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REVERBERATION AS A FACTOR IN SONAR PERFORMANCE

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Introduction

When a sonar set is used for detecting targets in the sea the acoustic signals received back at the set from the targets are often degraded by echoes from other scattering mechanisms in the water. These other echoes, known as reverberation, are of two different types.

a. boundary reverberation - so called because it consists of scattering from the sea surface and sea bed.

b. volume reverberation - which comes from discrete objects in the water - either organic or inorganic.

Both types of reverberation cause problems in the detection of a wanted target and effort has to be made in the design of sonar systems to minimise these effects. A better understanding of the reverberation process is necessary before these designs can be optimised. This paper discusses some of the work done in studying surface reverberation.

The first illustration (fig 1) shows how signals can be scattered back, from the sea surface to the sonar, which are comparable in range and bearing with those from the target, in particular if the target is near the sea surface. In this case the target might only be distinguishable by its frequency response or the magnitude of its echo under certain circumstances. An intensive programme has been undertaken to assess the manner in which sea surface reverberation varies as a function of sea state, frequency and angle of incidence.

Theory

Figure 2 illustrates a very simple case of a plane acoustic wave impinging upon a sinusoidal surface having a spatial wavelength L. If to a first approximation the surface is regarded as a diffraction grating with spacing equal to the period of the surface, then it can be seen that, when detected at certain angles and long ranges, the waves scattered from the grating will appear to be in phase at certain angles whereas at other angles there will be phase cancellation. The scattered wave will vary in amplitude as a function of acoustic frequency, periodicity of the surface, angle of incidence and scattering.

For the particular case of backscattering of sound from the surface to the source the amplitude will be a maximum when

$$\sin \theta_r = \frac{N\lambda}{2L} \qquad (1)$$

Where θ_r is the scattering angle, λ the acoustic wavelength and N is an integer. This example shows that scattering is very dependent upon the dimensions of the surface and is most affected by roughness of similar periodicity to the acoustic wavelength. Thus for a randomly rough surface having a continuous spectrum varying from much greater than the acoustic wavelength to very much less it will be only those components where L and λ are comparable which will significantly affect the backscattering.

Several theories have been put forward to relate the intensity of the scattered sound to the surface statistics, the most notable of these being that of Marsh. (1). His expression for the backscattering coefficient is

$$Q = \frac{\cot^4 \theta \; \omega^5 A^2(\omega)}{32g^2} \qquad (2)$$

where g is the acceleration due to gravity, θ the incidence angle, ω the acoustic frequency and $A^2(\omega)$ the power spectrum of the sea surface. Marsh's solution, which involves expressing the random sea surface statistics as a Fourier series, is really only conveniently applicable to low sea states where the rms height variations are less than the acoustic wavelength. At higher sea states the solution becomes rather unwieldy.

Several experimental and theoretical expressions are available for the power spectrum of the surface, most of which suggest a dependence on frequency of the form

$$A^2(\omega) = B\omega^{-5} \qquad (3)$$

first deduced by O.M.Phillips (2), for a saturated sea. This expression was used by Marsh in equation (2) to give a back-scattering ~~coefficient~~ of

$$Q = \frac{B \cot^4 \theta}{32g^2} \qquad (4)$$

It is notable that this expression is independent of both frequency and windspeed. This is due to the particular model of surface spectrum used, which is essentially a one dimensional spectrum with no allowance made for a windspeed dependent low frequency cut-off or directionality.

Crowther (3) has recently developed an alternative solution to the scattering equation whereby he is able to extend the theory to higher sea states where the rms height of the surface roughness is greater than the acoustic wavelength, but this theory too breaks down at high sea states. The theory is also able to take into account the directional dependence of the acoustic propagation relative to the wind direction and also shows a dependence of scattering upon frequency.

His expression is

$$Q = \frac{k_3^2}{4\pi^2} \exp(-4k_3^2\sigma^2) \int_{-\infty}^{\infty} \exp - \left[1 - 4k_3^2 \sigma^2 C(r)\right] \cos k_x r \, dr \qquad (5)$$

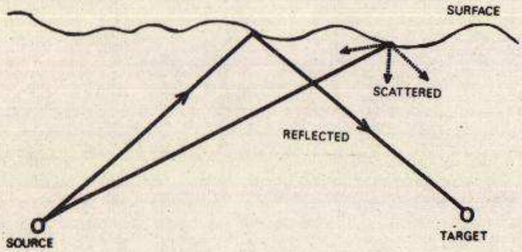
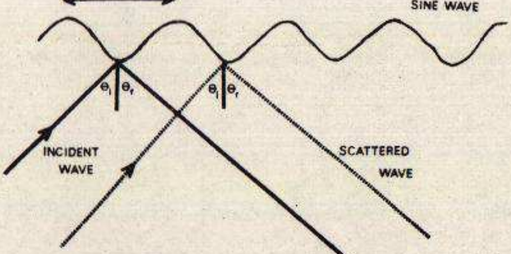


FIG 1



Phase difference $\phi = \frac{2\pi L}{\lambda}(\sin\theta_r - \sin\theta_i)$

Phase addition $\phi' = 2N\pi$

$\sin\theta_r = \sin\theta_i + \frac{N\lambda}{L}$: Backscatter $\theta_i = \theta_r$

$\sin\theta_r = \frac{N\lambda}{2L}$

FIG 2

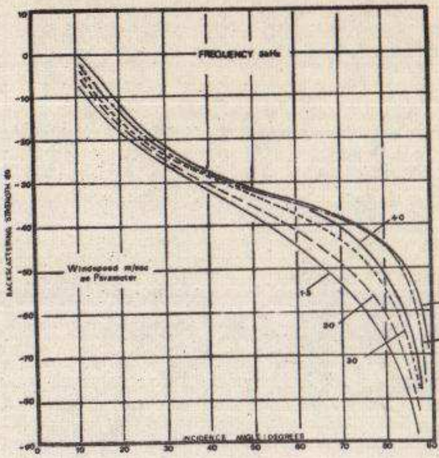

FREQUENCY
Windspeed m/sec as Parameter
BACKSCATTERING STRENGTH dB
INCIDENCE ANGLE DEGREES

FIG 3

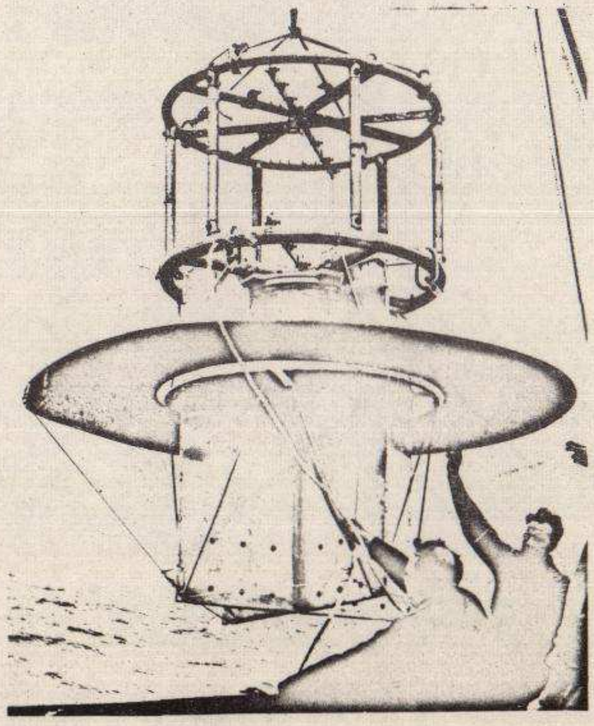


FIG 4

where $k_z = k\cos\theta$

$k_x = k\sin\theta$

C(r) is the autocorrelation function of the sea surface, measured in the direction of propagation, σ is the surface rms height roughness. C(r) is critically dependent upon the direction in which measurements are made, since it will be found to oscillate quickly in an upwind-downwind direction whereas it can be almost constant when measured across a swell. Equation (5) is not readily evaluated, but a numerical analysis has been carried out using the Fourier transform of the power spectrum mentioned earlier. Curves for some of the parameters are shown, as a function of wind speed, for a frequency of 3kHz. (fig 3). These curves show that as the wind speed increases (or the sea state) then the backscattering strength increases. At low sea states the curves are identical with those of Marsh.

Experimentation

In any work undertaken to measure backscatter from the sea surface it is necessary to measure the surface statistics simultaneously with the backscattering. This normally introduces problems since with the acoustic wavelengths used being of the order of 50cm it is necessary to measure surface roughnesses with periods embracing this dimension, ie measuring wave lengths as short as 10 cm. To measure surface statistics to this order of accuracy it was necessary to build a new type of wavebuoy. This is shown in the next figure (fig 4). The buoy is arranged to measure the small and large components of the spectrum separately. The small components are measured with fine wire resistance probes arranged so that the correlation function of the surface can be determined for spacings between 5 and 120 cm. The larger wave components are measured with an accelerometer mounted in a pot below the probes. Pitch and roll of the buoy are monitored together with its orientation relative to the wind direction. In operation the buoy is streamed from the windward side of the ship and the information is fed to the ship through a 200 yard cable. Records are taken, on completion of the acoustic experiments, with the wavebuoy measuring the spectra upwind, downwind and cross-wind in turn.

Figure 5 shows a set of results taken with the buoy. The resultant curve is obtained by combining the probe measurements with the buoy displacement measurements obtained from the accelerometer readings. The results, taken in a sea state 3 to 4 indicate a low frequency cut off to the spectrum at about 0.2Hz, the straight line part of the curve has a gradient of -5 up to a frequency of 4Hz, but above this the gradient decreases slightly.

The acoustic measurements were performed from the cable ship ACS ST MARGARETS using either explosives as a broad band source extending over the band 1 to 10kHz or a cw source operating at the geometric mean of these two frequencies. A scheme for the experiment is shown in the next figure (fig 6). The array which could be used either as a transmitter receiver for narrow band signals or as a receiver for explosive signals was suspended from the bows of the ship by a single multicore cable, and arranged to point in any prescribed direction by streaming the ship in that direction at about ½ kt.

The array is fitted with electronic beam steering so that the angle from which backscatter is measured can be varied.

Experiments have been carried out in a variety of sea conditions ranging from flat calm to sea state 5, both with and without the presence of swell. Results are presented for two of these runs (fig 7 and 8), taken in sea states 2 and 5, and are compared with the theoretical predictions obtained using equation 5 and the appropriate wave buoy records. The experimental points are the mean of 50 3kHz acoustic pulses. Both these sets of data indicate a good agreement between theory and experiment, particularly at angles of incidence above 50^{o}. At smaller angles, around 20^{o} there is a tendency for the backscattering to be greater than that predicted; this has been attributed to experimental difficulties in determining the exact angle of incidence at these steep angles. It was shown, theoretically, that when a saturated form of the sea surface spectrum was used in determining the acoustic backscatter there was a noticeable change in the expected reverberation level with sea state, particularly at large angles of incidence. This is not very marked on the results presented, although they show a very close agreement with the theoretical curves computed from a knowledge of the sea surface statistics at the time of the acoustic measurements. This illustrates the importance of measuring both the acoustic and environmental parameters at the same time, since the latter are sensitive to small local wind changes, which can give a surface spectrum different from the Burling one.

Conclusions

Sonar performance can be limited by background noise in the sea especially reverberation. In the design of sonar sets this level should ideally be reduced to the ambient noise level. The work which has been done shows that it is possible to predict the level of backscatter from the sea surface for sea states between 0 and 5 provided that the relevant surface statistics are known.

References

1. Marsh, H.W. Sound Reflection and Scattering from the Sea Surface. JASA 35 1963 p. 240-244.

2. Phillips O.M. The dynamics of the upper ocean. Camb. Univ Press 1966.

3. Crowther, P. Private communication, to be published.

Acknowledgements

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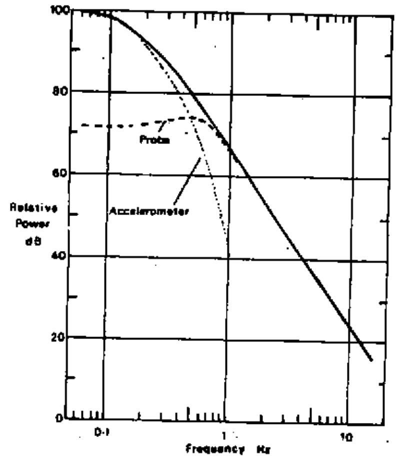

Spectrum for Sea State 3 - 4

5

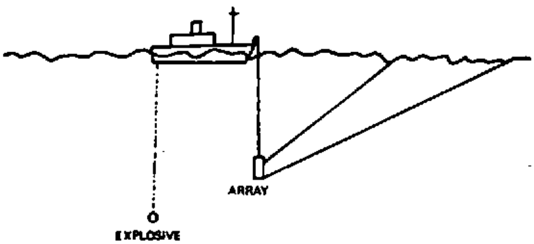

FIG 6

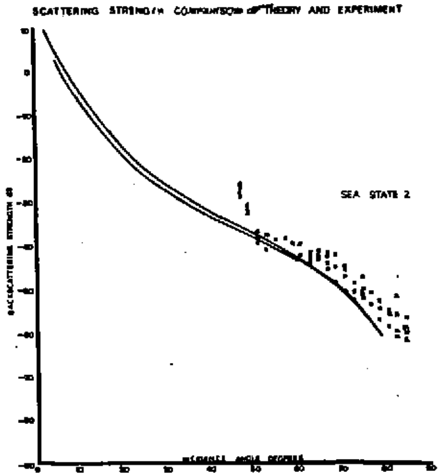
SCATTERING STRENGTH COMPARISON OF THEORY AND EXPERIMENT
SEA STATE 2

FIG 7

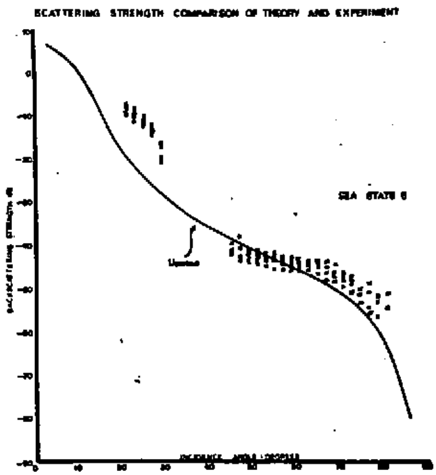
SCATTERING STRENGTH COMPARISON OF THEORY AND EXPERIMENT

FIG 8