Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 517161
UNCLASSIFIED	

TITLE

Seabed and sub-bottom classification using measurements of normal incidence backscatter measurements in the 1-10 kHz frequency band

System Number:

Patron Number:

Requester:

Notes: Paper #14 contained in Parent Sysnum #517147

DSIS Use only:

Deliver to: CL

This page is left blank

This page is left blank

#517161 (14)

Seabed and Sub-bottom Classification Using Measurements of Normal Incidence Backscatter Measurements in the 1-10 kHz Frequency Band

by

John C. Osler, Paul C. Hines, and Darcy J. MacDougald

Defence Research Establishment Atlantic, P.O. Box 1012, Dartmouth, NS, Canada, B2Y 3Z7, e-mail: osler@drea.dnd.ca

Abstract - It has been established that the first and second normal incidence acoustic returns from the seabed can be used as a classification tool to discriminate between, for example, sand, mud, or rock bottoms. Typically this is accomplished using mono-static echo sounder systems that operate in the range of several 10s of kHz so that bottom roughness at the seabed interface is the dominant scattering mechanism. Theoretical results indicate that at lower frequencies, returns from the sub-bottom should provide an additional discrimination tool without significantly corrupting the seabed information contained in the interface scatter returns. This paper presents an experimental methodology for making these normal incidence measurements made in the 1 to 10 kHz frequency band using a moored vertical line array of receivers and pair of projectors. The projectors have been used in tandem to create aliased cardiods that significantly reduce interference due to the sea surface reflection The conventional classification technique relies upon treating the first bottom echo as a mono-static arrival and the second bottom echo as a bi-static arrival The use of a vertical line array also allows a similar comparison to be made between hydrophones proximal to the source (mono-static) and hydrophones that are farther away (bi-static). Experimental results from the ONR Strataform area are presented

I. Introduction

A surficial sediment classification technique using the first and second normal incidence acoustic seabed returns, typically from mono-static echo sounder systems that operate in the range of several 10s of kHz, has been developed by Heald and Pace [1]. At these frequencies, bottom roughness at the seabed interface is the dominant scattering mechanism. The first seabed return (Fig. 1) is treated as a far-field, mono-static, arrival whose intensity is inversely proportional to the mean square slope—a roughness parameter [2]. The second seabed return is treated as a near-field bi-static arrival, with a virtual source above the water surface (Fig 1), whose intensity is proportional to the Rayleigh reflection coefficient. The intensity of the first and second seabed returns are integrated over time to yield energy, E_1 and E_2 respectively. (For E_1, the integration is performed over only the tail of the return to avoid overload of the receive amplifier whereas E_2 is integrated over the complete backscatter return). The ratio E_1/E_2 is used to classify different sediment types [1]. The technique is based on a Helmholtz-Kirchhoff model with gaussian roughness and ignores any coherent reflections and seabed penetration.

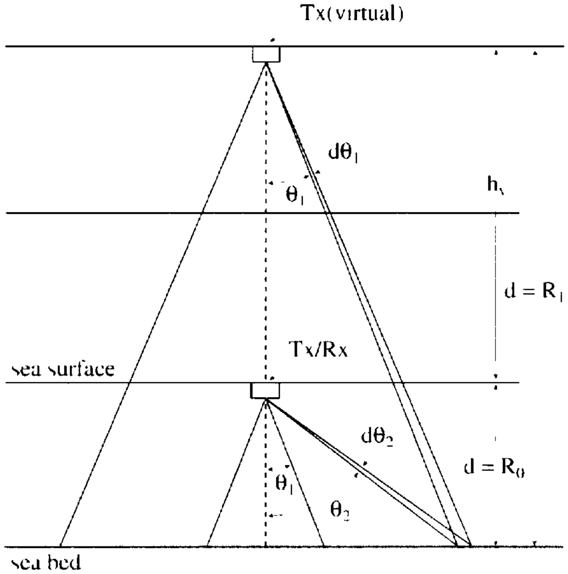

Figure 1: Schematic of the equivalent geometry with virtual source for the 2nd seabed return from the seabed interface located above the sea surface

Hines and Heald [3] have extended this technique to lower frequency (1 to 10 kHz range) by including volume scatter from coherent energy penetrating into the seabed In this frequency range, scatter from the interface initially dominates the intensity of the arrivals. However, because of its rapid decay, the intensity is subsequently dominated by volume scatter that decays more gradually. The transition between surface and volume scatter, and their respective rates of decay, form the basis of the sub-seabed classification technique. The intensity time series are a function of roughness parameters, frequency, and the composition of the surficial sediment layer Wide bandwidth, or multi-frequency systems, may exploit the frequency dependence and provide further discrimination regarding seabed composition

An example of the Hines and Heald [3] intensity versus time model predictions for the first seabed arrival are presented in Figure 2 for a 5 ms pulse vertically incident on a sand seabed. The surface scatter intensity, I_{sb1}, is calculated for three values of surface roughness and a fixed correlation length of 1.5 m The volume scatter intensity, I_{vb1}, is calculated using the roughness parameters specified in [3] and the remaining physical parameters are from [4]. The predicted intensity of the volume and surface scatter are superimposed on the same plot in Figure 2. The intensity curves start at 5 ms, that is the time when the pulse that is incident on the seabed transitions to an annulus from a spot. This time is also when the peak in I_{sb1} and I_{vb1} is expected to occur. The decay of I_{sb1} is a function of seabed roughness. The decay and initial level of

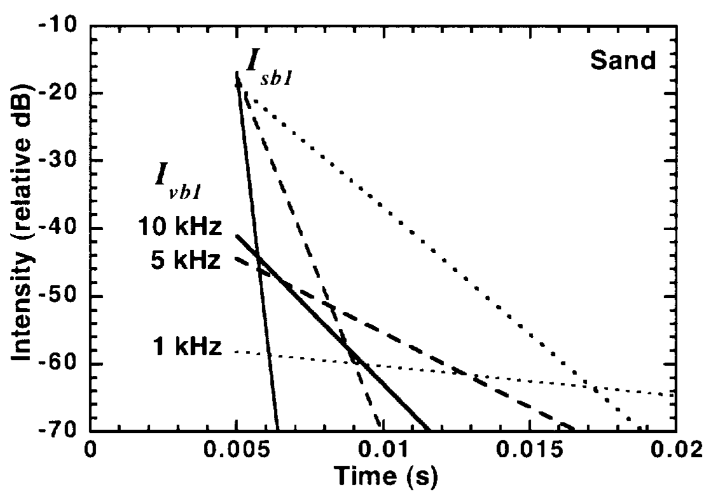

Figure 2: Comparison of I_{sb1} for a sand bottom with rms roughness of 3.75 cm (solid black line), 7.5 cm (dashed red line), and 15 cm (dotted blue line) and I_{vb1} at frequencies of 1, 5, and 10 kHz

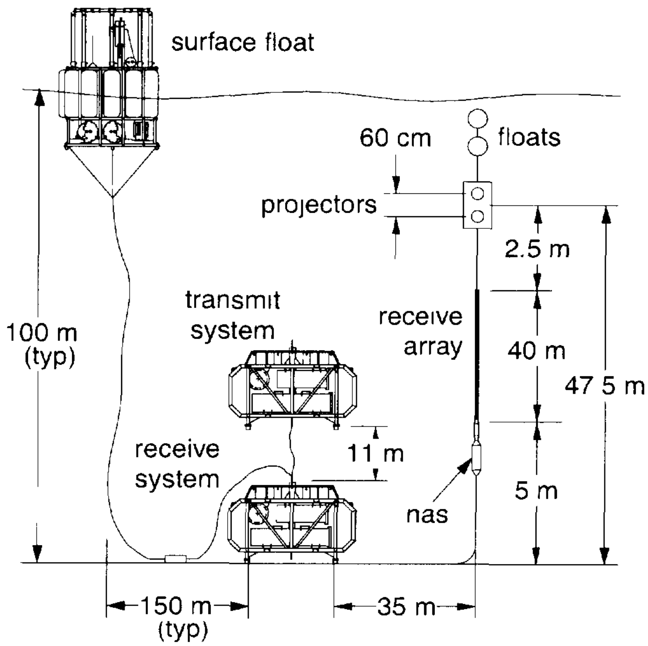

Figure 3. Schematic diagram of the DREA Underwater Acoustic Target deployment.

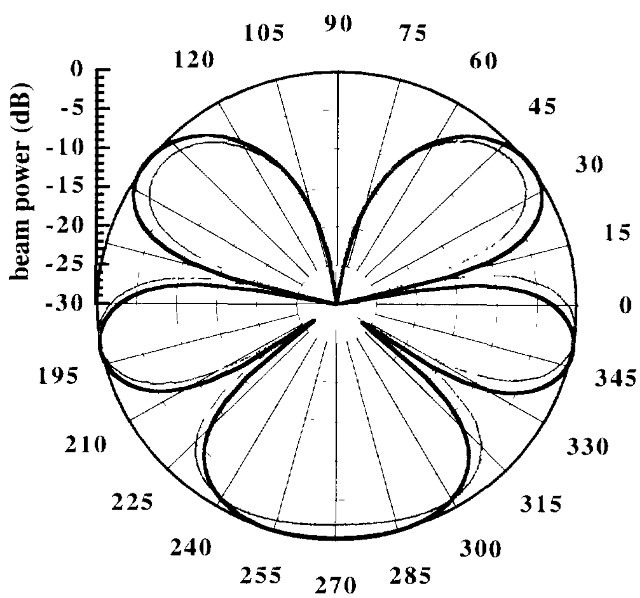

Figure 4 Theoretical (solid black line) and measured (closely spaced red dots) beam patterns for the steady state radiation from a pair of transducers separated by 5λ/4 and driven in phase quadrature. The null is directed at the sea surface.

I_{sbl} is a function of frequency and sediment type.

II. Experimental Methodology

Experiments were conducted using the Defence Research Establishment Atlantic (DREA) Underwater Acoustic Target (UAT). The UAT is a ship-launched echo-repeater with a 15 hydrophone vertical line array (VLA) and a non-acoustic section (NAS) suspended beneath the VLA (Fig. 3) Up to 8 hydrophones can be recorded simultaneously, but must be selected prior to deployment. For the seabed classification experiments, the hydrophones were selected to be equally spaced, to include the hydrophone closest to the projectors, and to provide the maximum possible aperture. Immediately above the VLA, there is a pair of ITC 1007B 16 cm diameter spherical projectors whose acoustic centers are separated by 62.5 cm The projectors are controlled individually but may be used in tandem with user specified time and phase delays. With echo-repeat mode disabled, the UAT functions as a remotely controlled source and receiver Although the UAT can be used in a free-floating mode, it was bottom tethered for this application. The power and electronics modules for the UAT are housed in two space frames, for the transmit and receive systems respectively. These space frames were displaced as far as possible horizontally from the VLA to minimize their influence on the scattering measurements. Data can be recorded internally by the UAT or telemetered by radio link to the tending ship–the latter being the preferred and typical mode of operation.

For these seabed classification experiments, acoustic energy that propagates from the source and is reflected by the sea surface gives rise to a series of arrivals that are unwanted and can mask the seabed reflected arrivals that are of interest. The amplitude–and hence the importance–of these arrivals can be reduced by using a directional source with the main lobe pointed at the seabed This was achieved by time delaying and phase inverting the output from the upper projector such that cancellation occurs above the transducers and reinforcement occurs below (Fig. 4). The time delay was equal to the time of flight between the transducers, with the upper projector delayed relative to the lower Frequencies were selected such that the transducers were separated by $5\lambda/4$, $9\lambda/4$, and $13\lambda/4$ (approximately 3 kHz, 5.3 kHz, and 7.7 kHz respectively).

III. Results

The median intensity of two hundred 1 ms duration pings at 5333 Hz measured on four hydrophones in the vertical array is displayed in Figure 5. There are numerous arrivals in each time series including the direct arrival, 'D', and arrivals with a number of sea surface, 'S', and/or seabed, 'B', reflections.

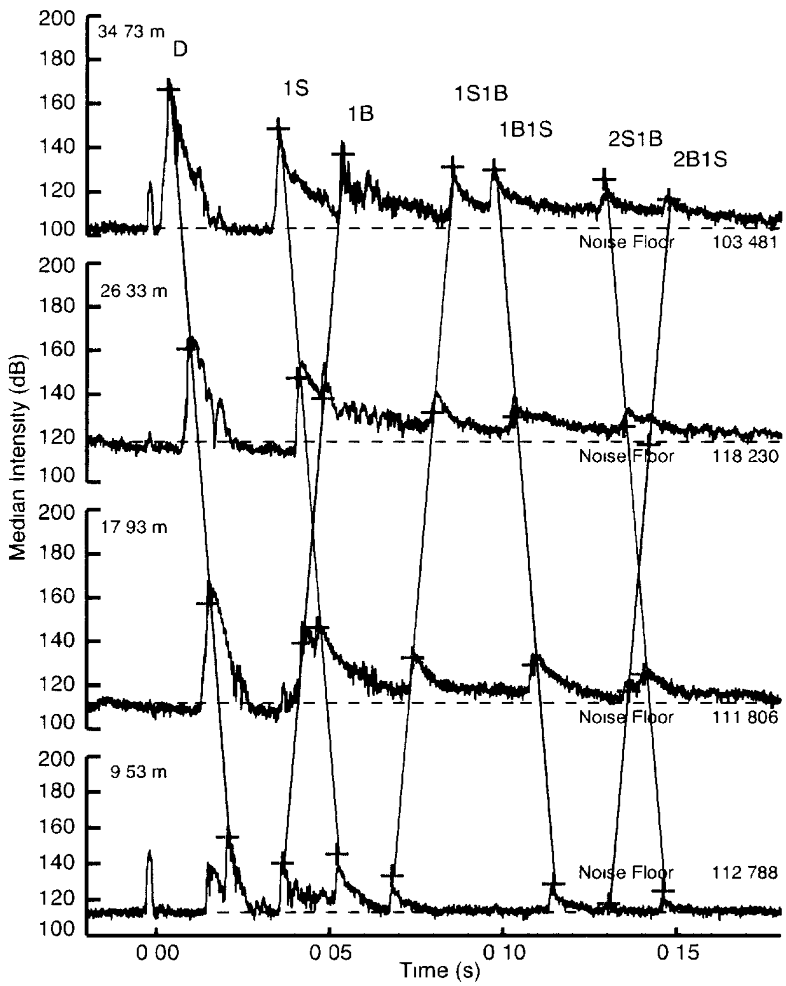

Figure 5: Time series of median intensity on four equally spaced hydrophones during a seabed classification experiment. Green crosses represent theoretical arrival times and amplitudes. Diagonal lines denote the initial direction of propagation, downward (blue) or upward (red). Inset numbers are height of the hydrophone above the seabed.

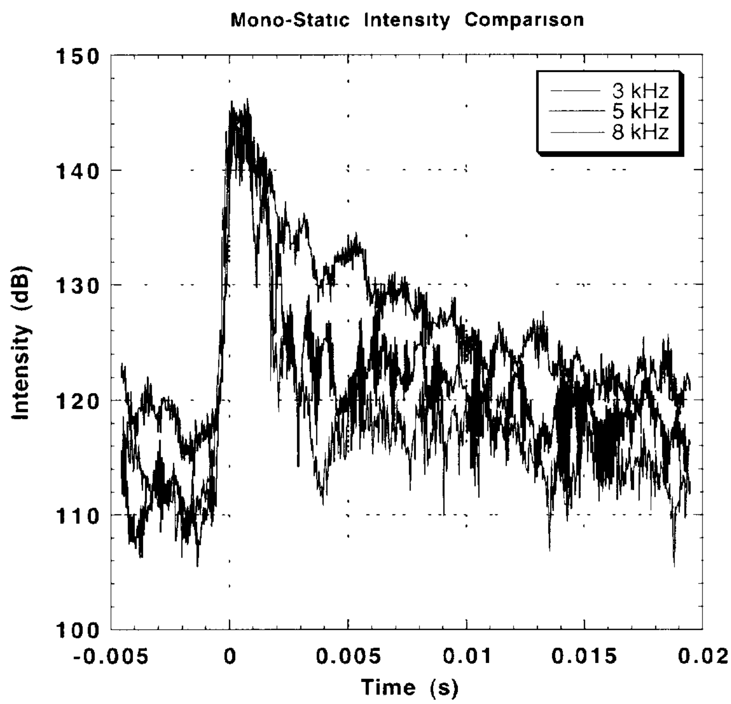

Figure 6: Time series of median intensity of the 1B arrival on the uppermost hydrophone at three frequencies for a 1 ms duration pulse

The theoretical arrival times (green crosses in Fig. 5) use a depth averaged sound speed of 1465 m/s and assume that the VLA is perfectly vertical. The amplitude calculations employ the drive voltage and transmitting voltage response curves for the projectors to determine the source level, assume a spreading loss of 20log(r), where r is the length of the propagation path, a reflection loss of 0 dB at the sea surface and 10 dB for each seabed reflection. Although there are some calibrations issues to be resolved (as evidenced by the amplitude mismatch of the direct arrivals), the amplitude discrepancy between the 1S theoretical value and the median intensity is due to the effectiveness of the phase quadrature beam pattern in eliminating radiation to the sea surface and any scattering that may have happened. (Winds were 20 knots during the experiment and both the wind and seas had been building during the previous eight hours).

The decay of the 1B arrivals on the uppermost hydrophone at three frequencies is displayed in Figure 6 The shapes of these curves are consistent with the theoretical predictions for a sand dominated seabed (Fig 2) Although the decay curves have a considerable amount of structure, perhaps due to some layering in the seabed, their slopes and relative levels are as predicted The initial decay is most rapid at the lowest frequency followed by a rapid transition to a slowly decaying volume scattering regime At the two higher frequencies, the intensity levels at the onset of volume scattering are progressively higher and decay more rapidly than the lowest frequency. These results were collected in the vicinity of the AMCOR 6010 on the ONR Strataform experimental area–a location where geoacoustic seabed properties have been measured by independent means and summarized in [5]. The seabed is described as having "near surface layering" with the first twenty five metres being a "sandy-silty-clay" layer. The average compressional sound speed in the first 5 m is 1560 m/s and reaches 1830 m/s at 30 m depth

While this paper has focused on the first seabed reflection, 1B, received on the hydrophone that is closest to the source location, there are two other arrivals that will be considered in subsequent research. These are the second seabed reflection, 2B1S, and a 1B arrival measured on the deepest hydrophone, as far away from the source as possible, in order to have the maximum bi-static angle. The former will allow a more direct comparison of the lower frequency model extension [3] with the original higher frequency classification technique [1] The latter should provide an alternate means of obtaining the bi-static geometry, required by [1], using an arrival that has a higher signal to noise ratio than the 2B1S arrival (Fig. 8)

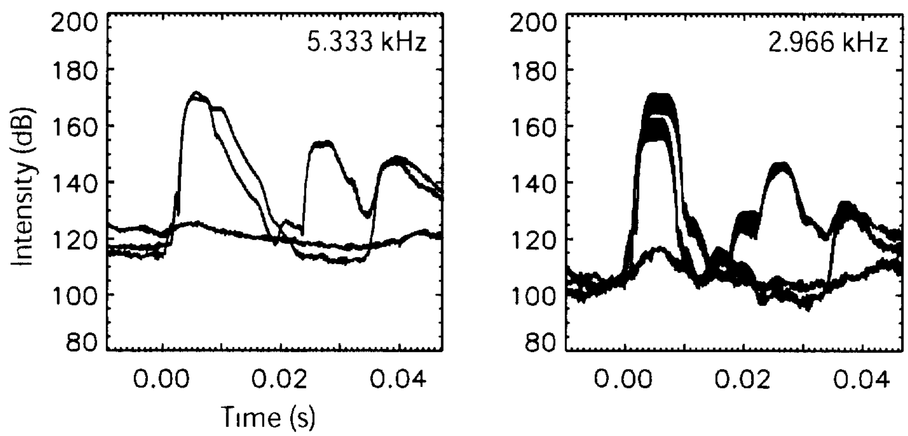

Figure 8· Time series of median intensity for a 5 ms pulse at two frequencies. Red line is the 1B arrival on the uppermost hydrophone, blue line is the 2B1S on the uppermost hydrophone, and the black line is the 1B arrival on the deepest hydrophone.

IV. Conclusions

An experimental geometry for testing model predictions for seabed and sub-seabed sediment classification has been developed and experiments have been conducted in open ocean conditions Initial results from these experiments on a sand dominated seabed have a frequency dependence that is consistent with theoretical predictions. This suggests that a broadband normal incidence sonar system operating in the 1 to 10 kHz band may be used for purposes of seabed and sub-seabed sediment classification.

V. References

1 Heald, G.J , and Pace, N.G., An analysis of 1st and 2nd echoes for seabed classification, Proceedings: 3rd European Conference on Underwater Acoustics, edited by J S Papadakis, Forth-IACM, Heraklion, 1996, pp. 649-654

2 Pace, N.G., Al-Hamdani, Z.K.S., Thorne, P.D., The range dependence of normal incidence acoustic backscatter from a rough surface, J Acoust. Soc. Amer , 1985, 77, pp. 101-112

3 Hines, Paul C., and Heald, G J., Seabed classification using normal incidence backscatter measurements in the 1-10 kHz frequency band, Proceedings of the Institute of Acoustics Conference on Acoustical Oceanography, Southhampton, United Kingdom, 2001, vol 23, Pt. 2, pp 42-50

4 Ivakin, A. N , Models for seafloor roughness and volume scattering, Proceedings Oceans '98, Nice, France, 1998, pp. 518-521.

5 Carey, W.M , Doutt, J , Evans. R B , and Dillman, L.M., Shallow-water sound transmission measurements on the New Jersey Continental Shelf, IEEE Journal of Oceanic Engineering, 1995, vol. 20, pp 321-336.