RADIARION OF SYSTEM OF LINEAR WIRES IN MAGNETOPLASMA

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Abstract. **A problem of excitement of currents in the system consisting of two think parallel wires, arbitrarily oriented in anisotropic plasma (magnetoplasma) was solved by method of partial averaging. Numerical analysis of obtained expressions was carried out and dependencies of current distribution and electromagnetic field from lengths of wires, distances between them and parameters of plasma were explored.**

Keywords: **magnetoplasma, liner wires, currents distributions, electromagnetic field, power in far zone.**

1. Introduction

The studies of linear wires in anisotropic mediums are important in such applications as radio communication in space, heating of plasma by high-frequency electromagnetic fields, diagnostics of magnetoactive plasma, electromagnetic compatibility of electronic devices, etc. The purpose of the present work is the solution of the problem on excitation of a system of thin impedance wires arbitrary located in anisotropic plasma and to determine conditions of effective transfer of energy from the wires to plasma.

2. Statement of the problem

We consider a system of parallel linear impedance wires (Fig.1) located under an arbitrary angle γ to the direction of an external magnetic field (the axis of anisotropy) in magnetoactive plasma, permittivity of which is a diagonal tensor

$$\varepsilon = \begin{pmatrix} \varepsilon_1 & 0 & 0 \\ 0 & \varepsilon_1 & 0 \\ 0 & 0 & \varepsilon_3 \end{pmatrix}$$

with components $\varepsilon_1 = 1 - \omega_N^2 / \left(\omega^2 - \omega_B^2\right)$, $\varepsilon_3 = 1 - \omega_N^2 / \omega^2$, ω_N^2 is the Lengmur's frequency; ω_B^2 is the Larmor's frequency; ω is the working frequency. The magnetic field is directed along axis OZ.

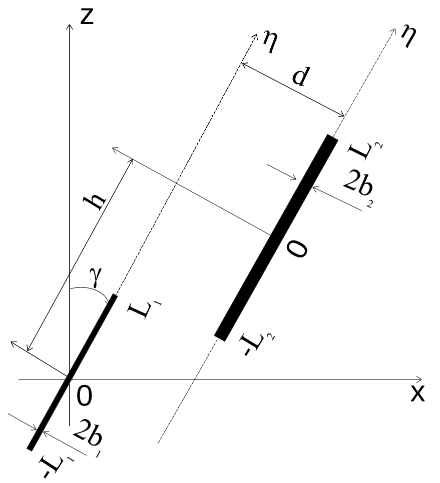

Fig. 1. Geometry of wires

Our goal is to study the dependence of the current in each wire, fields of radiation in far zone and radiation pattern of the antenna system on the sizes of wires, distance between wires (*d* and *h*), values of the complex surface impedance of wires, orientations of wires concerning the axis of anisotropy and values of components of permittivity tensor of plasma.

3. Method of the solution.

The solution of our problem is to be obtained on the basis of integral equations of electromagnetics derived from exact expressions of the Green's function for uniaxial anisotropic medium [1]. These equations are completely equivalent of the Maxwell equations and boundary conditions; they can be written as

$$i\omega\sqrt{\varepsilon_1}\left[\vec{E}(\vec{r}_n) - \vec{E}_0(\vec{r}_n)\right] =$$

$$= \left(graddiv + k_0^2\varepsilon_1\varepsilon_3\varepsilon^{-1}\right)\left[\vec{A}_{n1}(\vec{r}_n) + A_{n2}(\vec{r}_n)\right] +$$

$$+ ik_0 \, rot\, \vec{e}_z \left[B_{n1}(\vec{r}_n) + B_{n2}(\vec{r}_n)\right], \qquad (1)$$

$$i\omega\sqrt{\varepsilon_1}\left[\vec{H}(\vec{r}_n) - \vec{H}_0(\vec{r}_n)\right] =$$

$$= ik_0\varepsilon_1\varepsilon_3\varepsilon^{-1} rot\left[\vec{A}_{n1}(\vec{r}_n)+\vec{A}_{n2}(\vec{r}_n)\right]-$$
$$-\left(grad\frac{\partial}{\partial z}-\vec{e}_z\Delta\right)\left[B_{n1}(\vec{r}_n)+B_{n2}(\vec{r}_n)\right], \qquad (2)$$

where

$$\vec{A}_{nm}(\vec{r}_n)=$$
$$=\int\limits_{V_m}\frac{\vec{j}_m(\vec{r}\,'_m)exp\left(-ik_0\sqrt{\varepsilon_3|\vec{\rho}_n-\vec{\rho}\,'_m|^2+\varepsilon_1(z_n-z'_m)^2}\right)}{\sqrt{\varepsilon_3|\vec{\rho}_n-\vec{\rho}\,'_m|^2+\varepsilon_1(z_n-z'_m)^2}}d\vec{r}\,'_m,$$

$$B_{nm}(\vec{r}_n)=\int\limits_{V_m}\left(\vec{j}_m(\vec{r}\,'_m)\times grad\left|\vec{\rho}_n-\vec{\rho}\,'_m\right|\right)_z\times$$
$$\times\left[\frac{exp\left(-ik_0\sqrt{\varepsilon_1}\left|\vec{r}_n-\vec{r}\,'_m\right|\right)}{\left|\vec{\rho}_n-\vec{\rho}\,'_m\right|}-\right.$$
$$\left.-\frac{exp\left(-ik_0\sqrt{\varepsilon_3\left|\vec{\rho}_n-\vec{\rho}\,'_m\right|^2+\varepsilon_1(z_n-z'_m)^2}\right)}{\left|\vec{\rho}_n-\vec{\rho}\,'_m\right|}\right]d\vec{r}\,'_m,$$

where $\vec{E}_0$, $\vec{H}_0$ are the electric and magnetic fields of the source; $\vec{E}$, $\vec{H}$ are the scattered electric and magnetic fields; $k_0=\omega/c$ is the wave number, ω is the frequency, c is the velocity of light; V_m is the volume of m-th wire; $\vec{e}_z$ is the ort along the axis of anisotropy; $\vec{r}_n=\vec{r}_n(x_n,y_n,z_n)$ and $\vec{r}\,'_m=\vec{r}\,'_m(x'_m,y'_m,z'_m)$ are the radius-vectors of points of observation and integration respectively; the index z in the expressions for $B_{nm}(\vec{r}_n)$ points out to the projection of the vector product on the axis of anisotropy (axis OZ); $\left|\vec{\rho}_n-\vec{\rho}\,'_m\right|=\sqrt{(x_n-x'_m)^2+(y_n-y'_m)^2}$; $\vec{j}_m(\vec{r}_m)$ is the volume density of the current in the m-th wire; in all formulas n, m = 1, 2.

The advantage of the method of integral equations [2] is that it enables us, in an analytical form, to solve a large class of boundary problems of electromagnetism. The algorithm of solution by this method contains two stages. At the first stage we find the currents excited in each wire by the field of the source and the field produced by the other wire. In this case initial integral equations (1), (2) form a set Fredholm's integral equations of the first kind having a unique solution. At the second stage, based on already known currents we construction the total field. In this case equations (1), (2) are identifies representing the total field as a sum of the field of the source and the scattered field.

A problem about excitement of electrical current in the system consisting of two parallel linear wires with lengths $2L_1$, $2L_2$, radiuses b_1, b_2, situated under any angle γ to axis of anisotropy will consider on the base of these integral equations. As far as wires are fine: $b_i/L_i \langle\langle 1$; $b_i/\lambda \langle\langle 1$, $i=1,2$, where λ - a wavelength of falling electromagnetic field, only that electrical currents will be essential which current along wire; it is possible to neglect of transverse currents.

Considering that tangential components of full electrical field on surfaces of perfectly conducting wire are a zero, equations for density of currents, induced in each wire by given falling field and field, which generate other wire, will be obtained having designed equations (1) on axis of wires. For this it's need move over in new coordinate system $\chi\eta\xi$, having directed one of its axis's ($o\eta$) parallel to axis of wires. Relationship between coordinates of new and old systems is installed by formulas

$$\chi=x,\quad \eta=y\sin\gamma+z\cos\gamma,\quad \xi=-y\cos\gamma+z\sin\gamma$$

Then equations for density of currents are obtained in the manner of

$$-i\omega\sqrt{\varepsilon_1}E_{0\eta1}(\eta_1)=\left(\frac{\partial^2}{\partial\eta_1^2}+k_0^2\delta^2\right)\times$$
$$\times\left\{\int\limits_{V_1}\frac{j_{1\eta}(\vec{r}\,'_1)exp(-ik_0R_{11})}{R_{11}}d\vec{r}\,'_1+\int\limits_{V_2}\frac{j_{2\eta}(\vec{r}\,'_2)exp(-ik_0R_{12})}{R_{12}}d\vec{r}\,'_2\right\}+$$
$$+ik_0\sin^2\gamma\frac{\partial}{\partial\chi_1}\times$$
$$\times\left\{\int\limits_{V_1}j_{1\eta}(\vec{r}\,'_1)(\chi_1-\chi'_1)\frac{exp\left(-ik_0\sqrt{\varepsilon_1}\left|\vec{r}_1-\vec{r}\,'_1\right|\right)-exp(-ik_0R_{11})}{T_{11}}d\vec{r}\,'_1+\right.$$
$$\left.+\int\limits_{V_2}j_{2\eta}(\vec{r}\,'_2)(\chi_1-\chi'_2)\frac{exp\left(-ik_0\sqrt{\varepsilon_1}\left|\vec{r}_1-\vec{r}\,'_2\right|\right)-exp(-ik_0R_{12})}{T_{12}}d\vec{r}\,'_2\right\},$$

(3)

where $\delta^2=\varepsilon_3\sin^2\gamma+\varepsilon_1\cos^2\gamma$,

$$-i\omega\sqrt{\varepsilon_1}E_{0\eta2}(\eta_2)=\left(\frac{\partial^2}{\partial\eta_2^2}+k_0^2\delta^2\right)\times$$

$$\times\left\{\int\limits_{V_2}\frac{j_{2\eta}(\vec{r}_2')exp(-ik_0R_{22})}{R_{22}}d\vec{r}_2'+\int\limits_{V_1}\frac{j_{1\eta}(\vec{r}_1')exp(-ik_0R_{21})}{R_{21}}d\vec{r}_1'\right\}+$$

$$+ik_0 sin^2\gamma\frac{\partial}{\partial\chi_2}\times$$

$$\times\left\{\int\limits_{V_2}j_{2\eta}(\vec{r}_2')(\chi_2-\chi_2')\frac{exp\left(-ik_0\sqrt{\varepsilon_1}\left|\vec{r}_2-\vec{r}_2'\right|\right)-exp(-ik_0R_{22})}{T_{22}}d\vec{r}_2'+\right.$$

$$\left.+\int\limits_{V_1}j_{1\eta}(\vec{r}_1')(\chi_2-\chi_1')\frac{exp\left(-ik_0\sqrt{\varepsilon_1}\left|\vec{r}_2-\vec{r}_1'\right|\right)-exp(-ik_0R_{21})}{T_{21}}d\vec{r}_1'\right\},$$

(4)

where
$R_{ij}=\sqrt{\delta^2(\eta_i-\eta_j')^2+\varepsilon_3(\chi_i-\chi_j')^2+(\varepsilon_1\varepsilon_3/\delta^2)(\xi_i-\xi_j')^2}$,
$T_{ij}=\left[(\eta_i-\eta_j')sin\gamma-(\xi_i-\xi_j')cos\gamma\right]^2+(\chi_i-\chi_j')^2$;
$E_{0\eta i}(\eta_i)$-tangential to surface of i-th wire component of intensity of falling electrical field (field of the source), $i,j=1,2$.

It's possible to consider equations (3), (4) as analogues of Poclington's equations well-known in theory of secluded linear wire situated in isotropic medium, spreading and generalising its to the linear wire system, situated in the anisotropic medium. In these equations integral addends in right parts, co-keeping $R_{11},R_{22},T_{11},T_{22}$, have a singularity when coinciding the points of the source and observation ($\vec{r}_i=\vec{r}_i'$, $i=1,2$). As far as singularities in the dynamics and in the static have one and same nature, it's possible to select their, determining electrostatic parts corresponding integral addends. As a result we obtain equations with small parameters for currents $I_1(\eta_1)$ and $I_2(\eta_2)$, generated in each wire:

$$\frac{d^2I_1(\eta_1)}{d\eta_1^2}+k_0^2\varepsilon_{eq}I_1(\eta_1)=$$

$$=\alpha_1\delta\left\{i\omega\sqrt{\varepsilon_1}E_{0\eta 1}(\eta_1)+F_{11}(\eta_1,I_1)+\right.$$

$$\left.+F_{12}(\eta_1,I_2)+\left[K_{11}(\eta_1,I_1)+K_{12}(\eta_1,I_2)\right]sin^2\gamma\right\},\quad(5)$$

$$\frac{d^2I_2(\eta_2)}{d\eta_2^2}+k_0^2\varepsilon_{eq}I_2(\eta_2)=$$

$$=\alpha_2\delta\left\{i\omega\sqrt{\varepsilon_1}E_{0\eta 2}(\eta_2)+F_{22}(\eta_2,I_2)+\right.$$

$$\left.+F_{21}(\eta_2,I_1)+\left[K_{22}(\eta_2,I_2)+K_{21}(\eta_2,I_1)\right]sin^2\gamma\right\},\quad(6)$$

where $\varepsilon_{eq}=\delta^2cos^2\gamma+\delta\sqrt{\varepsilon_1}sin^2\gamma$ - equivalent permittivity;

$$\alpha_1=-\frac{1}{2ln\left(\frac{2L_1}{b_1}\frac{2\delta^2/\sqrt{\varepsilon_3}}{\sqrt{\varepsilon_1}+\delta}\right)},$$

$$\alpha_2=-\frac{1}{2ln\left(\frac{2L_2}{b_2}\frac{2\delta^2/\sqrt{\varepsilon_3}}{\sqrt{\varepsilon_1}+\delta}\right)}$$ - small parameters.

The addends F_{11}, K_{11} and F_{22}, K_{22} describe own fields of first and second wires accordingly, addends F_{12}, K_{12} describe an influence of fields, generated second wire, on the amperage, excited in the first wire. Similarly, F_{21} and K_{21} describe an influence of field's first wire on the current in the second wire.

$$F_{11}(\eta_1)=\left(\frac{\partial^2}{\partial\eta_1^2}+k_0^2\delta^2\right)\times$$

$$\times\int\limits_{-L_1}^{L_1}\frac{I_1(\eta_1')exp\left(-ik_0\sqrt{\delta^2(\eta_1-\eta_1')^2+r_{eq1}^2}\right)-I_1(\eta_1)}{\sqrt{\delta^2(\eta_1-\eta_1')^2+r_{eq1}^2}}d\eta_1',$$

$$F_{12}(\eta_1)=-\frac{dI_2(\eta_2')}{d\eta_2'}\times$$

$$\times\left.\frac{exp\left(-ik_0\sqrt{\delta^2(\eta_1-\eta_2')^2+d_{eq}^2}\right)}{\sqrt{\delta^2(\eta_1-\eta_2')^2+d_{eq}^2}}\right|_{\eta_2'=-L_2}^{\eta_2'=L_2}+$$

$$+\int\limits_{-L_2}^{L_2}\left[\frac{d^2I_2(\eta_2')}{d\eta_2'^2}+k_0^2\delta^2I_2(\eta_2')\right]\times$$

$$\times\frac{exp\left(-ik_0\sqrt{\delta^2(\eta_1-\eta_2')^2+d_{eq}^2}\right)}{\sqrt{\delta^2(\eta_1-\eta_2')^2+d_{eq}^2}}d\eta_2',$$

where $d_{eq}^2=d^2\varepsilon_3\delta^2\left(\delta^2sin^2\tau+\varepsilon_1cos^2\tau\right)$- equivalent distance between wires, τ - angle between d (on planes $\chi o\xi$) and axis $o\xi$, where

$r_{eq\,i}^2 = \left(\varepsilon_3 \sqrt{\varepsilon_1} / \delta\right) b_i^2$ - equivalent radius i-th wire, i = 1, 2;

$$F_{22}(\eta_2) = \left(\frac{\partial^2}{\partial \eta^2} + k_0^2 \delta^2\right) \times$$

$$\times \left[\int_{-L_2}^{L_2} \frac{I_2(\eta_2') exp\left(-ik_0 \sqrt{\delta^2 (\eta_2 - \eta_2')^2 + r_{eq2}^2}\right)}{\sqrt{\delta^2 (\eta_2 - \eta_2')^2 + r_{eq2}^2}} d\eta_2' - \right.$$

$$\left. - \int_{-L_2}^{L_2} \frac{I_2(\eta_2)}{\sqrt{\delta^2 (\eta_2 - \eta_2')^2 + r_{eq2}^2}} d\eta_2' \right],$$

$$F_{21}(\eta_2) =$$

$$- \frac{dI_1(\eta_1')}{d\eta_1'} \cdot \frac{exp\left(-ik_0 \sqrt{\delta^2 (\eta_2 - \eta_1')^2 + d_{eq}^2}\right)}{\sqrt{\delta^2 (\eta_2 - \eta_1')^2 + d_{eq}^2}} \Bigg|_{\eta_1' = -L_1}^{\eta_1' = L_1} +$$

$$+ \int_{-L_1}^{L_1} \left[\frac{d^2 I_1(\eta_1')}{d\eta_1'^2} + k_0^2 \delta^2 I_1(\eta_1') \right] \times$$

$$\times \frac{exp\left(-ik_0 \sqrt{\delta^2 (\eta_2 - \eta_1')^2 + d_{eq}^2}\right)}{\sqrt{\delta^2 (\eta_2 - \eta_1')^2 + d_{eq}^2}} d\eta_1',$$

$$K_{11}(\eta_1) = ik_0 \times$$

$$\times \left\{ \int_{-L_1}^{L_1} I_1(\eta_1') \frac{exp\left(-ik_0 \sqrt{\varepsilon_1} \sqrt{(\eta_1 - \eta_1')^2 + b_1^2}\right)}{(\eta_1 - \eta_1')^2 + b_1^2} d\eta_1' - \right.$$

$$\left. - \int_{-L_1}^{L_1} I_1(\eta_1') \frac{exp\left(-ik_0 \sqrt{\delta^2 (\eta_1 - \eta_1')^2 + r_{eq1}^2}\right)}{(\eta_1 - \eta_1')^2 + b_1^2} d\eta_1' \right\} -$$

$$- k_0^2 \left[\int_{-L_1}^{L_1} I_1(\eta_1) \frac{\sqrt{\varepsilon_1} \sqrt{(\eta_1 - \eta_1')^2 + b_1^2}}{(\eta_1 - \eta_1')^2 + b_1^2} d\eta_1' - \right.$$

$$\left. - \int_{-L_1}^{L_1} I_1(\eta_1) \frac{\sqrt{\delta^2 (\eta_1 - \eta_1')^2 + r_{eq1}^2}}{(\eta_1 - \eta_1')^2 + b_1^2} d\eta_1' \right],$$

$$K_{12}(\eta_1) = ik_0 \times$$

$$\times \left\{ \int_{-L_2}^{L_2} I_2(\eta_2') \frac{exp\left(-ik_0 \sqrt{\varepsilon_1} \sqrt{(\eta_1 - \eta_2')^2 + d^2}\right)}{(\eta_1 - \eta_2')^2 + d^2} d\eta_2' - \right.$$

$$\left. - \int_{-L_2}^{L_2} I_2(\eta_2') \frac{exp\left(-ik_0 \sqrt{\delta^2 (\eta_1 - \eta_2')^2 + d_{eq}^2}\right)}{(\eta_1 - \eta_2')^2 + d^2} d\eta_2' \right\};$$

$$K_{22}(\eta_2) = ik_0 \times$$

$$\times \left\{ \int_{-L_2}^{L_2} I_2(\eta_2') \frac{exp\left(-ik_0 \sqrt{\varepsilon_1} \sqrt{(\eta_2 - \eta_2')^2 + b_2^2}\right)}{(\eta_2 - \eta_2')^2 + b_2^2} d\eta_2' - \right.$$

$$\left. - \int_{-L_2}^{L_2} I_2(\eta_2') \frac{exp\left(-ik_0 \sqrt{\delta^2 (\eta_2 - \eta_2')^2 + r_{eq2}^2}\right)}{(\eta_2 - \eta_2')^2 + b_2^2} d\eta_2' \right\} -$$

$$- k_0^2 \left[\int_{-L_1}^{L_1} I_1(\eta_1) \frac{\sqrt{\varepsilon_1} \sqrt{(\eta_1 - \eta_1')^2 + b_1^2}}{(\eta_1 - \eta_1')^2 + b_1^2} d\eta_1' - \right.$$

$$\left. - \int_{-L_1}^{L_1} I_1(\eta_1) \frac{\sqrt{\delta^2 (\eta_1 - \eta_1')^2 + r_{eq1}^2}}{(\eta_1 - \eta_1')^2 + b_1^2} d\eta_1' \right],$$

$$K_{21}(\eta_2) = ik_0 \times$$

$$\times \left\{ \int_{-L_1}^{L_1} I_1(\eta_1') \frac{exp\left(-ik_0 \sqrt{\varepsilon_1} \sqrt{(\eta_2 - \eta_1')^2 + d^2}\right)}{(\eta_2 - \eta_1')^2 + d^2} d\eta_1' - \right.$$

$$\left. - \int_{-L_1}^{L_1} I_1(\eta_1') \frac{exp\left(-ik_0 \sqrt{\delta^2 (\eta_2 - \eta_1')^2 + d_{eq}^2}\right)}{(\eta_2 - \eta_1')^2 + d^2} d\eta_1' \right\}.$$

Equations obtained in this way are solved by the method of averaging [3]. The advantage of the method of averaging is that it enables us to obtain uniform analytical expressions for the currents that are correct for wires of any length, including resonant

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one. The obtained analytical expressions describe the currents in wires of any length with positive and negative values of $\varepsilon_1, \varepsilon_3$. So for two symmetric active wires excited by δ-generators, connected in the centres of wires $E_{0\eta 1}(\eta_1) = V_{01}\delta(\eta_1)$, , $E_{0\eta 2}(\eta_2) = V_{02}\delta(\eta_2)$, the expressions for currents look like

$$I_1(\eta_1) = V_{01}\frac{\sin k_1(L_1 - |\eta_1|)}{Z_{11}} +$$

$$+V_{02}\frac{U_{12}(\eta_1)\sin 2k_1L_1 - M_{12}\sin k_1(L_1+\eta_1)}{Z_{12}}, \quad (7)$$

$$I_2(\eta_2) = V_{02}\frac{\sin k_2(L_2 - |\eta_2|)}{Z_{22}} +$$

$$+V_{01}\frac{U_{21}(\eta_2)\sin 2k_2L_2 - M_{21}\sin k_2(L_2+\eta_2)}{Z_{21}}, \quad (8)$$

where

$U_{12}(\eta_1) =$

$$= \int_{-L_1}^{\eta_1}(\eta_1')\sin k_1(\eta_1-\eta_1')\int_{-L_2}^{L_2}S_{12}(\eta_1',\eta_2')\cos k_2(\eta_2'-L_2)d\eta_2'd\eta_1',$$

$U_{21}(\eta_2) =$

$$= \int_{-L_2}^{\eta_2}\eta_2'\sin k_2(\eta_2-\eta_2')\int_{-L_1}^{L_1}S_{21}(\eta_2',\eta_1')\cos k_1(\eta_1'-L_1)d\eta_1'd\eta_2',$$

$M_{12} = U_{12}(\eta_1)\big|_{\eta_1=L_1}$, $M_{21} = U_{21}(\eta_2)\big|_{\eta_2=L_2}$ - integral functions describing mutual influence of wires, Z_{11}, Z_{22} - own entrance resistance of wires, Z_{12}, Z_{21} - mutual resistance; $k_n = k_n' + ik_n'' = k_0\left[\sqrt{\varepsilon_{eq}} + i\alpha_n\left(\delta\sqrt{\varepsilon_1/\varepsilon_{eq}}/k_0 b_n\right)Z_n\right]$, where $Z_n = R_n + iX_n$ - complex skin impedance n-th wires normalized on 120 π; $n = 1,2$.

The influence of the surface impedance of wires on the currents is characterised by variations of complex wave numbers $k_n = k_n' + ik_n''$, that include dielectric characteristics of medium, geometry of wires and their orientation in magnetoactive plasma.

The characteristics (Fig2., Fig.3) were calculated for symmetrical wires (7), (8) situated in the laboratory plasma with parameters: electron concentration 10^8 sm^{-3}, constant magnetic field 3500 e, Langmuir frequency ω_N=5.6·10^8Hz, Larmor frequency ω_B=6·10^{10} Hz. Under changing work frequency ω in range, where $\omega_B >> \omega >> \omega_N^2/\omega_B$ plasma is described by diagonal tensor ε. In this range the component ε_1 doesn't depend on frequency ($\varepsilon_1 \cong 1$), component ε_3 is function of frequency.

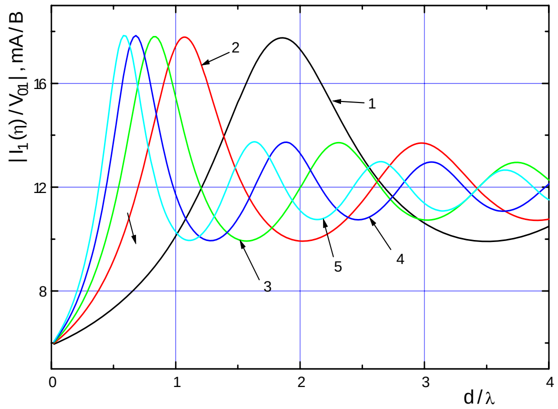

Fig.2. The dependence of input current (η=0) in first wire under L_1/λ =0,25 , L_2/λ =0,25, from distance d/λ between wires under different ε_3 (1 -0,1; 2 -0,3; 3 -0,5; 4 -0,75; 5 -1) and orientation γ=0 (parallel to anisotropy axis OZ).

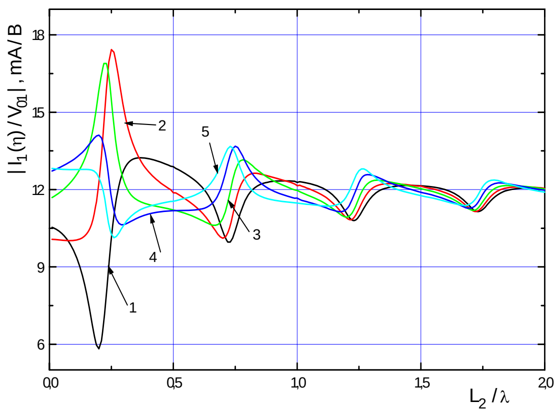

Fig.3. The dependence of input current (η=0) in first wire L_1/λ=0,25 , under, d/λ=1 from different ε_3 (1 -0,1; 2 -0,3; 3 -0,5; 4 -0,75; 5 -1) under orientation γ=0 (parallel to axis of anisotropy OZ).

Based on the distributions of currents according to the formulas (1), (2), it is possible to find the fields of radiation at any distance from wires. In particular, the expressions for the fields in far zone in the spherical system of coordinates r, θ, φ are as follows:

$E_r = H_r = 0$,

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$$E_\theta = \frac{k_0^2 \sqrt{\varepsilon_1}\varepsilon_3}{i\omega N^3} \times$$
$$\times (sin\gamma cos\varphi cos\theta - cos\gamma sin\theta)\Pi_N \frac{exp(-ik_0 Nr)}{r},$$

$$E_\varphi = \frac{k_0^2 sin\gamma sin\varphi}{i\omega}\Pi_O \frac{exp\left(-ik_0\sqrt{\varepsilon_1}r\right)}{r},$$
$$H_\theta = \frac{k_0^2 \sqrt{\varepsilon_1}\, sin\gamma sin\varphi}{i\omega}\Pi_O \frac{exp\left(-ik_0\sqrt{\varepsilon_1}r\right)}{r},$$
$$H_\varphi = \frac{k_0^2 \sqrt{\varepsilon_1}\varepsilon_3}{i\omega N^2} \times$$
$$\times (\sin\gamma \cos\varphi \cos\theta - \cos\gamma \sin\theta)\Pi_N \frac{\exp(-ik_0 Nr)}{r},$$

where

$$N = \sqrt{\varepsilon_3 \sin^2\theta + \varepsilon_1 \cos^2\theta},$$

$$\Pi_O = \Pi_{O1} + \Pi_{O2} \exp\left[-ik_0\sqrt{\varepsilon_1}\left(h\cos\Gamma_1 + d\cos\Gamma_2\right)\right],$$

$$\Pi_N = \Pi_{N1} + \Pi_{N2} \exp\left[-ik_0 N\left(h\cos\Gamma_1 + d\cos\Gamma_2\right)\right],$$

$$\cos\Gamma_1 = \sin\gamma\cos\varphi\sin\theta + \cos\gamma\cos\theta,$$

$$\cos\Gamma_2 = \cos\gamma\cos\varphi\sin\theta - \sin\gamma\cos\theta,$$

$$\Pi_{Oj} = \int_{-L_j}^{L_j} I_j(\eta) exp\left(ik_0\sqrt{\varepsilon_1}\eta cos\Gamma_1\right)d\eta;$$

$$\Pi_{Nj} = \int_{-L_j}^{L_j} I_j(\eta)\exp\left(ik_0 N\eta\cos\Gamma_1\right)d\eta;$$

$I_j(\eta)$- current in j-th wire; Γ_j -angle between axis of *j*-wire and direction on observation point, *j*=1,2.

For the calculation of density of radiated power *T* we shall use the expression

$$T = \left(ck_0^4 / 8\pi r^2\omega^2\right)\left(T_1 + T_2\right), \qquad (3)$$

where

$$T_1 = $$
$$= \begin{cases} \left(\varepsilon_1\varepsilon_3^2 / N^5\right)\left|\Pi_N\right|^2 \left(sin\gamma cos\varphi cos\theta - cos\gamma sin\theta\right)^2, \\ \text{if } ReN \neq 0 \\ 0, \text{ if } ReN = 0 \end{cases}$$

$$T_2 = \begin{cases} \sqrt{\varepsilon_1}\left|\Pi_O\right|^2 sin^2\gamma\, sin^2\varphi, \text{if } \varepsilon_1 > 0 \\ 0, \text{if } \varepsilon_1 \leq 0 \end{cases}$$

4. Conclusion

Anisotropy of medium essentially changes all characteristics of wires. The functions of distribution of currents along wires is determined by equivalent permittivity ε_{eq} and equivalent distance between wires d_{eq}, which depend on the values of components $\varepsilon_1, \varepsilon_3$ of permittivity tensor and on the orientation of wire system in medium (angle γ). Hence, these factors determine the shape of patterns. It is possible to make a conclusion about two ways of the design of wires: electrical (changing the working frequency, that is $\varepsilon_1(\omega), \varepsilon_3(\omega)$) and mechanical (changing orientation in medium). It is known that if one of the components of permittivity tensor is negative, than with a certain orientation of wire system relatively to the axis of anisotropy, the current in the perfectly conducting wire not excited [4]. Excitation of significant currents in impedance wire in this case is possible, provided that surface impedance is selected so that it compensates the reaction of surrounding plasma. If in the expressions for the fields of radiation and currents one puts $\varepsilon_1 = \varepsilon_3$, we obtains the appropriate formulas for isotropic medium. By removing one of the wires to infinity, we obtain the formulas for the single wire.

Thus, in the present work a high efficiency of the method of integral equations is shown which has enabled us to solve the problem about excitation of two parallel wires arbitrary oriented in anisotropic medium. Without any special difficulties this method can be applied to studying the system consisting of large number of thin wires located in isotropic or anisotropic medium.

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