SCATTERING OF SURFACE WAVES IN THE TURBULENT PLASMA STREAM

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It is well known, that during the propagation of a surface electromagnetic wave along a dialectric plate or other slowing down system, placed in a homogeneous medium,the outside field exponentially decreases ia a transverse direction [1].If there are inhomogenities of permittivity in the enveloping space,then the surface wave will be partially scattered on them, and the scattered waves can propagate over great distances.

Let's consider the simpliest model of the slowing down system, consisting of a parallel-plane dialectric plate with great permittivity ε and 2L thick. The X axis of Cartesian frame of reference is perpendicular to the plate surfaces $|x|<L$;the cold turbulent plasma enveloping the plate moves along the Z axis with velocity $\vec{V}_0$.We suppose, that a turbulent plasma mixing velosities are so small with respect to $\vec{V}_0$that it's possible to use the "frozen" turbulent approximation [2].The most important case, which is realized in practical application is a medium parameter of small fluctuations,when the inequality is fulfiled $|N_1(\vec{r}-\vec{V}_0 t)|<<N_0$, where N_0 and N_1 are the mean, constant,homogeneous value of aundisturbed plasma electron concentration and its random deviation,respectively. If the scattered volume is not quite big, the task may be solved in the single-scattered approximation [2]. First of all it is nesessary to define the fields structure in a zero approximation without taking into account the influence of a plasma inhomogenities.

At the biginning we consider the TE-polarization,electric field being oriented along the Y axis. We shall seek the own solution in the frame of reference under consideration in $E_y^{(0)}=$ $=E(x)\exp(i\omega t-ihz)$ form. Proceeding from Maxwell's equations and Minkovskii's material ratio and utilizing the continuity condition of the tangentials,with respect to the plate surfaces, components of electrical and magnetic fields,the dispertion relation can be obtained

$$\frac{\left[\frac{\omega^2}{c^2}\varepsilon - h^2\right]^{1/2}}{\left[h^2 - \frac{\omega^2}{c^2}\left(1-\frac{\omega_p^2}{\omega^2}\right)\right]^{1/2}} \begin{matrix} \mathrm{tg} \\ \mathrm{ctg} \end{matrix} \left[\left(\frac{\omega^2}{c^2}\varepsilon - h^2\right)^{1/2} L\right] = \pm 1 \qquad (1)$$

in the frame of reference accompanying moving plasma having the permittivity $\varepsilon_p=1-\omega_p^2/\omega'^2$; where $\omega_p^2=4\pi N_o e^2/m$; e and m are electron's charge and mass, respectively. The upper line corresponds to the even solution, the lower-to the odd one [1]. The equation (1) doesn't contain the velocity V_o, because of the absence of the "carry away effect"in a moving cold plasma [3]. For the solution of the scattered problem it is necessary to derive the expression for electron perturbance velocity under the action of wave field in a zero approximation. The equation of electron motion, without taking into account medium parameters fluctuation is $\vec{u}^{(o)}=-ie\vec{E}^{(o)}/m\omega$.

In the case of TM wave polarization, where the electric field vector lies in the XOZ plane, the dispertion relation has another form - in the right side of the equation (1) instead of ±1 is $\pm\varepsilon/(1-\omega_p^2/\omega'^2)$. This dispersion equation consists of the plasma velocity (at the expence of dependence ω' on the value V_o).It is conditioned by the "sensitivity" of TM wave polarization structure to the plasma motion. Velocity of a plasma electron motion under the action of a wave field in a zero approximation is given by

$$\vec{u}^{(o)}=-\frac{ie}{m\omega}\left[\vec{E}^{(o)}+\frac{\vec{k}(\vec{V}_o\vec{E}^{(o)})}{\omega-hV_o}\right] \quad (2)$$

where $\vec{k}=-i\beta\vec{X}_o+h\vec{Z}_o$, $\beta=[h^2-\omega^2(1-\omega_p^2/\omega^2)/C^2]^{1/2}$.

Now we investigate the statistical characteristics of a scattered field $\vec{E}_1$. The initial equation is

$$\mathrm{rotrot}\vec{E}_1+\frac{1}{C^2}\frac{\partial^2\vec{E}_1}{\partial t^2}=-\frac{4\pi}{C^2}\vec{j}_s \quad (3)$$

where $\vec{j}$ is the current density, which differes from zero inside the scattered volume. The scattered current, linearly depends on the plasma concentration fluctuation is calculated by the single-scattered approximation,as a part of the current induced in the volume by the zero-order field.For simplicity,we believe that the plasma is enough discharged and the scattered field propagates in vacuum. The current density has the form:

$$\vec{j}_s=e(N_1\vec{u}^{(o)}+n^{(1)}\vec{V}_o) \quad (4)$$

where $n^{(1)}$is the perturbation part of a plasma electron concentration linearly dipendent on $N_1(\vec{r},t)$ and $\vec{E}^{(o)}$. It can be found from the continuity equation. The Green function of equation (3), for the scattered waves propagating over a great distance far away from the scattered volume, may be written in the form

$$G(\vec{r},t;\vec{r}',t')=\frac{1}{R}[\vec{n}[\vec{m}\vec{n}]]\delta(t-t'-\frac{R}{C})-\frac{1}{R'}[\vec{n}'[\vec{m}\vec{n}']]\delta(t-t'-\frac{R'}{C}) \quad (5)$$

where $\vec{r}$ and t are the radius-vector of the observation point with respect to the origin of coordinate system situating in the centre of the volume and the observation time, respectivelly; $\vec{r}'$ and t' are the radius-vector and the switch moment of a instantaneous source, $R=|\vec{r}-\vec{r}'|$-is the distance from the source to the observation point,$\vec{n}$ is the unit vector along the direction from the source towards the observation point;$\vec{m}$ is a unit vector along the $\partial\vec{j}_s/\partial t$ vector, $\vec{R}'$ is the distance between the observation point and the image reversed laterally with respect to the dialectric boundary, $\vec{n}'$is the vector along $\vec{R}'$. We supposed,that the total reflection of a single-scattered field from the boundary of a dialectric,having quite big permittivity ε, takes place.

At first let us consider the scattering of a TE-polarization surface wave. For the scattered field we obtain

$$\vec{E}_1(\vec{r},t)=\frac{4\pi e^2}{mC^2}E_o\frac{e^{i\omega t}}{r}\int M(\vec{r}')N_1(\vec{r}')e^{-\beta x'-ihz'}(e^{-ik_oR-ik_oR'})$$

$$\{[\vec{n}[\vec{y}_o\vec{n}]]\ [1+\frac{V_o}{\omega}(k_o(\vec{n}\vec{z}_o)-h)]-[\vec{n}[\vec{z}_o\vec{n}]]\frac{V_ok_o(\vec{n}\vec{y}_o)}{\omega-hV_o}[1-\frac{V_o}{\omega}(k_o(\vec{n}\vec{z}_o)-h]\}$$

$$dr' \qquad (6)$$

where $M(\vec{r}')=1$ within the effective scattered volume, restricted by the dialectric plate dimentions, $M(\vec{r}')=0$ outside the volume, $k_o=\omega/C$, $\vec{r}_1'=\vec{r}'-\vec{V}_o(t-R/C)$. Following the equation (6), it is easy to calculate the temporal correlation function of a scattered field and its Fourier conjugate frequency power spectrum $S(\Omega)$. At low speed of a plasma motion, when $\omega >> hV_o$, the frequency Ω of a scattered field changes depending on the direction to the observation point in accordance with Doppler law.The angular diagram is close to the dipol one. The axes of a reradiate dipoles are oriented towards the electric field vector of the surface wave, i.e. along the Y axis. The scattered diagram has the form (see Fig.1). The small-scale concentration fluctuations, when hl<<1 (l is the characteristic size of inhomogeneities) do not change the qualitative form of the diagram. It is possible to estimate the intensity of a scattered field

$$\int S(\Omega) \sim \frac{\langle N_1^2\rangle}{N_o^2}\left(\frac{\omega_p^2}{C^2}\right)^2 E_o^2\ \frac{l^3d^2}{r^2\beta} \qquad (7)$$

where $\langle N_1^2\rangle$ is the dispertion of electron concentration fluctuations, d is the size of dialectric plate-width and length. At high velocities of plasma motion,the most important case is the synchronizm case, when $\omega\sim hV_o$.The scattered waves intensity $(V_ok_o/(\omega-hV_o)^2)$ times exceeds the one detertmined by the formula (7).For the case,when plasma velocity is close to the plase velocity of surface wave, the scattered diagram has the form (see Fig.2) . Specific form of the diagram can be explained by the strong increase of plasma concentration perturbation under the action of wave field;the predominant term in the expression of scattered current (4) is the second one-convection term.Convection current is oriented along $\vec{V}_0 \| \vec{Z}$ ($\vec{n} \subset XOZ$). Therefore there is no scattering along the $\vec{Z}$ direction. The scattering is absent all over the XOZ plane too, because according to Bragg's condition, the scattering should take place on a spatial harmonics N_1 the wave vector $\vec{\varkappa} = h\vec{Z}_0 - k_0\vec{n}$ of which lies in the XOZ plane.

The scattering of TM-polarization surface waves we don't consider in detail. We emphasis only, that in this case there appear some features. Particularly, the scattered diagram does not contain zero and near the synchronizm the scattered waves intensity in $\omega^4 C^2 h\beta/\omega_p^4(\omega - hV_0)^2$ time exceeds one at low velocities of a plasma motion.

Thus, the obtained results show, that an angular diagram of the scattered surface waves is strongly distorted in the turbulent plasma stream, when the flow velocity approaches the phase velocity of slow surface wave. In this case, the scattered intensity increases significantly. In the real turbulent plasma streams the value of the mean velocity changes along the X axis. The obtained results do undergo qualitative changes if the area of synchronizm, where the value of stream velocity is close to the phase velocity of a surface waves is not so far from the plane surface. The surface waves are intensively scattered by those inhomogeneties, their velocities are close to the wave phase velocity.

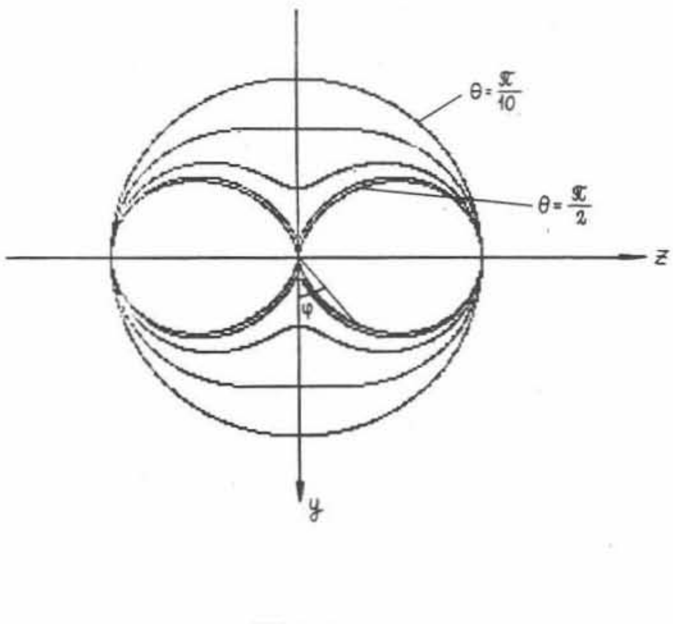

Fig.1

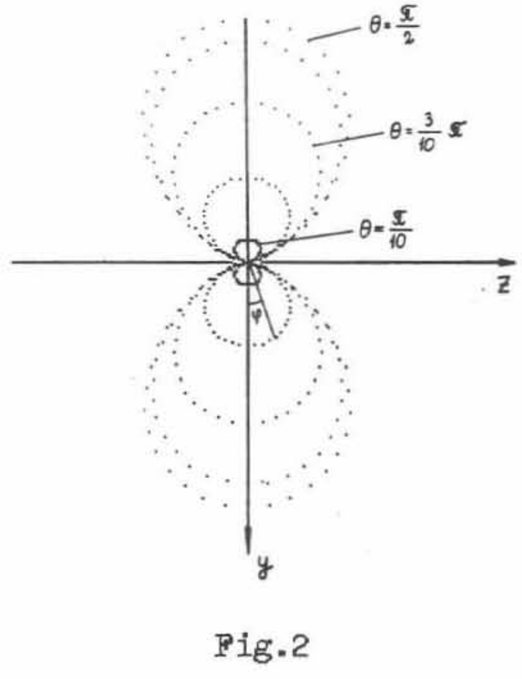

Fig.2

References

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