ON THE PROBLEM OF THE DOPPLER SPECTRUM OF A MICROWAVE RADAR SIGNAL BACKSCATTERED BY THE SEA SURFACE (TRANSITION REGION AND BRAGG COMPONENT)

V. Yu. Karaev

UDC 621.371.165

We consider the problem of backscattering of a microwave radar signal by a perturbed water surface in the transition region of incidence angles ($10^\circ - 25^\circ$). A theoretical model of the Doppler spectrum for the Bragg component of the reflected field is constructed within the framework of a two-scale model of the surface. Allowance for the large-scale component of waves indicates that the standard formulation of resonance scattering becomes invalid for small incidence angles. Large-scale waves restrict the power increase of the reflected signal prior to violation of the formal conditions for perturbation method applicability. It is shown that the new model is transformed to the known model of Doppler spectrum in the range of medium angles.

1. INTRODUCTION

Considerable success has been achieved in the last 30 years in the understanding of electromagnetic wave scattering by a rough water surface. However, the problem of developing the theoretical model of scattering is not yet solved for the entire range of incidence angles. In particular, the difficulties in the development of the scattering model in the transition region of incidence angles are related to the fact that the scattering surface involves a continuous spectrum of waves ranging from large-scale to small-scale ones compared with the wavelength of a microwave radar. It is exactly the microwave interval that is of particular interest from the standpoint of solving problems of remote monitoring of the ocean's surface layer.

We know theoretical models that describe scattering at small incidence angles for which the distance is called quasi-specular and at medium incidence angles for which the distance is resonant (see, for example, [1–8]).

According to the current knowledge, for the transition range of incidence angles (($10^\circ - 15^\circ$) $\leq \theta_0 \leq$ $(20^\circ - 25^\circ$)), whose boundaries depend on the state of the scattering surface, we must allow for both mechanisms of scattering. In this case the reflected signal is the sum of quasi-specular and Bragg components. However, the “quantitative” model, which would allow us to predict the spectral and power characteristics of the reflected signal on the basis of information on the scattering surface, is lacking.

To solve the direct problem and construct a quantitative model of scattering in the transition region, it is important to consider the relation between the powers of quasi-specular and Bragg components. However, a study of the backscattering cross-section alone does not enable us to estimate in a single-valued manner the role of each mechanism in the formation of the reflected signal. Therefore, our main attention is drawn to the development of a model of the Doppler spectrum.

Obviously, the width and shift of the Doppler spectra are different for the quasi-specular and the Bragg components [9]. Then the shape and parameters of the “summarized” or “total” Doppler spectrum in the transition region depend on the relation between the powers of quasi-specular and Bragg components, which allows us to check experimentally the correctness of the scattering model in the transition region, for example, by measuring the Doppler spectrum in and outside the slick [10].
In our previous papers we proposed a theoretical model of the Doppler spectrum for the quasi-specular component of the reflected signal [9, 11]. For medium angles of incidence we developed an approach described in [12] and constructed our own model of the Doppler spectrum allowing for the modern knowledge of specific features of scattering in this interval of incidence angles [9, 13]. The model is in good correspondence with experimental data. However, extending the model to the transition region and the range of small incidence angles we faced certain difficulties, which stimulated us to create a model of the Doppler spectrum allowing for the features of the transition region. At medium angles the new model is transformed to the existing one.

What are the disadvantages of the generally accepted formulation of the resonance (Bragg) model of scattering? The model performs well in the region of medium angles of incidence. Numerous experimental data confirm its correctness in this range. The strongest confirmation of its validity are the measurements of the Doppler spectra [14-19]. However, the resonance wavelength increases with decrease in the incidence angle and, correspondingly, the spectral density of the scattering ripple, which determines the power of the Bragg component of reflected signal, also increases. Therefore, the scattering cross-section increases and becomes greater than the cross-section of scattering of the quasi-specular component for small angles of incidence (in the region of quasi-specular scattering). This holds true for the case of the quasiplane surface. Allowance for the slopes of large-scale waves results in the much earlier appearance of this phenomenon, already in the transition region [8]. One of the methods used to overcome this disadvantage with respect to the backscattering cross-section is the formal replacement of one mechanism of scattering by another, when the cross-sections of the quasi-specular and the Bragg components become equal. As a result, we obtain a qualitatively correct dependence of the scattering cross-section on the incidence angle. Omitting the discussion of whether or not we have the right to use this method, we just note that this approach cannot be used for developing the model of Doppler spectrum since it will lead to jump-like variation of the Doppler spectrum parameters once one model is formally replaced by another.

The developed modified model of the Doppler spectrum of the Bragg component of the reflected signal enables us to start the construction of the theoretical model of the total Doppler spectrum for the transition region of incidence angles, which will be the subject of our next paper.

2. INITIAL PROBLEM

Let an immobile radar be elevated at a height $H_0$ above the sea surface. At a half power level, the width of the antenna directivity pattern is $\Delta_x$ and $\Delta_y$ in the horizontal and vertical planes, respectively. To disregard the variation of the incidence angle within the directivity pattern, the latter is assumed to be sufficiently narrow. The sounding is performed along the X axis, $\theta_0$ is the incidence angle, $R_0$ is the inclined distance to the center of the scattering platform, and $\vec{r}_0(z_0, 0)$ is the vector radius of the platform center in the XY plane. The general direction of wave propagation is $\vec{w}$ (see Fig. 1).

To describe the sea surface, let us use a two-scale surface model according to which the waves are represented in the form of a sum of large-scale and small-scale components with respect to the radar wavelength. To describe a large-scale random wave pattern, which varies in time and space, we introduce the function $\zeta(\vec{r}, t)$. This function describes large-scale waves for which $(1/kR_a)^{1/3} \ll 1$, where $R_a$ is the characteristic curvature radius of the surface and $k$ is the wave number of incident waves. The height distribution function is assumed to be Gaussian. The random function $\zeta(\vec{r}, t)$ describes the ripple field such that the following conditions are fulfilled for the large-scale component: $\sigma_{\zeta_w} ^2 < 1$ and $(k \cdot \sigma_{\zeta_h})^2 < 1$, where $\sigma_{\zeta_w} ^2$ and $\sigma_{\zeta_h} ^2$ are the dispersions of ripple slopes and heights, respectively.

Within the framework of the two-scale model, the amplitude of the scattered field of the Bragg component has the following form [1, 2]:

$$E_s(\vec{r}, t) = \frac{2k^2E_i}{R_0} \int G(\vec{r})\alpha_{wh} \cos^2 \theta \cdot \zeta(\vec{r}) \exp(-2kR \cdot t)d\vec{r},$$  \hspace{1cm} (1)

where $\theta$ is the local incidence angle, $R$ is the inclined distance to the reflection point, $E_i$ is the amplitude of