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Scattering Mechanism Analysis of Sea Clutter at UHF Band by Doppler Spectrum Characteristics

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Abstract

Using the sea clutter data observed by a coherent UHF band radar which is located on a shore-side platform with a height of 400m, this paper is a detailed research on the characteristics of the Doppler spectrum with different wave height and different intensity returns in a persistent sequence. Based on this, the correspondence analysis of scattering mechanisms in the above diverse conditions is carried out. The results indicate that at middle and low sea states, Bragg scattering is the major scattering mechanism. However, at high sea state, a composite scattering mechanism including white cap, Bragg and weak intensity returns scattering is the dominant scattering mechanism. It has important significance for analyzing properties of electromagnetic scattering and detecting targets at UHF band.

1. Introduction

Sea clutter is the major interference for radar detection of targets on the sea. In order to mitigate false alarms and increase the probability of target detection, intensively studying the characteristics of sea clutter scattering is very important [1] . The Doppler spectra of sea returns, which has abundant information on floating scatters, is an important method to explore the characteristics of sea clutter at frequency domain.

For many years, researchers numerously studied the Doppler characteristics from sea echoes and obtained many significant developments. Crombie [2] first discovers Bragg resonant scattering from sea returns at the HF band. From the discovery, Barricket al. [3] established the first-order and second-order Doppler models based on the small perturbation method. Subsequently, more investigations concentrated on the microwave band sea scattering. Plant and Keller [4] found the evidence of Bragg scattering in the microwave Doppler spectra by analyzing the L, X and Ku band sea returns. Additionally, they formulated the assumption that Bragg scattering is the major source of microwave sea return at intermediate incidence angles and low to moderate wind speed. As the investigation deeply developed, some special characteristics of the Doppler spectra different from the Bragg scattering were observed. Lee [5, 6] used the wave tank microwave data to analyse the characteristics of the Doppler spectra; he created a new Doppler model consisting of Gaussian, Lorentzian and Voigtian models. The last two components correspond to the non-Bragg scattering mechanism. A simplified Doppler model based on the Lee model produced by Walker [7, 8] to analyze the wave tank data and radar sea clutter data from cliff. This model assumes that the overall Doppler spectrum is the sum of only the Gaussian lineshapes representing the three-component scattering mechanisms: Bragg, whitecap and burst, which provides the probable physical understanding for electromagnetic wave scattering. Striving for further improvement, Ward [1, 9] proposed a temporally varying short-time Doppler spectrum model. Recently, through sufficient work on the sea clutter data at middle and high grazing angle, Watts [10-13] and Rosenberg [14] gave a new two-component model suitable for this condition which is a simplified approximation of the Walker model. The researches above are mainly about microwave band, only Randell [15] analyzed the UHF band sea clutter data in small grazing angles and discovered that the UHF band Doppler spectra has evident Bragg resonant phenomenon at low sea state.

By using the UHF band sea clutter data, this paper makes a detailed research on the characteristics of Doppler spectrum with different wave height and different intensity returns in a persistent sequence. The results indicate that the scattering mechanisms of the UHF band sea clutter vary with the sea states, and particularly there are three types scattering mechanism corresponding with different intensity returns at high sea state. These new discoveries are important for analyzing properties of electromagnetic scattering and radar design at the UHF band.

2. The scattering mechanisms of sea clutter

Many sources, such as currents, weather, surface tension, and gravity contribute to the wide variety of wave structures in the ocean. When the incident electromagnetic waves act on this complex wave structures, it creates a composite scattering mechanism related to the radar wavelength and the grazing angle. These composite scattering mechanisms are probably called the three-component compound electromagnetic scattering theory consisting of Bragg, white cap and bust scattering.

Bragg resonant scattering for sea clutter strongly occurs if the radar wavelength is twice that of the water wavelength, but further depends on the grazing angle as:

$$\Lambda \cos(\varphi) = n \cdot \frac{\lambda}{2}, n = 0,1,2 \cdots \quad (1).$$

Where Λ is the resonant sea wavelength, λ is the electromagnetic wavelength and φ is the grazing angle. Bragg scattering gives VV amplitude greater than HH and have two symmetrical peaks with its Doppler spectra. At near-zero grazing angles, the Bragg Doppler shifts are by the dispersion relationship:

$$f_B = \sqrt{\frac{g}{\pi\lambda}} \quad (2).$$

The dispersion relationship predicts Bragg frequencies on the order of $\pm$2.2Hz at the UHF frequency range.

Whitecaps are foamy, rough, surface wave crests that produce noisy scattering reflections from the toppling of the breaking wave crest down the wave front slope. Whitecap scattering amplitudes are similar for vertical and horizontal polarizations and their magnitude is much greater than Bragg scattering. The phenomenon lasts seconds in duration, but decorrelates within milliseconds. The Doppler spectrum is very broad and centered proportionately about the phase speed of gravity waves, which is much higher than the Bragg Doppler frequency shift.

Burst scattering appears to arise from the crests of waves, just before they spill[1]. This type of scattering gives a strong cross-section with HH polarization but much smaller cross-section with VV polarization, which seems to be caused by constructive multipath interference at HH. Bursts generally last for a short duration (of the order of 0.1 s) but remain coherent over that time. A narrow Doppler spectrum and a Doppler shift are evidently consistent with the velocity of the wave top that is higher than Bragg scattering.

3. The description of UHF band sea clutter data

The sea clutter data of this paper is observed by a coherent UHF radar with HH polarization. This radar is setup on shore-side platform with the height of 400 m above sea level. The range of grazing angle is from 2° to 7°. The sea states including the information of wave height and wave direction is recorded during experiment.

Figure 1 and 2 show the examples of sea clutter data and pictures of the sea surface at five sea states. At the high sea state, the sea surface is very rough, and swells accompanied with white caps. The magnitude of the high-state data severely varies.Table 1 shows the sea clutter data of UHF band and the corresponding information of sea states used in this paper. These data are all up-wave direction and almost same wave periods, but with different wave heights.

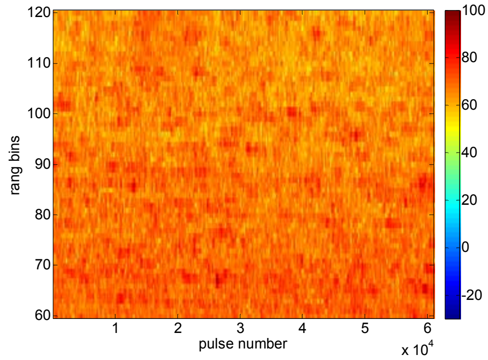

Figure 1. An example of sea clutter data at five-level sea states(Rang bins-pulse number magnitude image).

Figure 2.A picture of the sea surface during experiment at five-level sea states.

Table 1. Sea clutter data of UHF band and the information of sea states used in this paper

Data number	Douglas sea state	Wave Height (m)	Relative Wave Direction	Wave Period (s)
Data 0918193218	1	0.3	Up-wave direction	3.8
Data 0903172415	2	0.6		4
Data 0924112030	3	1.2		4.1
Data 1106085824	5	2.7		5.1

4. The Doppler analysis of UHF band sea clutter data

4.1 The characteristics of Doppler spectrum for UHF band sea clutter with different wave height

Analyse the four sets sea clutter data (table 1) with the Welch method. In order to get enough samples and smooth lineshape with property resolution, the sequence length of the selected samples is selected 49,152 pulses. And the window length of the Welch is 4096 pulses considering that the wave periods are about four seconds. The corresponding grazing angle is 4.1°.

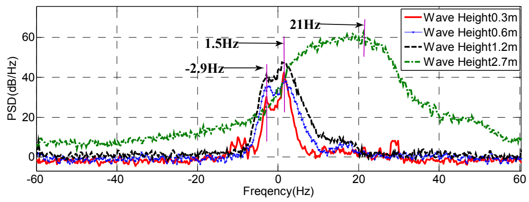

Figure 3. The comparison of UHF band sea clutter Doppler spectrum at different wave heights.

Figure 3 shows the comparison of UHF band sea clutter Doppler spectrum at different wave heights. From the comparison results, the frequency shift of the high sea state (2.7m wave height) which is 21 Hz is much more than the frequency shifts of the middle and low sea state (0.3m, 0.6m, 1.2m wave height) which are all about only 0 Hz. Furthermore, the lineshapes of the middle and low sea state show two symmetrical peaks about 0 Hz, but absent at high sea state. The frequency shifts of the two peaks are 1.5Hz and -2.9Hz, respectively, approximating the results of Equation (2).

From the results above, we can reasonably infer that at the low sea state, the low waves and capillary waves on the sea surface are the major scatters and Bragg scattering is the major mechanism for UHF band sea clutter. However, at the high state, the long swells and whitecaps are the major scatters, and the characteristics of Bragg scattering are almost vanished. And the frequency shift and band width are big. The following work concentrates on UHF band sea clutter Doppler at the high sea state.

4.2 The characteristics of sea clutter Doppler spectrum at high wave height

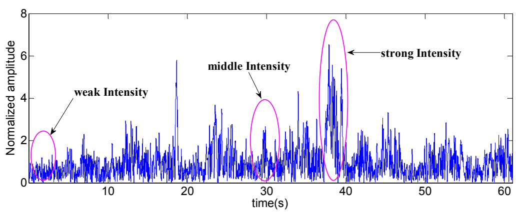

Figure 4. The sea clutter series of UHF bandat the wave height of 2.7m.

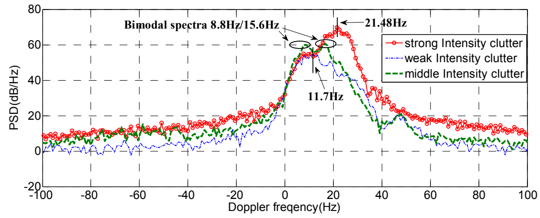

Figure 5. The comparison of UHF band sea clutter Doppler spectrum with different intensity.

The data illustrated in Figure 4 is a clutter series of a range bin with a wave height of 2.7m. The amplitude of this sea clutter series has been normalized by the mean value and the corresponding grazing angle is 4.1°. From this figure, the amplitude severely varies with some periodic high-low-high varieties. The strongest intensity echoes are even more than six times of the mean value. In order to analyze the scattering of mechanisms of the high sea state sea clutter even more detailed, the series is divided into three types sea echoes according to the intensity of returns, which are weak, middle and strong intensity echoes, as labeled by red circles in Figure 4. Next, the characteristics of these three echo types of the Doppler spectrum is analyzed.

Figure 5 shows the comparison of these three echo types of Doppler spectrum. Figure 5 shows that the lineshape of the weak intensity sea echoes Doppler spectrum is a single peak, and the frequency shift is about 11.7 Hz. The lineshape of middle intensity sea echoes obviously has two symmetrical peaks whose frequency shifts are about 8.8Hz and 15.6Hz, respectively. Its center frequency shift is consistent with the weak intensity sea echoes. However, the lineshape of strong intensity sea echoes is very different from the former two types. It also has two peaks but with different spectral intensity, and the frequency shift of the deputy peak is similar to the weak intensity and middle intensity sea echoes which is much smaller than the principal peak.

5. Conclusion

Through the analysis of sea clutter Doppler spectrum at different sea states, it is preliminary inferred that at small grazing angle, Bragg scattering is the major scattering mechanism of the UHF band sea clutter at middle and low sea states (wave height below 2.7m). But at high sea state, the compound scattering mechanism of Bragg scattering, whitecap scattering and weak intensity clutter scattering is the scattering mechanism for UHF band sea clutter, and whitecap scattering is a relative dominant mechanism. This compound scattering mechanism results in that Doppler spectrum of high sate sea clutter presents a broad spectral peak with a large frequency shift and bandwidth. The analysis of sea clutter Doppler spectrum at high sea state with different intensity shows that the middle intensity clutter is mostly caused by Bragg scattering because of its two symmetrical spectra peaks. And the scattering mechanism of the strong intensity clutter is the compound mechanism consisting of whitecap scattering and residual Bragg scattering according to its Doppler spectrum that contains a fast component which is similar to whitecap scattering and a slow component which is close to Bragg scattering. Comparatively speaking, whitecap scattering dominates in this compound mechanism. For the weak intensity sea clutter, with a single spectrum peak, the frequency shift is small. Some assumptions are proposed that this sea clutter may be caused by the eliminating interference of multipath scattering or the weak reflection between electromagnetic waves and the relative peace sea surface which exists after the disappearance of whitecaps or before the creation of new waves. In addition, burst scattering is not found at present by the analysis above for UHF band sea clutter, and it needs to be confirmed in depth by more sea clutter data analyzing at higher state and full-polarization.

6. References

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