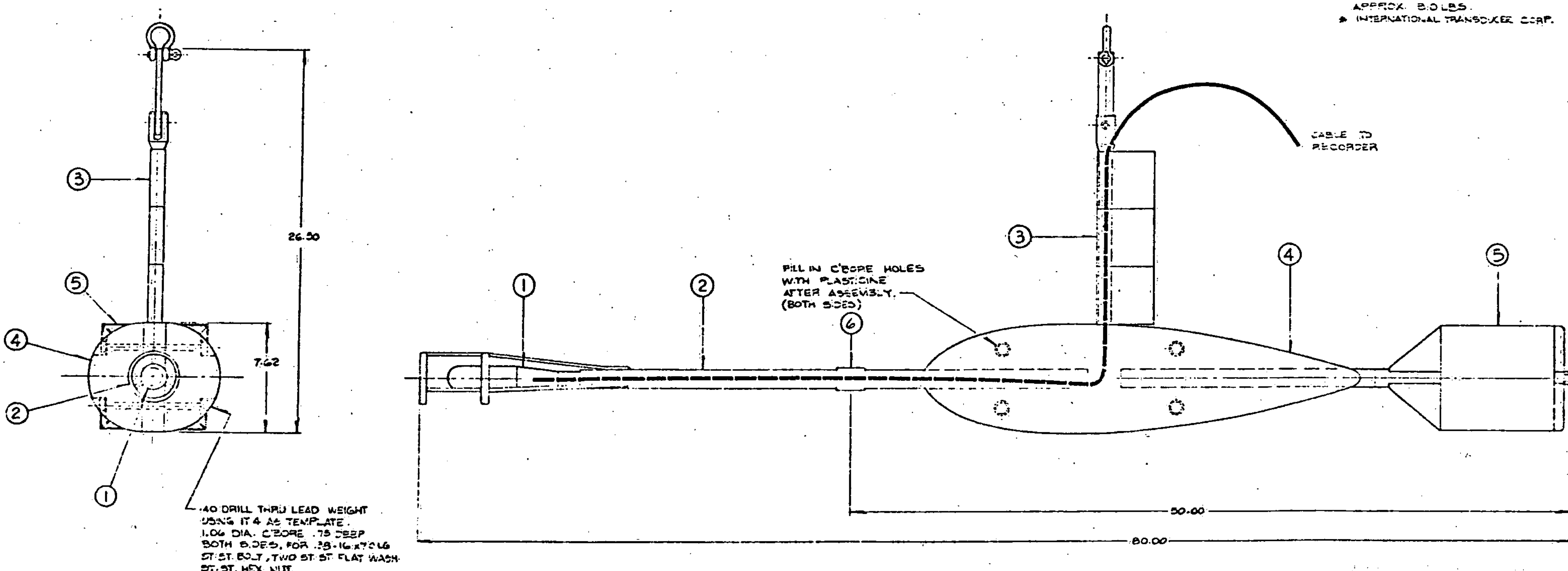


DIRECTIONAL RESPONSE - 40 kHz

Figure 8(j)

PART NO.	DESCRIPTION	QTY.
1 *	HYDROPHONE SUB-ASSY ITC 542	1
2	PIPE & CAGE SUPPORT ASSY 183-2	1
3	FAIRED TOWING BAR ASSY 183-3	1
4	FRAME & WEIGHT ASSY [illegible]-4	1
5	ORIENTING FIN ASSY 1831-5	1
6	1" STD ST.ST. PIPE CPLG (THREAD)	1

NOTE: GENERAL ASSY WEIGHT APPROX. 810 LBS.
* INTERNATIONAL TRANSDUCER CORP.



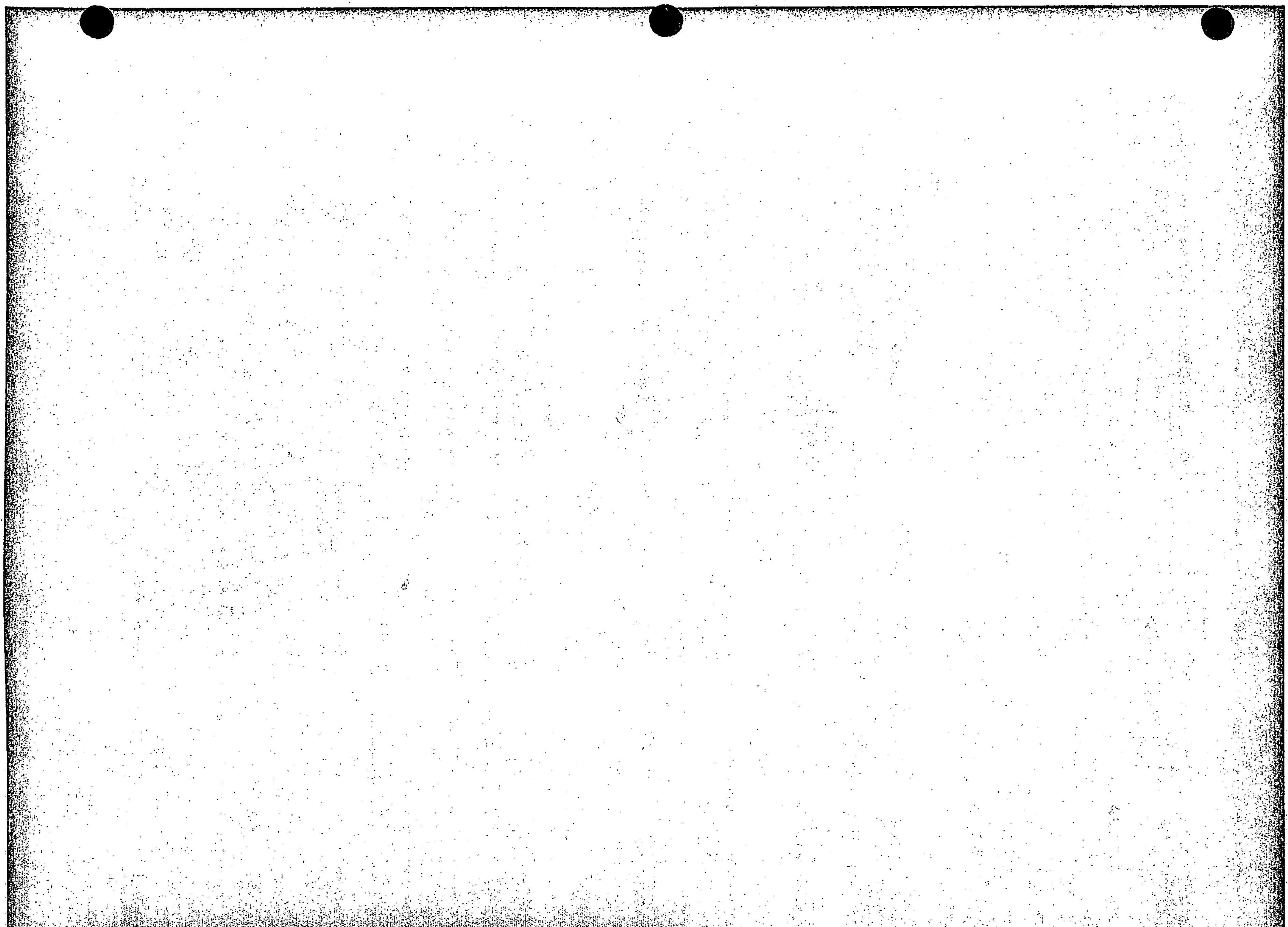
MECHANICAL DETAILS OF HYDROPHONE ASSEMBLY

FIGURE 9

Environment Canada — Environnement Canada
Canada Centre for Inland Waters — Centre Canadien des Eaux Interieures

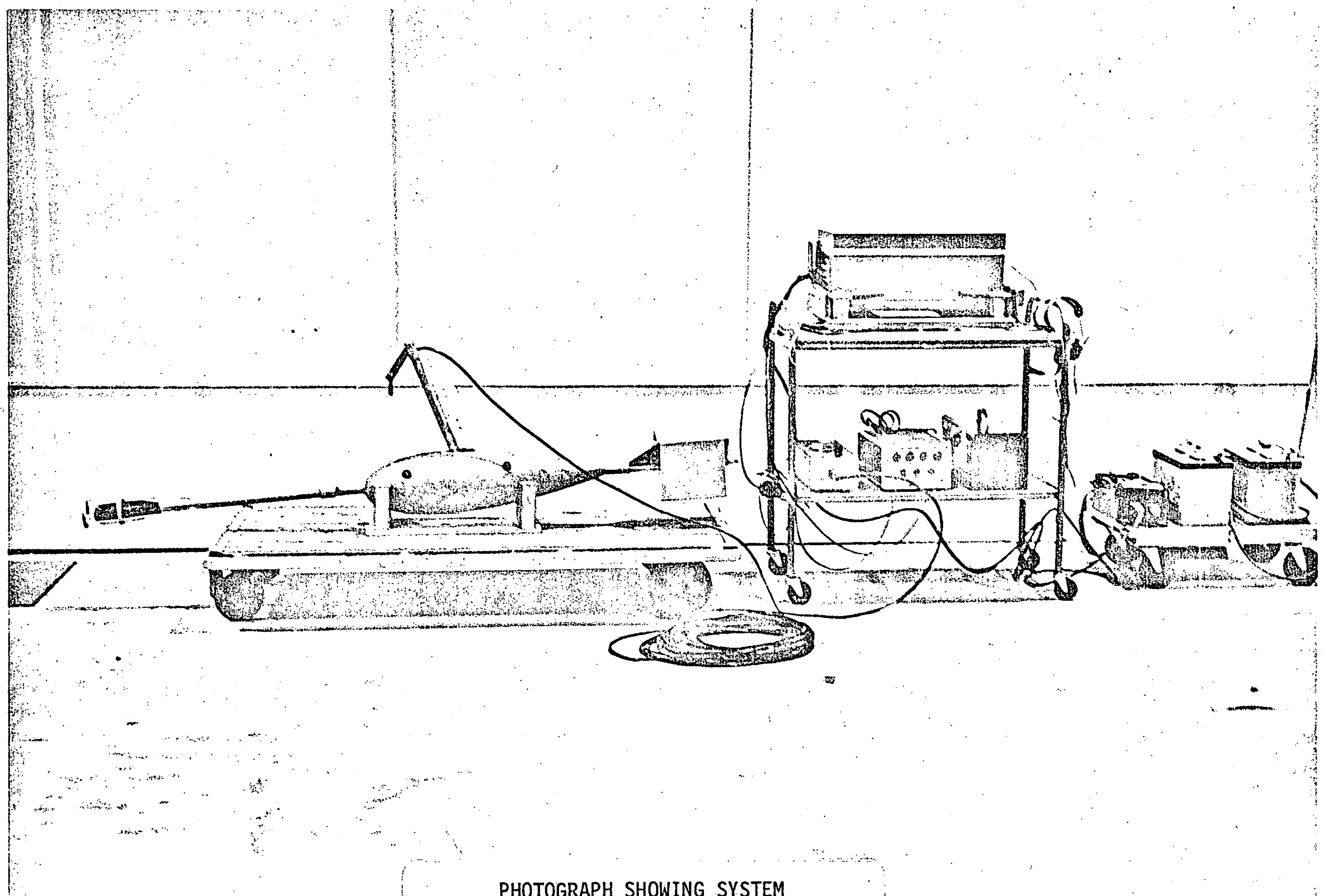
TITLE: HYDROPHONE GENERAL ASSY. FOR 1974 CCIW BED LOAD TRANSPORT [illegible] SYSTEM

DESIGNED BY: H. SAVILLE | CHECKED BY | APPROVED BY
DRAWN BY | CHECKED BY | DRAWING NO. 1831-1
SCALE: NTS | DATE | SHEET OF



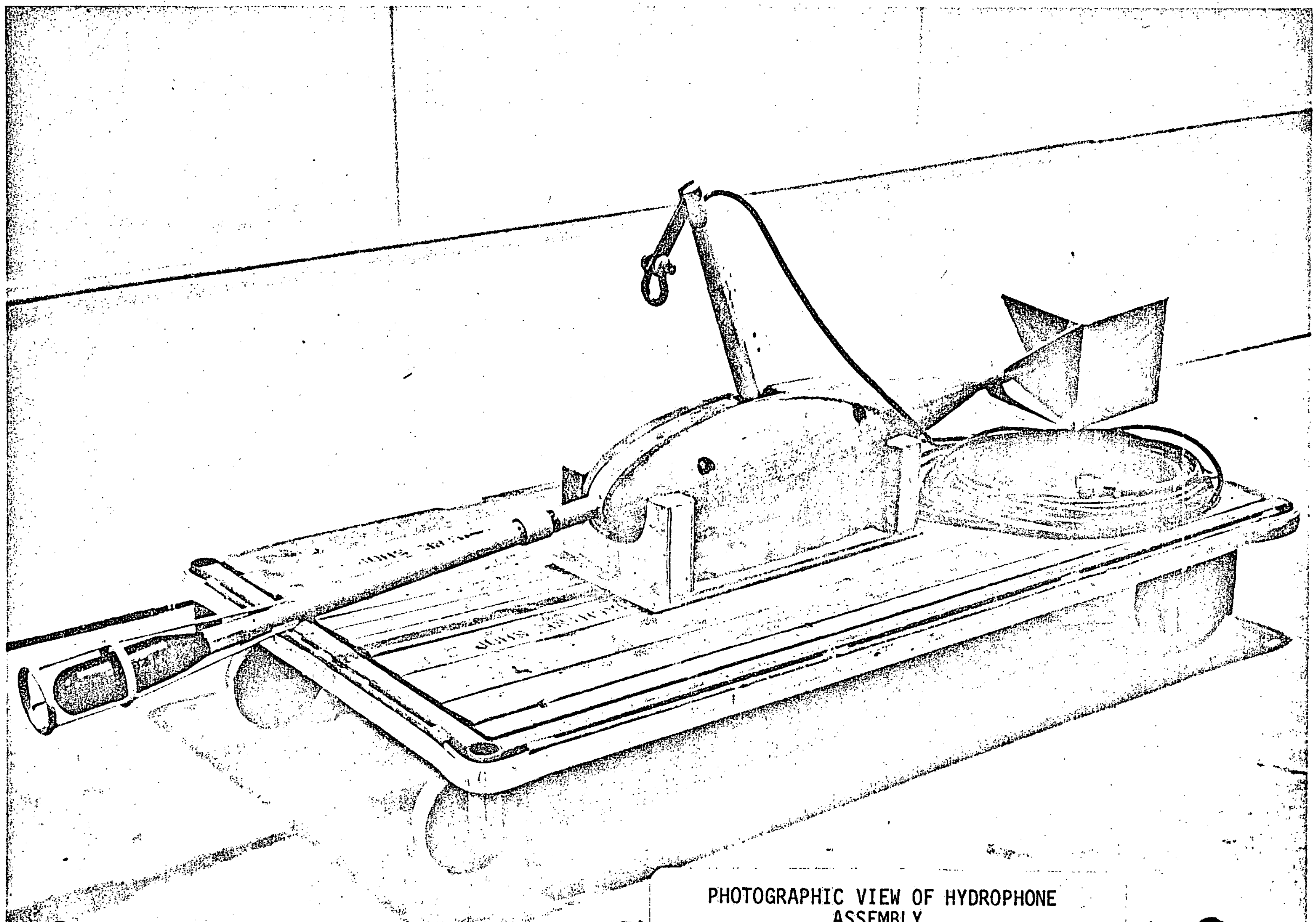
HYDROPHONE ASSEMBLY UNDERGOING TOWED TESTS AT CCIW

FIGURE 11



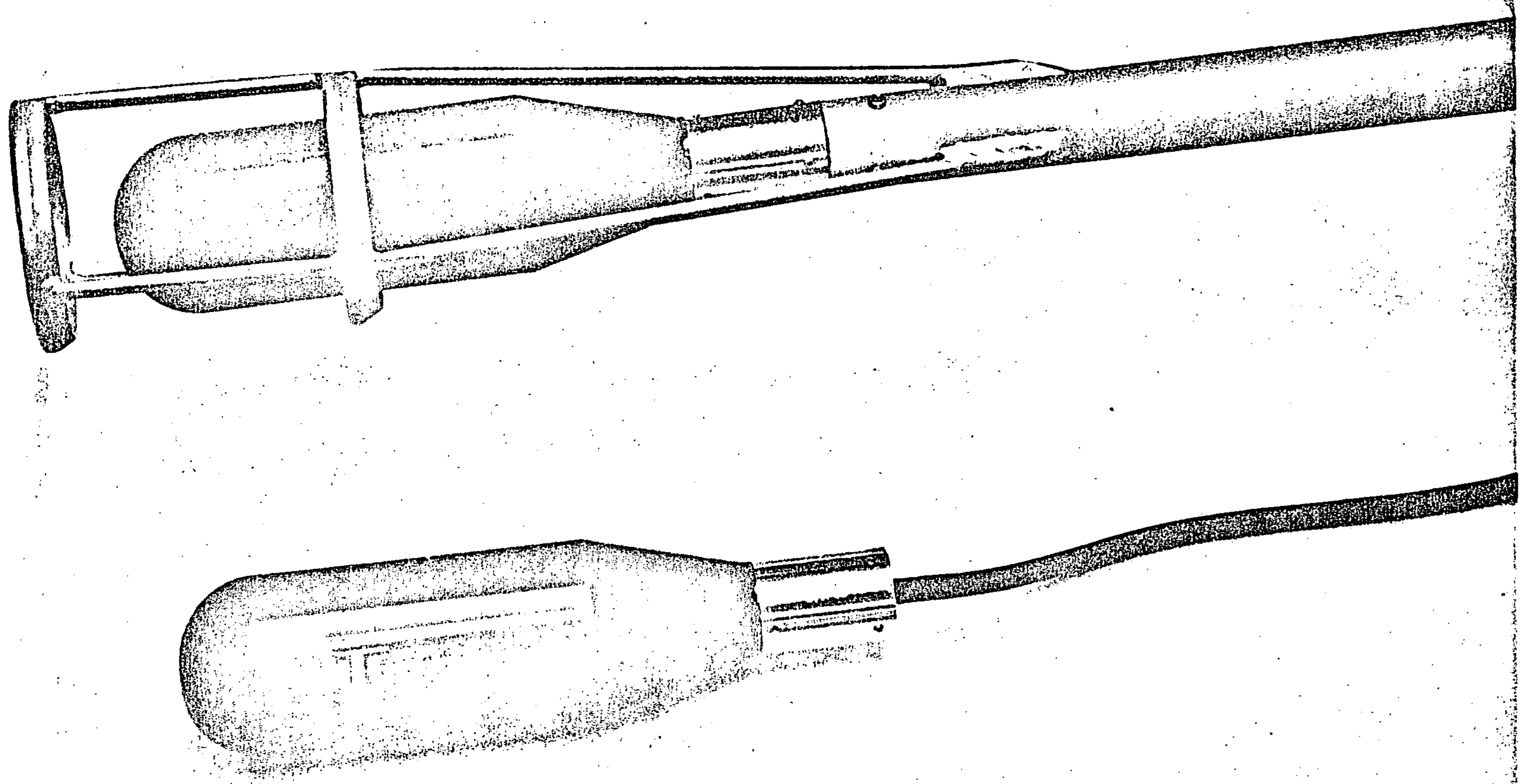
PHOTOGRAPH SHOWING SYSTEM INSTRUMENTATION

FIGURE 3



PHOTOGRAPHIC VIEW OF HYDROPHONE ASSEMBLY

FIGURE 10



PHOTOGRAPH OF HYDROPHONE SUBASSEMBLY
(with and without rod cage)
FIGURE 6(a)