MICROWAVE BACKSCATTERING ON WATER SURFACES -HIGHER ORDER BRAGG SCATTERING-

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Introduction

Microwave back-scattered signals from water surfaces, for example, of the sea have strong power due to the Bragg scattering in the case of 20 degree to 80 degree incidence angles . The main energy of this back-scattered signals is composed of the first Bragg scattering, and in this case the back-scattered microwave power is proportional to the wave-height power spectrum of the target water surface. Therefore there are many applications of microwave scattering, for example, monitoring of the sea states(roughness), sea conditions(pollutions), wind speed and so on.

In addition to the first Bragg scattering signal, the scattered microwave power comprises a lot of spectral components which are zero doppler component and higher order Bragg scattered components. The higher order ones are produced by the interaction between microwave energy and the target water surface waves of which wavelengths are integral multiples of that of water waves resulting the first order resonant scattering . These higher doppler components are generated at slightly different frequencies from that of the first order component. These may be a source of spreading the total doppler spectrum when the target waves are develcped.

This paper describes the analytical estimation of the spectra of microwave back-scatterd signals by a simple sinusoidally shaped water surface model, and the experiments about the dependency of the microwave back-scattered signal especially the second and third order scattering components on the frequency and amplitude of the target water wave with a 9.93GHz coherent scatterometer and a water tank.

Spectral estimation

We evaluated the spectra of the back-scattered electromagnetic waves to show the resonant (Bragg) scattering from simply shaped water waves. We set an analytical model composed of many small scattering cells on the water surface. Each cell is assumed to scatter the incident microwave energy omnidirectionally. The surface wave function z(x,t) of this model is set as follows

$$z(x,t) = h \sin (w t - k x) \qquad (1)$$

where h, w, and k are the amplitude, angular frequency and wave number of the water wave, respectively. After the scattering coefficient of a unit area is defined as "s", the total scattering coefficient S(t) of a whole illuminated area is derived as follows, [1]

$$S(t) = s \sum_{n=-\infty}^{\infty} J_n(2kh\cos T)\, \mathrm{sinc}(BL)\, \exp(jnwt) \qquad (2)$$

$$B = 2\, K \sin T - n\, k \qquad (3)$$

where
J_n is the n-th order Bessel function,

K is the wave number of the incident microwave,
T is the incidence angle,
L is the length of the illuminated area in the direction parallel to microwave propagation and
n is an integer.

(2) shows the modulation of the scattered signal by the target water wave. This signal S(t) is phase modulated by the vibrating target surface, and S(t) has the spectral components whose frequencies are multiples of the water frequency w. The intensity of each spectral component is determined by two coefficients, Jn(..) and sinc(BL). When the illuminated area is constant, the latter function depends only on "B", since L is constant. This function has maximum value 1, when

$$B = 2\ K \sin T - n\ k = 0 \tag{4}$$

This shows the n-th order resonance condition of the Bragg scattering. When this condition exists for n, the n-th order spectral line becomes its maximum. And only under the resonance condition , the frequency of n times w is equal to the calculated one from the water wave velocity by the general doppler effect.

The former coefficient of Jn(2KhcosT) depends on the wave amplitude h. Especially when the variable 2KhcosT is sufficiently small, the Bessel funcion is approximated to be the first term in its expansion and the intensity of the n-th order spectral line is assumed to be proportional to the n-th power of the wave amplitude h. This is true independently of the Bragg resonance condition. As known well, the microwave scattering intesity of the sea is proportional to the wave height and the first order spectral component of this simple wave form model is the same as the case of the sea.

Experiments

An X-band CW coherent scatterometer with a 20 dB horn antenna was used to observe the scattered spectra from tapped water-waves in a test tank. The model of the tapped water-waves was related in the previous section. The homodyne detected output signals are analyzed in the range of DC to 50 Hz of the doppler frequency using a FFT-type spectral analyzer. The tank used is 1.8m long, 0.7m wide and 0.2m deep. The water-waves generated by a bakelite flap are in the range from 2 to 16 Hz. The flap is drived by the stepping motor with a pushrod. The amplitude of flap vibration is arranged by selecting the diameters of the crank shaft of the motor. The scattering experiments were carried out for the polarizations of VV, HH, and HV, for the incidence angle of 60 degree.

At first, we observed some Bragg scattering spectra from first order to 5 th order. Fig.1 shows the second order (n=2) Bragg scattered spectra observed under the condition that the water wave frequency is 7.4 Hz. The Bragg scattering component in this scattered microwave energy is obviously included in the spectral line located at 14.8 Hz. This value of 14.8 Hz is twice that of the target water-waves in the tank. In addition to the strong second spectral peak, there are several peaks (first, third and 4th) located at the frequencies n times the water-wave frequency, 7.4 Hz. This spectral form is composed of peaks of integral multiples of the water-wave frequency as shown in (2). Some other peaks in the vicinity of 0 Hz are due to the slow swings of the water surface.

It has been shown that the corresponding spectral peak grows up in the case of resonance as shown Fig. 1. From (2) it can be easily obtained that the dependency of the peak height on the water-wave frequency is sinc function, so the scattered signal spectra from the water surface waves from 2 to 16 Hz are observed. Fig. 2 shows a group of these spectra. These are normalized by wave-heights measured simultaneously by a metal wire wave (height) meter in order to compare the first order peaks in the line marked by an arrow, because they are proportional to the target wave height. The group of first order peaks has maximum at about 13 Hz, and this value agrees with that calculated by the Bragg condition (4). In Fig. 2, a part of the groups of the second and third spectral peaks is detected.

Fig. 3 shows the characteristics of first, second and third spectral peaks depending on the target water frequency. "n" shows the spectral order and solid lines and open circles are the theoretical estimations by (2) and the measured values of peaks in Fig.2, respectively. The form of the estimation are sinc functions, and their maxima are located in 13.2 Hz(13.2Hz), 14.8Hz(7.4Hz) and 17.1Hz(5.7Hz). The values in the parentheses are target water-wave frequencies. The amplitude relations between different order measured values are not kept and this figure is likely used to evaluate the form of the characteristic in an order. In the case of the first order, the measured values agrees with the estimation at the point of having the maximum at the same frequency, but the higher ones do not, especially in the higher frequency range of the second order. It is because the normalization procedure uses twice and 3 powers of the wave heights and there were not enough accuracy of measured wave heights. Further it is necessary to compare them after wave height measurements in the neighbourhood of the resonant peaks.

Next we examined the dependency of the spectral peaks on the target water wave heights. From (2) the characteristics are n order Bessel functions and practically spectral peaks are approximated to be proportional to n-th power of the target wave height because the wave heights are not so large. Fig. 4 shows the measured characteristics of first, second and third spectral peaks for H-H polarization. The solid lines have the inclinations of 1, 2 and 3 coresponding to each order measurement. As known well the 1st order scattering proportional to the teaget wave height and it is clear that the higher order scatterings have higher order dependency on the wave height.

Conclusions

Microwave back-scattering properties from periodically formed water waves are explained by a simple sinusoidal wave model. The spectra of the scattered microwave signals comprise peaks at integral (n) multiple frequencies of those of the target water waves. Each peak has the characteristic of sinc function to the water wave frequency and show its maximum at the frequency determined by the n-th order resonance condition. And regarding the target wave height dependency, the intensity of n-th order spectral peak is proportional to n-th power of the wave height. These characteristics of the microwave back-scattering from water waves are confirmed by the experiments using the X-band coherent scatterometer and a test water tank.

From these results, it is indicated that the higher order Bragg scattered components, which have slightly different frequencies from that of the first order, are one of the sources of spreading the doppler width of the total scattered signal from wind generated water waves, since the spectral components whose powers are proportional to the second and higher powers of that of the target wave, grow higher and occupy a considerable part of the total doppler spectra.

References

[1] K.Komiyama,Y.Kato and I.Yokoshima,"Microwave Scattering from Water Surface with Simple Wave Motion", Proc. of 1984 International Symposium on EMC, Tokyo, Oct. 1984.

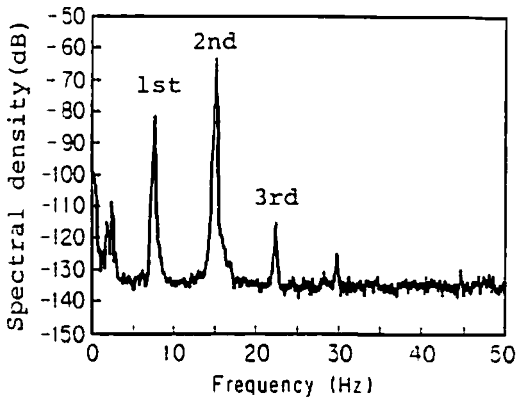

Fig. 1 Observed spectrum under the Bragg resonance condition of 2nd order.

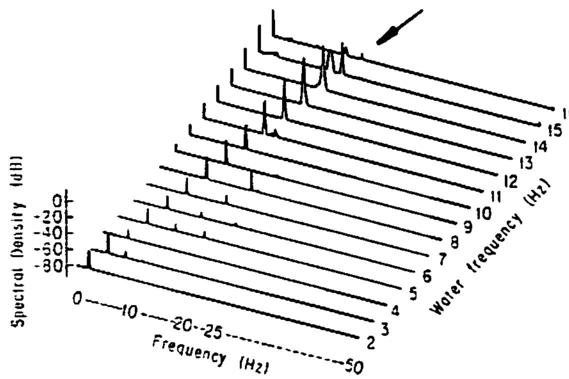

Fig. 2 Observed spectra of the scattered microwave from the tapped water-wave of 2-16 Hz

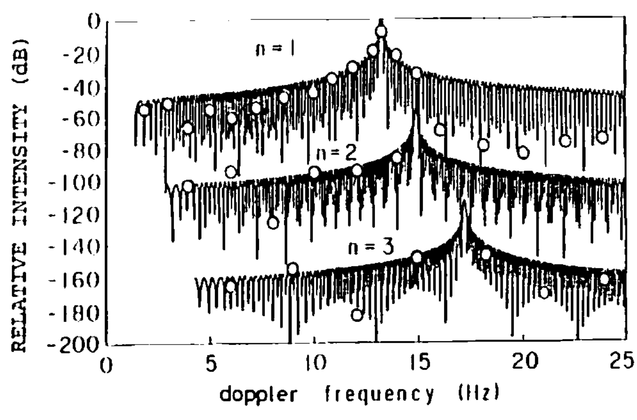

Fig. 3 Characterristics of the intensities of the 1st, 2nd and 3rd spectral line depending on the doppler (water-wave) frequency, obtained in experiments and estimated by the simple scattering model.

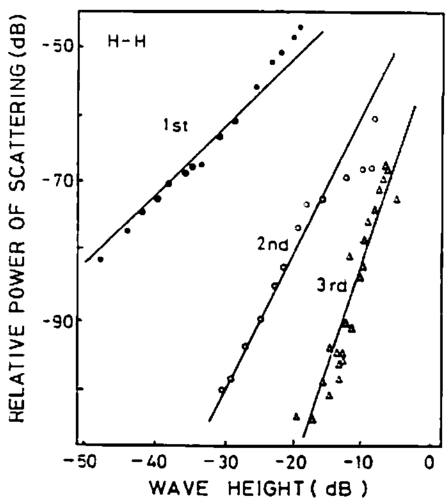

Fig. 4 Intensity characteristics of the microwave 1st to 3rd Bragg scattering regarding to the target wave height.

wave height 11mm=0dB