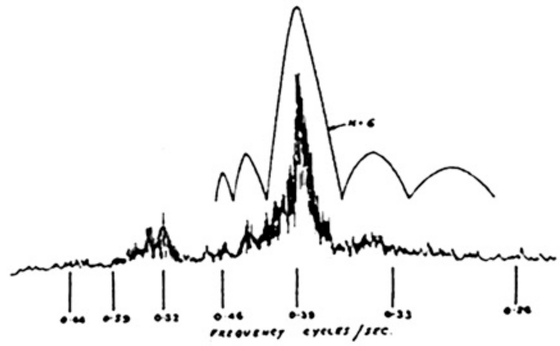

Fig. 2

Doppler Spectrum of Sea Echo at 13·56 Mc./s.

THE Doppler frequency shift of radio waves reflected from the sea surface at 13·56 Mc./s. has been recorded and a portion of a typical record is shown in Fig. 1. Such records show the following unexpected features: (*a*) the frequency of the principal component (as initially obtained by measurement of the length of individual cycles on the record) is surprisingly constant at about 0·38 c./s., irrespective of wind conditions and state of the sea; (*b*) the records show that the range of frequencies present is small. Spectrum analysis of the records made with an Admiralty wave analyser[1] confirmed these findings. Fig. 2 is a reproduction of a sample spectrum analysis which shows a large but narrow peak at a frequency of 0·38 c./s. accompanied by a smaller peak at a frequency of about 0·54 c./s.

A tentative explanation of these features can be offered if it is assumed that the sea waves act as diffraction gratings. It is known[2] that, under a given wind, sea waves of all lengths up to a maximum dependent on the wind velocity are generated. Of this multiplicity of waves, some travelling radially to the antenna will have a wave-length L and will reflect back a large signal when $L = \lambda/2$, λ being the radio wave-length. Since the velocity v of a sea wave of length L is given by $v = \sqrt{\frac{g}{2\pi} L}$, g being the acceleration due to gravity, then the Doppler shift Δf of this enhanced signal will be

$$\Delta f = \frac{2v}{\lambda} = \frac{2}{\lambda}\sqrt{\frac{g}{2\pi}\cdot\frac{\lambda}{2}} = \sqrt{\frac{g}{\pi}\cdot\frac{1}{\lambda}}$$

In the present case, $\lambda = 22\cdot1$ m., $g = 9\cdot81$ m./sec.^{2}, gives $\Delta f = 0\cdot376$ c./s., agreeing closely with the value for $\Delta f = 0\cdot38$ c./s. found from Fig. 2.

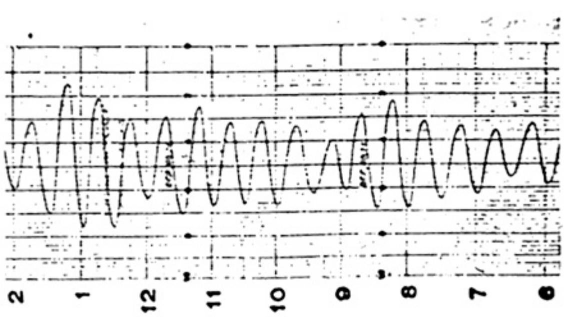

Fig. 1

It might also be expected that components of non-sinusoidal waves of wave-length $L = n\lambda/2$, n being an integer, travelling radially towards the antenna, would cause reinforcement and thus large reflected signals. These would then have Doppler shifts $\Delta f = \sqrt{\frac{g}{\pi}\frac{n}{\lambda}}$. The subsidiary peak in Fig. 2 at a frequency of 0·54 c./s. $\approx 0\cdot38\sqrt{2}$ thus suggests that this is due to waves having a length $L = \lambda$.

Both the peaks in Fig. 2 depart considerably from line spectra. At first sight this could be explained by considering that the relatively short waves of length $L \approx \lambda/2$ are superimposed on the crests of much longer waves and thus have velocities dependent on the lengths and heights of the larger waves. However, this would lead to a continuous spectrum, whereas in the neighbourhood of the larger peak in Fig. 2 there are small subsidiary maxima which on this argument would be unlikely to occur. An alternative explanation of the shape of the spectra is that the sea waves exist in short trains. The first-order ($n = 1$) diffraction patterns of short sea-wave gratings of variable spacing L have been calculated, and by the use of the relation $\Delta f = \frac{2}{\pi}\sqrt{\frac{g}{2\pi}\cdot L}$, may be drawn as Doppler shift spectra. Superimposed on Fig. 2 is such a spectrum obtained for a grating containing six wave crests. The agreement is considered to be good. This may be of interest to oceanographers, since the explanation does not completely conform with accepted ideas of the behaviour of sea waves.

The explanation above would suggest that by the use of radio waves of lower frequency longer sea waves would be observed, and that the use of an equipment of variable frequency would result in a sea-wave spectrometer. At very high frequencies under extremely calm conditions, however, when sea waves of length comparable with the radio wave-length are dominant, similar results to those found here at lower frequencies should be obtained.

It is interesting to note that, because capillary waves have a velocity which decreases with wave-length, then the Doppler shift for radio wave-lengths less than 4 cm. under very calm conditions should increase more rapidly with decreasing wave-length than at longer radio wave-lengths. Under normal conditions, however, when waves of much greater length are dominant, then in the expression for Doppler shift $\Delta f = \sqrt{\frac{g}{\pi} \cdot \frac{n}{\lambda}}$, n will be large and a continuous spectrum may result if the mechanism suggested above is responsible.

I am indebted to Mr. N. F. Barber for valuable discussions on sea waves and to Mr. W. H. Ward under whose direction this work was undertaken.

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[2] Russel, R. C. H., and MacMillan, D. H., "Waves and Tides", 58 (Hutchinson, London, 1952).