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DEVELOPMENTS IN NARROW BEAM ECHO SOUNDERS

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ABSTRACT

To accurately delineate the sea floor in areas of irregular sea bottom topography, it is necessary that a narrow beam sounding system be employed and that the transducer be stabilized in pitch and roll. In early 1973 an investigation was commenced on the types and availability of various narrow beam echo sounders for hydrographic and oceanographic use. This search concluded with the selection of a narrow beam echo sounder for initial fitting on CSS *Hudson*. In this paper the various types of narrow beam echo sounders available, along with their limitations and capabilities in hydrographic and oceanographic surveys, are discussed.

GENERAL DISCUSSION

A narrow beam echo sounder is considered to be a sounding system in which the transducer beamwidth to the half power (-3 dB) points is 5° or less. Narrow beam echo sounders normally utilize transducers mechanically or electronically stabilized in pitch and roll to ensure that the transducer face is effectively level on transmit and receive. There is no point in making the transducer beamwidth narrow if the transducer beam pattern pitches and rolls in unison with the ship.

There are a number of reasons for using a narrow beam sounding system for oceanographic and hydrographic surveys. The basic reasons however are:

1) To be able to obtain information vertically beneath the transducer and not off to one side if the ship is operating over steep slopes.
2) To improve the quality of the information obtained.

If we consider a standard hydrographic survey system for offshore surveys, the transducer beamwidth is as shown in figure 1; and if the ship is operating over a sea bottom with a 5° slope in water depths exceeding

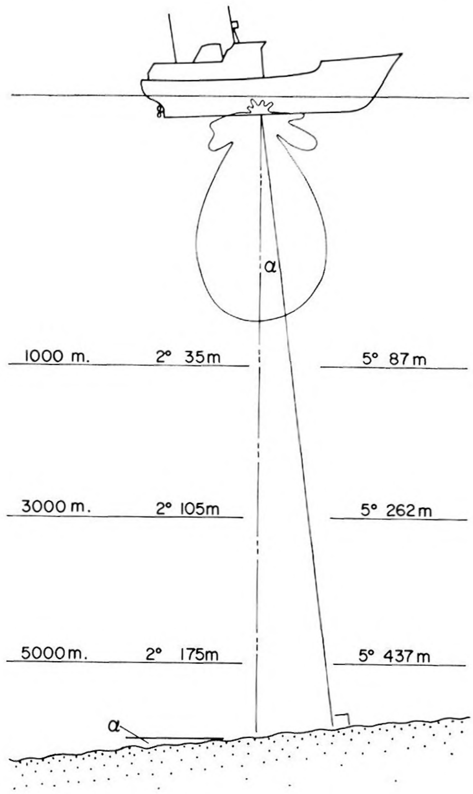

FIG. 1. — Error in sounding position as a function of sea bottom slope.

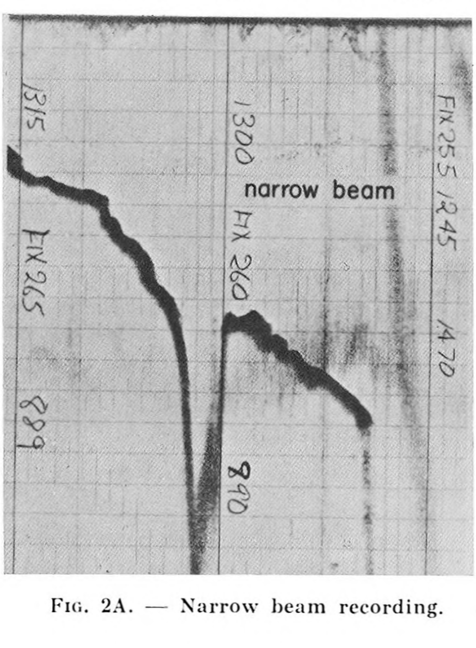

FIG. 2A. — Narrow beam recording.

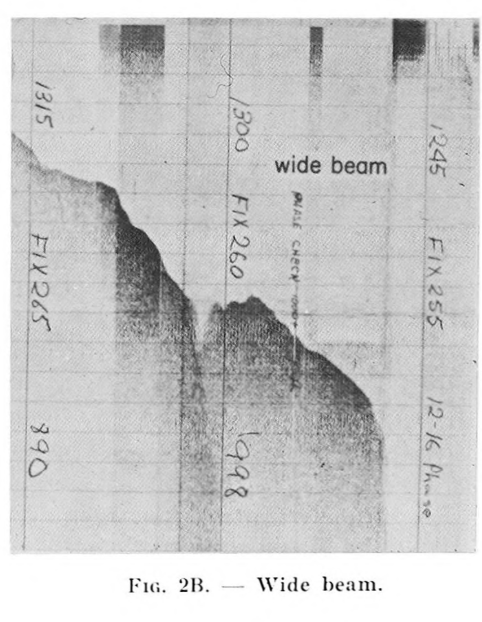

FIG. 2B. — Wide beam.

3 000 metres, the incident echo is arriving from a point laterally displaced from the ship by over 250 metres. In most instances this is not important. Indeed up until quite recently, ships' positioning was not accurate enough so that it was worth trying to eliminate this error. In recent time however with positioning accuracy to approximately 100 metres, this becomes quite significant.

An even more important reason for utilizing narrow beam sounders is to provide better delineation of undulations in the sea floor. Reference to figures 2A & B, 3A & B and 4A & B easily demonstrates the improvement in information resulting from the use of a narrow beam echo sounder. The narrow beam recordings were obtained on a 16 kHz, 6°, 2 kW system while the wide beam recordings were obtained on a 12 kHz, 30°, 2 kW system.

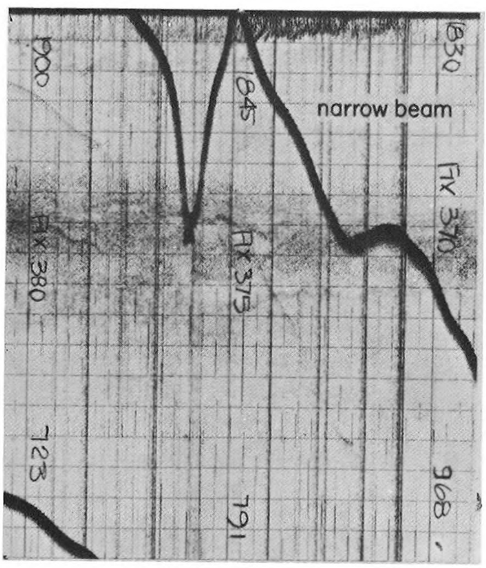

Fig. 3A. — Narrow beam.

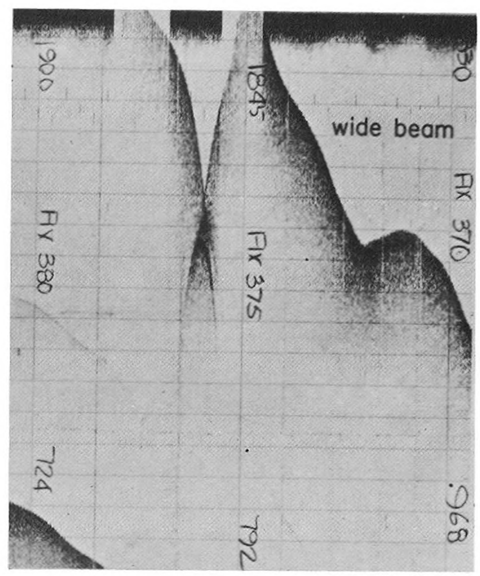

Fig. 3B. — Wide beam.

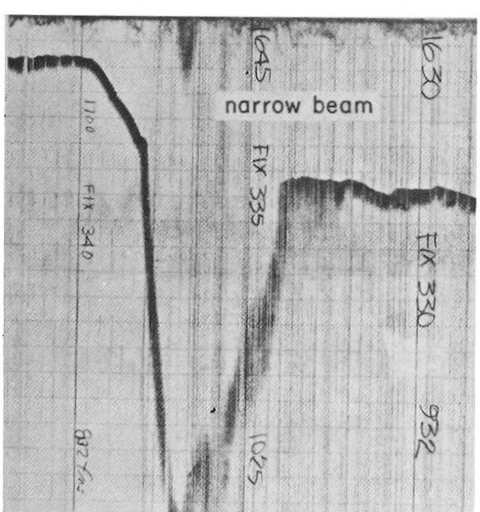

Fig. 4A. — Narrow beam.

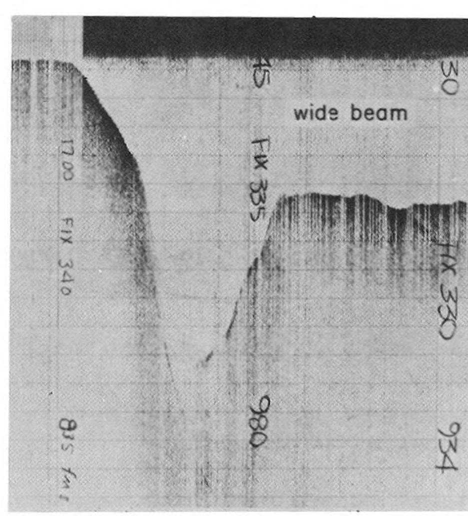

Fig. 4B. — Wide beam.

SPECIFICATION FOR SYSTEM

In 1973 when Bedford Institute of Oceanography first became interested in narrow beam echo sounders, the following specification was prepared and submitted to a large number of companies engaged in underwater acoustic research and development.

Range	0 - 4 000 m with appropriate range scales.
Frequency	5-50 kHz (dependent upon processing, available power and other parameters).
Stabilization	To within one degree for pitch and roll, up to ± 20°.
Beam Width	Equivalent to conical 3° total beam angle, or less.
Display	Dry paper graphic recorder.
Processing	Signal processing to be used if required.
Transducer Mounting ..	Hull mounting with provision for a towed array if feasible.
Operating Conditions	To withstand ships operation in heavy ice. Not necessary that system operate in heavy ice, but necessary that transducers not be damaged.
Transducer	Training in elevation and azimuth to be considered an asset but not a requirement.

At this time, it was felt that this basic specification met most of our requirements. Initially five replies were received and in the next few paragraphs I would like to discuss the salient features of the systems as proposed by the various companies.

RAYTHEON SYSTEM

One of the greatest drawbacks in the development of narrow beam echo sounder systems is caused by the large physical dimensions of the transducer required to produce the narrow beamwidth at frequencies where the attenuation is sufficiently low to allow strong echo returns in deep water. For example at 12 kHz, a transducer 3.7 metres in diameter is required to produce a 2° beamwidth to the −3dB points, while at 3.5 kHz a transducer of 12.5 metres in diameter is required for the same beamwidth. A one-metre diameter transducer at 12 kHz has a total beamwidth of 7½ degrees at the half power points. It is clear from those examples that developing narrow beam echo sounders from conventional linear techniques, although effective, is a brute force method. An advantage may be obtained by raising the frequency but it must be borne in mind that as the frequency is raised the two-way attenuation is correspondingly raised according to well known laws. One way around this problem is to employ the principle of non-linear acoustics. This principle, although well documented many years ago, was not developed into hardware until quite

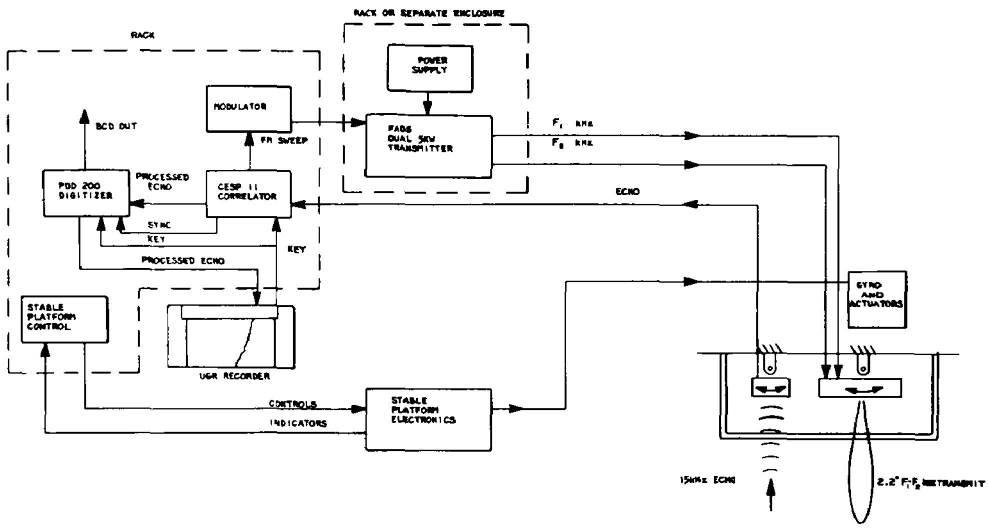

FIG. 5. — Block diagram, Raytheon FADS System.

recently. Raytheon Corporation have developed the first marketable system and they are the leaders in this field of research. Their system is called the Finite Amplitude Depth Sounding System (FADS).

The FADS technique involves the propagation of two high frequencies simultaneously, both of large amplitude. Because of the slight non-linearity of the water, the two frequencies are mixed in the area in front of the transducer to produce a parametric signal at the difference frequency. The water column in essence serves as a mixer or modulator and generates a secondary sonar transmission in the water at a frequency equal to the difference frequency of the two primary sources. This low frequency has the narrow beamwidth of the high frequency components, does not have side lobes, and has an attenuation factor corresponding to a linear system operating at the difference frequency. In a system of this nature a single stabilized transducer is used with matrixed elements to accommodate all three frequencies; or separate transducers are designed for "transmit" and "receive", the projector being a matrixed high frequency transducer and the hydrophone a broad beam low frequency transducer. It is not necessary that the "receive" transducer have a narrow beamwidth, though a higher directivity index does however improve the signal/noise ratio.

One disadvantage of non-linear systems is that they do require higher transmitter power levels to provide the same source level at the lower frequency than do linear systems. This however is not too serious for major ship fittings, where there is normally adequate ship's service power and space for housing the necessary transmitting electronics. Maximum conversion efficiency is achieved by careful selection of the primary frequencies for a required secondary frequency. Conversion efficiency may also be increased by increasing the acoustic intensity because the rate of attenuation of acoustic waves is not constant but is a complicated function of intensity and frequency. BIRKEN and BERKTAY have published a considerable amount of information on parametric optimization as a function of source level and conversion ratio. The attenuation losses that one might expect are in the order of 20-40 dB for downshift ratios in the range of three to twenty.

In summary, the net effect is that higher primary source levels are required because of the conversion loss, but the higher source levels are quite easily achieved because at the higher primary frequencies the cavitation threshold is higher and the power source is not normally difficult to obtain. A block diagram of a Raytheon FADS system is shown in figure 5.

GENERAL INSTRUMENTS SYSTEM

Most narrow beam echo sounders have one basic limitation particularly apparent if the sounder is to be used for hydrographic surveys — it gives no information on either side of the ship's track. This one shortcoming is significant enough to make it mandatory that broadbeam systems be operated in conjunction with conventional narrow beam systems for maximum information recovery. General Instruments Corporation have developed a multibeam deep sea oceanographic and hydrographic sounder to alleviate this problem of conventional narrow beam systems. The General Instruments system permits full coverage of a significant swath symmetrically placed about the ship's track with a resolution corresponding to an effective beamwidth of approximately 2.5°. This is achieved by taking full advantage of a multiple crossed fan beam configuration. Beam formation is achieved with separate orthogonal fan beam arrays for transmitting and receiving the acoustic energy. The narrow beam echo sounder multibeam pattern as developed by the General Instruments System is shown in figure 6.

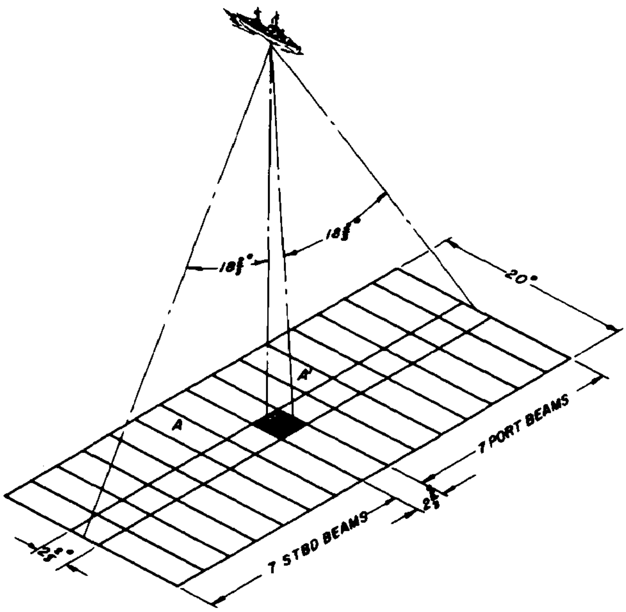

FIG. 6. — Multibeam pattern, General Instruments System.

The projector is a high power linear array at a frequency of 12.15 kHz mounted in the fore and aft direction. The beam pattern from this array spans more than 40° in the athwartships direction and approximately $2\frac{1}{2}$ degrees in the fore and aft direction. The transmitting array is made up of twenty projectors and is electronically stabilized by using twenty separate power amplifiers all fed through phase resolvers obtaining their vertical orientation from a vertical gyro. The transmitting array is stabilized in pitch only.

The receiving array is approximately three metres long and is made up of forty hydrophones mounted athwartships. The signals from the forty hydrophones are amplified and phase-shifted to provide quadrature inputs to the beam forming network. A precise contribution in both amplitude and phase of each hydrophone signal is combined by a resistive network to form the fifteen or sixteen received beams. The synthesized received beams are fed to a roll compensator from where the vertical beam is obtained. The vertical beam is interpreted from the two most nearly vertical beams if no one beam is sufficiently vertical.

This system supplies a great deal of information on the athwartships bottom profile. The only difficulty is in storing and handling the great quantity of data obtained. Digital plotters, graphic recorders, oscilloscopes and digital computers have all been employed for this purpose. This system is large and complicated for fitting on existing ships but conceptually is the most important system available for installation in new vessels.

ELECTROACUSTIC GmbH SYSTEM

Electroacustic GmbH (ELAC) have been active in the development of narrow beam sounding systems for a number of years and probably were responsible for the first narrow beam sounder fitting. ELAC systems have been fitted and used extensively in German research ships such as *Planet, Valdivia* and *Meteor II*. They also have marketed several systems to other governments. The newest ELAC system is the VM 11. This system has

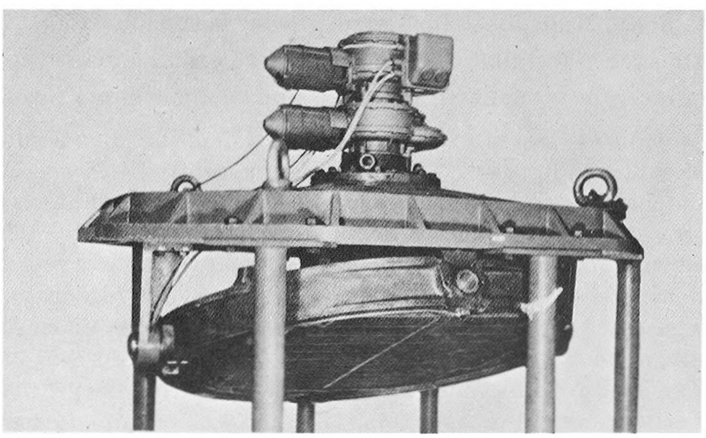

FIG. 7. — Stabilized transducer, ELAC System.

an extremely narrow beamwidth, ± 1.4° at the −3dB points and it operates at 30 kHz. It is a stabilized transducer system with a transducer as shown in figure 7. The ELAC system is a high power system capable of operating to depths exceeding 6 000 metres. The main drawback of the system is its vulnerability to ice damage. Because of its large size (transducer diameter of 1 metre) it would also be very expensive for fitting on an existing vessel.

EDO WESTERN CORPORATION SYSTEM

EDO Western Corporation have a large number of narrow beam echo sounder fittings of various configurations and complexities. EDO systems are for the most part tri-frequency systems with narrow beam capabilities at the highest frequency, and progressively wider beamwidths as the frequency is decreased. The EDO systems use vertical gyro reference error signals applied to solid-state hydraulically actuated servo control systems to maintain a level transducer. They have also packaged a similar system in a towed body.

One of the unique features of the EDO system is that for operation in an ocean environment where floating ice may be encountered, they utilize massive gate-valves so that the transducer may be protected while it is not being operated. By closing the gate-valve the transducer may also be removed for servicing while the ship is at sea.

The first narrow beam echo sounder purchased by Bedford Institute of Oceanography is an EDO Western Model 554 bathymetric system with the following design capabilities :

1) 3 000 metre depth capability at the narrowest beamwidth;
2) Frequency — front-panel selectable at 16, 30 and 50 kHz;
3) Beamwidth to the −3dB points:

16 kHz	16°
30 kHz	9°
50 kHz	5°;

4) Stabilized transducer for narrow beam performance in heavy seas;
5) Transducer installation into a 16″ (40.6 cm) diameter gate-valve;
6) Manually retractable transducer and stabilized platform.

The transducer assembly of the 554 system is shown in figure 8 and the electronics in figure 9. The system is currently fitted on CSS *Hudson* but a second gate-valve has been purchased and it is planned to fit the system on a charter vessel or on CSS *Baffin* at a later date. The system will be used on CSS *Hudson* mainly during geophysical surveys, while on CSS *Baffin* or the charter vessel its capability as a hydrographic survey tool will be assessed. It should be borne in mind that the model 554 system is really quite a small system and that much larger systems will be required for narrower beamwidths and for operation in the deep ocean. EDO Western Corporation have marketed one system complete with a 48″ gate-valve.

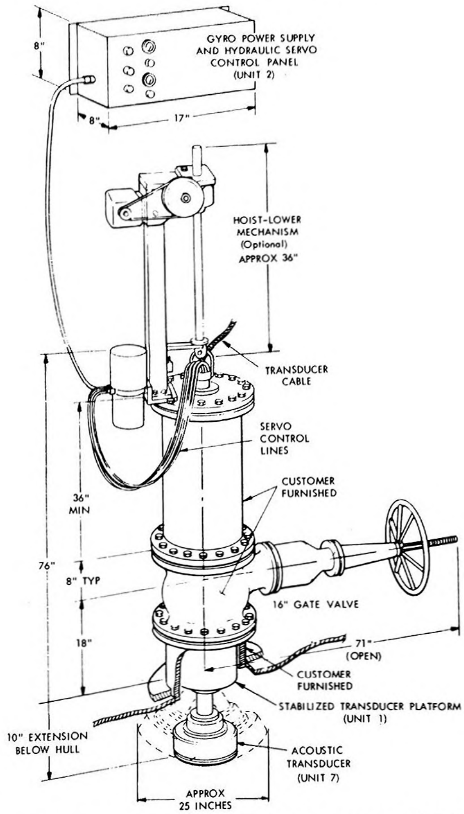

FIG. 8. — Transducer assembly, EDO Western model 554 System.

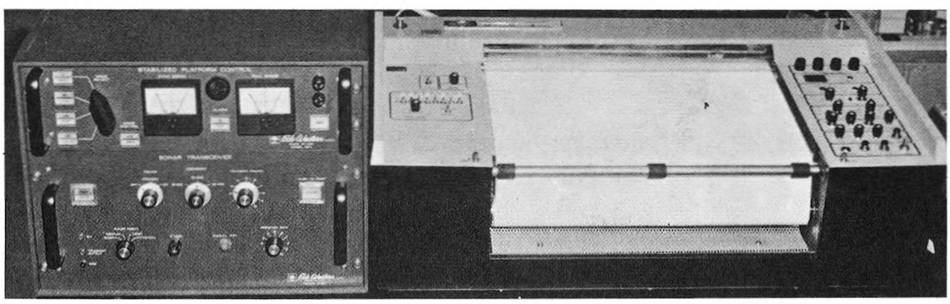

FIG. 9. — Electronics, EDO Western System.

FUTURE DEVELOPMENTS

It is my belief that not one of the systems described fully meets our requirements. The greatest shortcoming of all the systems is in the way that the transducers are fitted. For the severe environments encountered in oceanographic and hydrographic surveys in areas where floating ice may be encountered, it is necessary that the transducer be given additional protection. The General Instruments system provides some protection for the transducer, but in this system if a transducer fault occurs the ship must be dry docked for repair. The EDO system with the large gate-valves allows transducer changing with the ship afloat, but the transducer and attached assemblies are quite easily damaged. Systems such as the FADS and the EDO are available with the transducers fitted in towed bodies. It is our experience however that towed transducers, although increasing flexibility, are difficult to maintain because of fairing and cable problems and also because of damage incurred in streaming and recovering.

Ideally a future system should have the operational flexibility of a General Instruments system and have transducers that will not be damaged by ice and that are easily replaced without dry docking. It is felt that this can be accomplished by mounting fan-type arrays of transducers on the ship's bottom, and transmitting and receiving *through* the normally fitted ship's plates or through an asdic area made from a material with acoustic properties similar to Rho-C rubber. Transducer replacement in a system of this nature could easily be implemented without dry docking.

The technology for developing the electronics for narrow beam sounders has been available for some time. It is felt that the fitting arrangements are the most serious shortcoming and that these problems are now being fully recognized and solved. It is further considered that any new ships constructed for oceanography or hydrography should be fitted with narrow beam echo sounders to improve their operational efficiency.

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