DEFORMATION OF THE SPATIAL SPECTRUM OF SCATTERED RADIATION IN ABSORPTIVE MAGNETOACTIVE PLASMA

G.V. Jandieri*, V.G. Gavrilenko [1], V.G. Jandieri, N.M. Daraselia
Physics Department, Georgian Technical University
Kostava str. 77, 380075 Tbilisi - Georgia; E-mail: jandieri@access.sanet.ge
[1] Department of Radiowave Propagation. Nizhny Novgorod State University, Gagarin ave., 23, 603600 Nizhny Novgorod, Russia; E-mail: vgg@rf.unn.ru

Introduction

It is known nowadays that reasonable strong absorption in a chaotic inhomogeneous media exerts significant influence on statistical characteristics of multiply scattered radiation. Small-angle incidence on the interface of homogeneous transparent and random inhomogeneous absorptive media leads to monotonic broadening of the angular power spectrum of scattered radiation with increasing the immersion depth into second medium. The width of the spectrum tends to a certain asymptotic value at large values of the depth (so called depth wave propagation mode). A lot of essentially new phenomena arise at rather big angles of the oblique incidence of radiation on the same interface. It was found out that the maximum of the angular power distribution is monotonically displaced towards the normal direction to the interface, as with a small incidence angle. However, the spectrum width varies non-monotonically with the increase of the distance from the interface. With sufficiently strong absorption there is an interval of distances where the spectrum width substantially exceeds its depth asymptotic value. In this interval and close to the illuminated interface the width of the angular power distribution is increased in proportion to the absorption, all other things being equal. In this interval the angular power spectrum is substantially assymetrical with respect to its maximum. Those effects are a consequence of an asymmetric statement of the problem. Such asymmetry arises not only in the case of oblique illumination of the interface; it can be an internal property of a propagation medium itself owing to its anisotropy. A typical example of a chaotically inhomogeneous absorptive anisotropic medium is a turbulent collisional magnetoactive plasma. Multiple scattering of waves in such plasma has been investigated less than wave scattering in chaotic isotropic media. The oblique incidence of a small amplitude electromagnetic wave on a plane layer of the turbulent absorptive plasma in an external homogeneous magnetic field is considered. It was found out that in a certain direction two asymmetric factors of the problem (oblique incidence and medium anisotropy) compensate each other.

Formulation of the problem

Let a semi-infinite layer of a collisional magnetoactive turbulent plasma is illuminated by a plane alectromagnetic wave incident on it from vacuum. XY plane Cartesian frame of reference is the boundary between two media and the Z-axis be directed inside plasma. The coordinate plane XZ should be arranged so that it might coincide with the plane formed by a vector of an external magnetic field $\mathbf{B_0}$ and a wave vector of a refracted wave $\mathbf{k_0}$. θ_0 - is the angle between magnetic field and Z-axis, θ - is the angle between $\mathbf{B_0}$ and $\mathbf{k_0}$ vectors, θ' - is the angle of refraction with respect to the normal to the boundary, θ_i - is the angle of incidence with respect to the normal to the boundary. The electron concentration in plasma

0-7803-7846-6/03/$17.00

layer is the sum $p(\mathbf{r}) = p_0 + p_1(\mathbf{r})$, where p_0 - is a constant component, $p_1(\mathbf{r})$ is a random function of spatial coordinates, which describes electron concentration fluctuations. A magnetoactive plasma, in the general case, is an anisotropic medium and the components of its permittivity tensor $\hat{\varepsilon}$ are determined by

$$n^2 = 1 + \frac{2\nu(1-\nu-is)}{2(1-is)(1-\nu-is) - u\sin^2\theta \pm \sqrt{u^2\sin^4\theta + 4u(1-\nu-is)^2\cos^2\theta}} ,$$

where: $u = \omega_B^2/\omega^2$, $\nu = \omega_p^2/\omega^2$, $s = \nu_{eff}/\omega$, ω is a cyclic frequency of an incident wave, ν_{eff} is an effective collision frequency between electrons and other particles in plasma, $\omega_p = e(4\pi p/m)^{1/2}$ plasma frequency and $\omega_B = eB_0/mc$ is a cyclic gyrofrequency, e and m are respectively the charge and the mass of an electron, c is the velocity of light in vacuum, B_0 is the induction of an external magnetic field. The characteristic scale of inhomogeneities is assumed to exceed substantionally the wavelength. This allows utilizing the geometrical optics techniques for determining statistical characteristics of the scattered field. In zero approximation the contribution into the resulting field is given only by plane initial wave incident on the layer from vacuum. Chaotical inhomogeneities of electron concentration in a plasma give rise to fluctuations of the wave field at the observation point. Phase characteristics of any normal wave in the approximation of geometrical optics are given by the eikonal equation. Refractive index of anisotropic medium depends on the direction of the wave vector $n^2 = n^2(p(\mathbf{r}), \omega, k_x, k_y)$. We obtain dispersion equation $\mathbf{k}\cdot\nabla\mathbf{k} - \frac{1}{2}\frac{\omega^2}{c^2}\frac{\partial n^2}{\partial \mathbf{k}_\perp}\cdot\nabla\mathbf{k} = \frac{1}{2}\frac{\omega^2}{c^2}\frac{\partial n^2}{\partial p}\cdot\nabla p$, where $\mathbf{k}_\perp = \{k_x, k_y\}$. Fluctuating components of $\mathbf{k_1}$ and φ_1 are proportional to a small dimensionless parameter p_1/p_0. First approximation we obtain:

$$\varphi_1 = \frac{\alpha}{k_{z_2}} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} dk_x dk_y \exp(ik_x x + ik_y y) \times$$
$$\times \int_0^z d\xi\, p_1(k_x, k_y, \xi) \exp\left\{- ik_x \left(\frac{\partial k_{z_2}}{\partial k_x}\right)_0 (z-\xi)\right\},$$

where $\alpha = -\frac{1}{2}\frac{\omega^2}{c^2}\frac{\partial n^2}{\partial p}$ the electron concentration fluctuations are expressed as their two-dimensional Fourier-transform. Using transversal correlation function of the phase, In the nost interesting case of strong fluctuation of the phase $<\varphi_1\varphi_1^*> >> 1$. Spatial power spectrum has the Gaussian form:

$$S(k_x, k_y, z) = S_0 \exp\left\{-\frac{(k_x - k_x^0 - \Delta k_x)^2}{2<k_x^2>} - \frac{k_y^2}{2<k_y^2>}\right\}$$

where Δk_x determines the displacement of a spatial power spectrum maximum of scattered radiation caused by random inhomogeneities; $<k_x^2>$ and $<k_y^2>$ determine the width of this spectrum in the planes XZ and YZ respectively. The expressions for Δk_x, $<k_x^2>$ and $<k_y^2>$ can be obtained by differentiation of correlation function of the phase. Anomalous broadening of the angular power spectrum and the displacement of its maximum are revealed if $k_{xm}\gamma z > 1$ (k_{xm} determines the width of the spatial spectrum). This effecct will take place when waves propagate at another angle, while the centre of gravity of the angular power spectrum being displaced to the direction of compensation with increasing immersion depth into a layer.

Numerical analysis of the angular power spectrum

The influence of absorption on statistical characteristics of waves in chaotic medium substantially depends on the form of the spatial power spectrum of random inhomogeneities. Therefore the most realistic power-association model was chosen for such a spectrum (for example, for ionosphere plasma); this model for simplicity is considered to be statistically isotropic:

$$\Phi_p(k) = \begin{cases} C\left(\dfrac{\sqrt{2}}{90}\right)^{-3,5}, & k \in \left[0, \dfrac{\sqrt{2}}{90}\dfrac{\omega}{c}\right] \\ C k^{-3,5}, & k \in \left[\dfrac{\sqrt{2}}{90}\dfrac{\omega}{c}, \sqrt{2}\dfrac{\omega}{c}\right] \\ 0, & k > \sqrt{2}\dfrac{\omega}{c} \end{cases}$$

One of the most convenient approaches for the numerical solution of the problem is a statistical simulation of the radiation propagation process (Monte Carlo method). In this paper the realization of that method for a magnetoactive turbulent plasma takes into account the dependence of differential cross-section of scattering (and, consequently, extinction coefficient too) on the angle between a magnetic field and a wave vector. The numerical experiment was carried out with different values of plasma parameters u, ν, s and the oblliquity of an external magnetic field θ_0. For each set of parameters a series of computer-based calculations of power spectra of scattered radiation has been accomplished for various initial angles of refraction of the incident wave. After completion of numerical simulations we found the angle at which the effect of compensation can be observed. The results of simulation for the magnetic field obliquity of θ_0 = 20 degrees and the following plasma parameters: u = 1.25; ν = 0.2; s = 0.02 are illustrated in Fig. 1, 2. Fig. 1 gives the dependance of the gravity centre of the angular power spectrum versus the immersion depth into the layer. It is evident that the results of numerical simulation completely coincide with theoretical predictions: there is no gravity centre displacement when the refracted wave propagates along the direction of compensation. With refraction at some other angle the gravity centre asymptotically tends to the direction of compensation with increase in immersion depth into a layer. At small depths $\Delta k_x \propto z^2$, which is in good agreement with the results of the numerical experiment. The plot of dependence of the second central momentum (dispertion in the plane of incidence) is presented in Fig. 2. As geometrical optics suggest, in the direction of compensation this dependence (curve 1) is closely similar to that in the case of a plane wave normally incident to an isotropic medium layer. Two factors of the asymmetry of the problem (anisotropy of the medium and oblique incidence on the layer) completely compensate each other, which prevents the anomalous broadening and the non-monotonic dispersion growth from manifesting themselves. Beyond the compensation direction (curves 2 and 3) the influence of some of the reasons of asymmetry predominates and then both the non-monotonic dependence of dispersion versus an immersion depth and the effect of anomalous broadening take place.

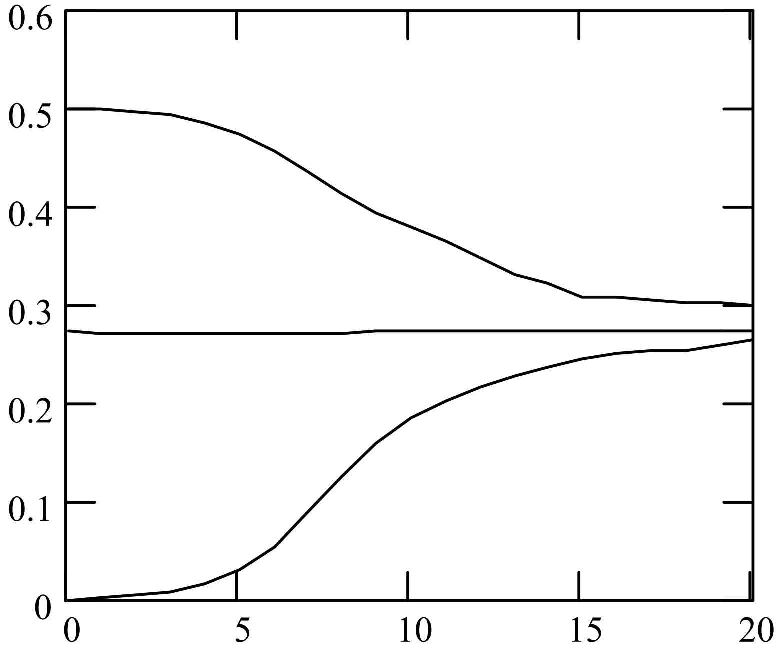

Figure 1

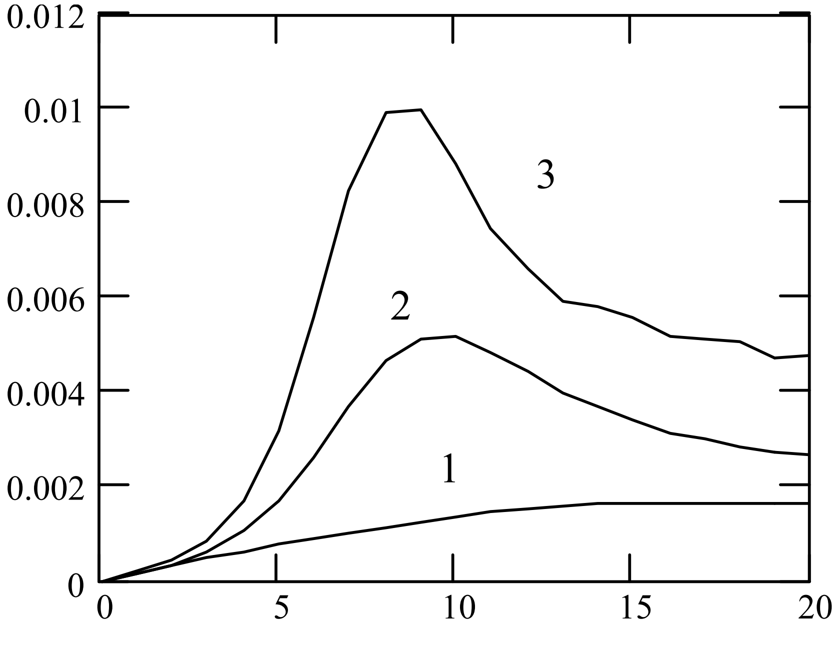

Figure 2