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ACOUSTIC BACKSCATTER AND SEA BED CHARACTERISTICS

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1 Introduction

Over the years many attempts have been made to develop schemes for the remote acoustic classification of the sea bed in terms of its roughness, its acoustic impedance ,its sediment parameters or some combination of these properties. [1]

In this paper an outline account is presented of some theoretical and laboratory experimental studies of rough surface acoustic scatter and how it might be applied to sea bed sensing particularly at near normal incidence.

2 The Scattering Coefficient

The total acoustic intensity backscattered at normal incidence from a rough surface consists of a coherent part and an incoherent part. The former is proportional to the square of the coherently averaged pressure $\langle p\rangle^2$,the average being over a number of realisations of the surface scattering patch and the latter is proportional to the difference between the average of the pressure squared $\langle p^2\rangle$ and $\langle p\rangle^2$.Assuming the incident pressure is a spatially limited, spherically spreading wave having been radiated from a finite aperture transducer and providing the beam pattern is not too narrow ,the range dependence of the coherently scattered signal is well known to be given by the image solution. That is to say the range variation of the coherently scattered signal is simply an extension of that of the signal incident on the surface. On the other hand the incoherent intensity varies in the Fraunhofer régime inversely with the square of the range, measured from the surface. The result is that the range dependence of the total scattered intensity depends on the ranges of the transmitter and receiver as well as on the surface statistics. This effect is well known [2].If the normal incidence backscattered signals are observed in a manner which involves changes in the transmitter range to the scattering surface as well as that of the receiver then the variation of the peak received signal with range to the scattering surface has in addition a dependence on the scattering patch size which may be limited either by the beam pattern or by the pulse length of the transmitted signal.

Here the range dependence of the incoherent normal incidence backscattered intensity is considered. As mentioned above this is usually expected to vary inversely with range and on this basis the usual definition of the Scattering Coefficient is

$$S = \frac{I_{BS}}{I_0}\frac{R_0^2 R_1^2}{R_{ref}^2 A} \tag{1}$$

where I_{BS} is the ensemble averaged backscattered intensity at distance R_1 from the scattering patch and I_0 is the source intensity at the reference distance R_{ref} (=1m) from the source. The source is located a distance R_0 from the scattering patch which has an effective area A

Such a definition provides a descriptor of the surface independent of the measurement arrangement. The portability of the values depend on the effective area A being well defined .

There are situations in which the combination of surface statistics and experimental geometry place the receiving position within what is termed as the nearfield of the scattering patch. As will be shown below this nearfield distance can be surprisingly large and is not dependent on frequency in the sense of the familiar transducer nearfield. Experimentally measured scattering coefficients may thus unwittingly be severely underestimated. The existence of this effect may be employed in sensing the surface statistics.

2.1 Some theoretical expressions

The basis for the expressions presented below is the Helmholtz-Kirchoff integral evaluated using a Fresnel phase approximation[3]. The solutions pertain to surfaces which may be described by Gaussian statistics and to acoustic sources and receivers whose beam patterns can be described by Gaussian directivity functions. The effective insonified area A required by equation (1) is determined by the e^{-1} pressure contours of the transmitting and receiving beam patterns. The theory is usually [4] considered to be limited to surfaces for which local radii of curvature are much larger than the acoustic wavelength. All the expressions below are for the situation in which $h/\lambda \geq 0.5$ where h is the rms surface roughness and λ is the acoustic wavelength. This excludes the coherent component of the scattered intensity from the expressions.

2.2 Far-Field Backscattering Coefficient

For backscatter at an angle of θ

$$S_1(\theta) = \frac{\Re^2 T^2}{32\pi h^2} \frac{\exp\left(-\frac{T^2 \tan^2(\theta)}{4h^2}\right)}{\cos^4(\theta)} \tag{2}$$

where T is the surface correlation length. An rms surface slope can be defined as

$$\sigma^2 = 2\frac{h^2}{T^2} \tag{3}$$

When the angle of incidence and scatter are θ_1 and θ_2 the scattering coefficient becomes

$$S_2(\theta_1, \theta_2) = \frac{\Re^2 T^2}{32\pi h^2} \frac{\exp\left(-\frac{T^2 \tan^2\left(\frac{\Delta\theta}{2}\right)}{4h^2}\right)}{\cos^4\left(\frac{\Delta\theta}{2}\right)} \tag{4}$$

An angular half width of the scattering pattern may be defined as

$$\theta_s = 2\sqrt{2}\,\sigma \tag{5}$$

At normal incidence the backscatter coefficient becomes

$$S_3 = S_{FF} = \frac{\Re^2}{16\pi\sigma^2} \tag{6}$$

where S_{FF} is the far field scattering coefficient.

2.3 Nearfield normal incidence backscatter coefficient

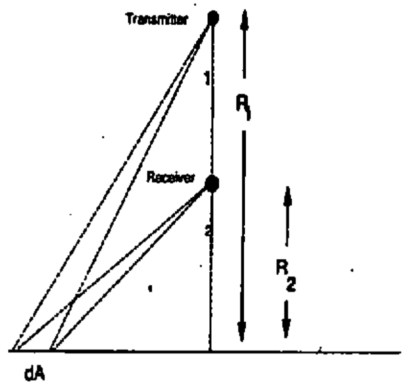

Figure 1 .Arrangement of transmitter and receiver relative to the scattering surface

For the geometry shown in Figure 1 and the case of the insonified area being limited only by the beam patterns, the backscatter coefficient is

$$S_4 = \frac{\Re^2}{16\pi\sigma^2}\left\{1 + \theta_0^2\frac{(1+\alpha)^2}{16\sigma^2}\right\}^{-1} \quad (7)$$

where the receiver is omnidirectional and the transmitter has an e^{-1} half beam angle of θ_0 and

$$\alpha = \frac{R_1}{R_2} \quad (8)$$

When the transmitter and receiver are coincident with the same aperture

$$S_5 = \frac{\Re^2}{16\pi\sigma^2}\left\{1 + \frac{\theta_0^2}{8\sigma^2}\right\}^{-1} \quad (9)$$

If short pulses are radiated in this situation ,the peak value of the ensemble averaged backscattered intensity is given by

$$I_{BS} = \frac{I_0}{R_1^4} S_5 \frac{\pi R_1^2 \theta_0^2}{4}\{1 - \exp(-B\tau)\} \quad (10)$$

where

$$B = \left(1 + \frac{\theta_0^2}{8\sigma^2}\right)\frac{4c}{R_1\theta_0^2} \quad (11)$$

where τ is the duration of the radiated pulse and c is the speed of sound in water. Whether the scattering coefficient operative in equation (10) is considered to be S_5 or $S_5(1-\exp(-B\tau))$ is of little importance. What is important is that one knows one is in the scattering patch nearfield.

2.4 Discussion of nearfield effects

S_4 is a function of range, θ_0 and θ_r. A nearfield range R_{NF} may be defined as the range at which $S_4 = S_{FF}/2$

so that

$$R_{NF} = \frac{R_1}{\left(4\frac{\sigma}{\theta_0} - 1\right)} \qquad (12)$$

When $R_2 \gg R_{NF}$ then $S_4 \Rightarrow S_{FF}$. On the other hand, close to the surface when $R_2 \ll R_{NF}$ then

$$S_4 \Rightarrow \frac{\Re^2}{\pi\theta_0^2 R_1^2}\left\{\frac{R_1R_2}{R_1+R_2}\right\}^2 \qquad (13)$$

which is the scattering coefficient for a plane surface.

For the case of a coincident transmitter and receiver the scattering coefficient $S_5 \leq S_{FF}/2$ if $\theta_0 \geq \theta_r$

3 Range dependence experiments

Experiments in a laboratory tank were designed to explore the degree to which the expression for the scattering coefficient S_4 holds. Two surfaces each with different surface slopes were employed (see Table 1) in the geometry of Figure 1. S_4 Values were measured as a function of range at two frequencies. Careful measurements of the surface statistics allowed theory and experiment to be compared as is shown in Figure 2. A full account of these investigations is available[3] together with interpretation of further experimental data[5] using the expressions in Section 2.3.

Table 1

Surface	Reflection Coefficient	rms height/cm	Correlation length T/cm	Frequency of measurement /kHz
A	0.93	0.22	1.9	250
A	0.93	0.22	1.9	1000
B	0.6	0.18	0.33	250
B	0.6	0.18	0.33	1000

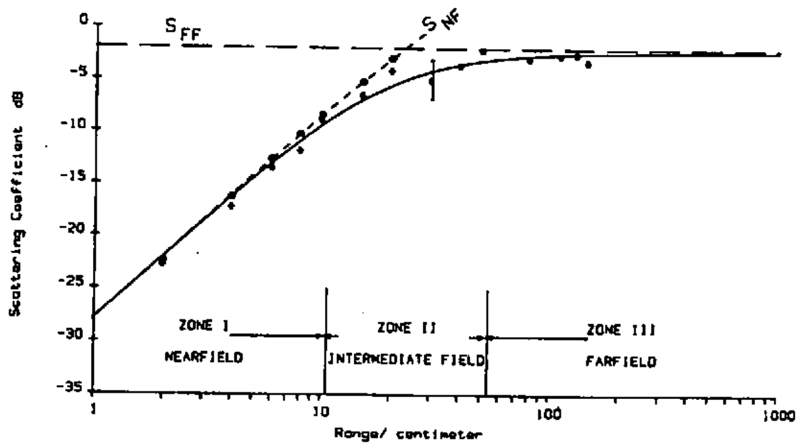

Figure 2a The scattering coefficient versus range is shown for surface A at a frequency of 250 kHz with θ_0 =5 degrees.(*) experimental values;(•) experimental values from a plane surface ; the lines are from equation(7)

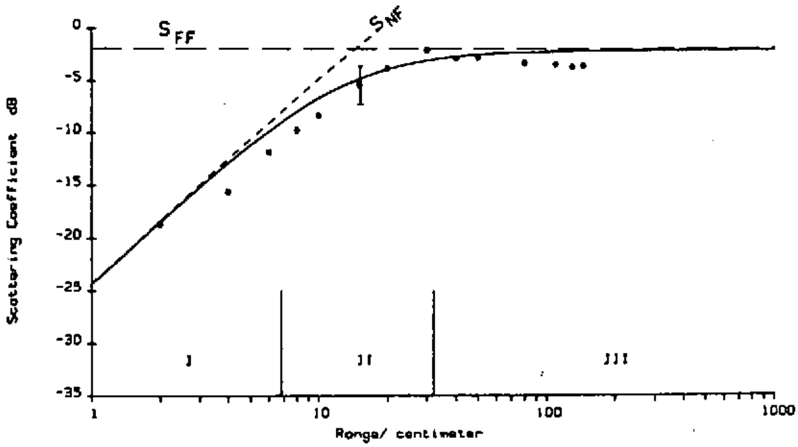

Figure 2b The scattering coefficient versus range is shown for surface A at a frequency of 1000 kHz with θ_0 =3.3 degrees.(*) experimental values; the lines are from equation(7)

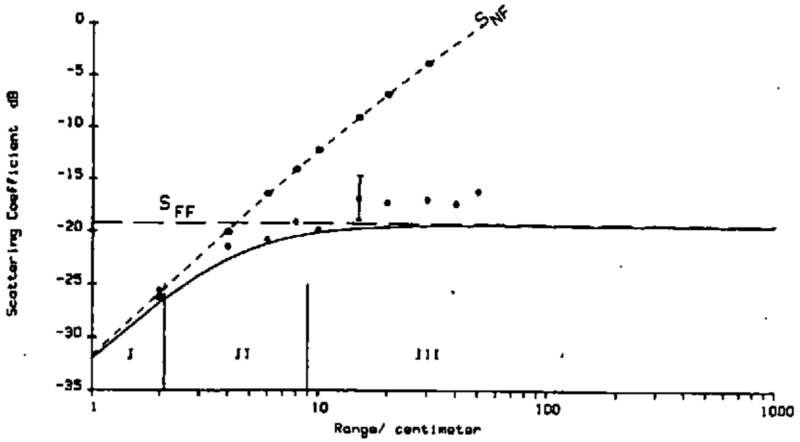

Figure 2c The scattering coefficient versus range is shown for surface B at a frequency of 250 kHz with θ_0 =5 degrees.(*) experimental values;(•) experimental value from a plane surface; the lines are from equation(7)

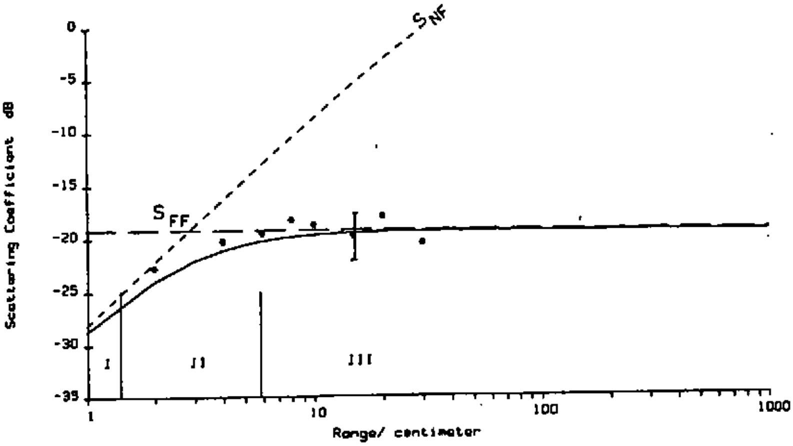

Figure 2d The scattering coefficient versus range is shown for surface B at a frequency of 1000 kHz with θ_0 =3.3 degrees.(*) experimental values; the lines are from equation(7)

4 Range dependence of backscattered intensity and surface characteristics

In order to estimate how significant the range dependence of scattering coefficients is in practice at sea ,values for the rms slope of seabeds is required. Clay and Leong [6] have given a relationship between the rms seabed roughness h and the correlation length T

$$T \sim 30h^{1.25} \quad \text{metres} \tag{14}$$

This relation allows the angular half width of the seabed scatter to be written as

$$\theta_s = 7.64h^{-1/4} \quad \textit{degrees} \tag{15}$$

This assumption gives, for example, $\theta_s = 24$ degrees for an rms roughness of 1 cm reducing to 14 degrees as the roughness increases to 10 cm. The condition for the scattering coefficient effective for coincident transmitter/receiver arrangement to be always less than half the far field value is $\theta_0 \geq \theta_s$ and thus may well occur in practice.

The ensemble averaged backscattered intensity corresponding to the arrangement under which S_4 is measured (equation (7)) may be expressed both

$$I_{BS} = \frac{I_0 \Re^2}{2\pi\theta_s^2} \frac{\pi R_1^2 \theta_0^2}{2} \frac{1}{R_1^2 R_2^2} \left\{ 1 + \frac{(1 + R_1/R_2)^2}{(1 + R_1/R_{NF})^2} \right\}^{-1} \tag{16}$$

and as

$$I_{BS} = constant \times R_2^{k(R_2)} \tag{17}$$

Measurement of the range dependence via k would provide a means for extracting the rms slope of the seabed. Figure (6) shows plots of k versus the ratio (R_1/R_2) with the ratio (R_1/R_{NF}) as parameter.

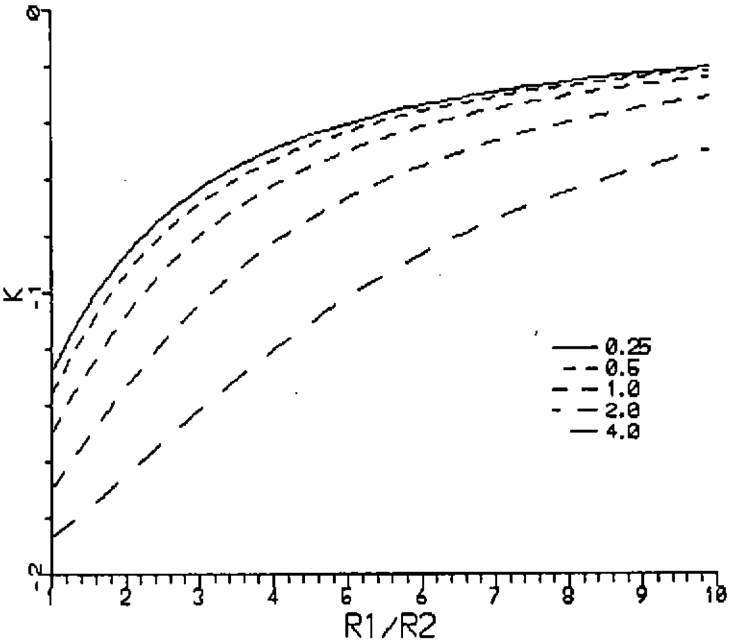

Figure (3)The dependence of the ensemble averaged intensity on range R_2 of a point receiver from the sea bed.The receiver is on the axis of a transmitter which is oriented for normal incidence on the sea bed at a range of R_1 from the sea bed.The backscatter depends on range as R_2^K. The parameter for the various curves is the ratio of the transmitter range R_1 to the nearfield range R_{NF}.

However this approach requires deployment of a receiver at a number of positions between the source and the sea bed. A more practical approach might be to employ the same transducer for both transmission and reception and obtain ensemble averaged backscattered intensities as a function of transmitted pulse length. The surface slope may then be extracted according to equations (10) and (11). These equations apply to the peak value of the backscattered signal which on average occurs at a time equal to the pulse duration after the first return. Expressions for the rise and fall times of such returns are readily derived and are also sensitive to surface statistics.

References

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