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BINARY MATERIALS IN RADIO ELECTRONIC DEVICES

ODESSA

1994

The binary materials are characterized with the interrelated matter equations which determine the dielectric and magnetic properties simultaneously. In these media, the electromagnetic waves are described with the new Maxwell equations solutions for example, in the form of the circular T,E,H-waves in the inhomogeneous isoimpedance media. Medium inhomogeneity and impedance constancy together create the unique conditions for the wave refraction with minimal scattering on the magnetodielectric bodies. The binary materials and circular (globally plane, sphere) waves are proposed for applications in antenna engineering as the circuit components miniaturization, in electronic and plasma devices, etc.

CONTENTS

INTRODUCTION

The creation of the radio electronic and electroengineering devices consists in the choice of the geometrical, mechanical, physical characteristics of the conductors, dielectrics, magnetics. The permittivity and permeability are contained in different material equations

$$\overline{D} = \varepsilon\overline{E}, \overline{B} = \mu\overline{H}, \tag{1}$$

which determine the relations between electric field vectors $\overline{D}, \overline{E}$ and magnetic field vectors $\overline{B}, \overline{H}$ separately.

Nowadays the great attention is devoted to the media which are described with the interrelated material equations. Generally they may be called as binary materials including following ones:

a) bi-isotropic (chiral),

b) segnetomagnetic,

c) inhomogeneous with wave constant velocity,

d) inhomogeneous isoimpedance.

The material equations system for bi-isotropic medium [1, 2] is:

$$\overline{D} = \varepsilon\overline{E} + \kappa\overline{H}, \overline{B} = -\kappa\overline{E} + \mu\overline{H}, \tag{2}$$

where coefficient κ accounts the additional abilities of magnetic field to affect on dielectric properties and also the electrical field on magnetic properties.

Segnetomagnetics are the crystals combining the properties of segnetoelectrics and magnetics [3, 4]. The material equations system for them contains the tensors:

$$\overline{D} = \hat{\varepsilon}\overline{E} + \hat{\alpha}\overline{H}, \overline{B} = \hat{\beta}\overline{E} + \hat{\mu}\overline{H}. \tag{3}$$

The equations (2), (3) characterize the media with spatial dispersion. But in the case of lack of the mentioned effect the material may be described with the help of the interrelated material equation. It takes place if we use the coordinate interrelation condition in addition to equations (1) for the inhomogeneous medium and the following presentation of the ratio permittivity and permeability:

$$f[\varepsilon_r(x, y, z), \mu_r(x, y, z)] = 0. \tag{4}$$

The significant results were obtained for two particular cases of the functional dependence (4): when the medium has constant wave number [5] and

$$\mu_r(x, y, z) = 1/\varepsilon_r(x, y, z), \qquad (5)$$

or constant impedance [6-8] and

$$\mu_r(x, y, z) = \varepsilon_r(x, y, z).$$

The shown media properties will be touched upon in the first chapter. The further chapters are devoted to detail description of the results in respect of the isoimpedance inhomogeneous media and the circular waves discovered by author.

CHAPTER 1. GENERAL INFORMATION ABOUT BINARY MATERIALS

1.1. Chiral non-reciprocal media

The chiral media are described with the help of equations (2) where the non-reciprocity of medium is shown due to different signs of coefficients κ in two equations. The variants of the real and image values of κ are considered in details. The media have spatial dispersion because the relation between $\overline{D}$ and $\kappa\overline{H}$ corresponds to the interrelation between $\overline{D}$ and spatial derivative for $\overline{H}$ in form of Maxwell's equation $j\omega\overline{D} = \mathrm{rot}\overline{H}$. The last relation is owed to vector $\overline{D}$ value at the fixed point of space depends upon vector $\overline{H}$ values in nearpoints continuum. The most detailed analysis of the spatial dispersion problems has been conducted for plasma. The lack of tensors in formula (2) allows us to consider the chiral non-reciprocal media also as bi-isotropic ones. The interest to these media is real in the optics where ones are called as optical active media. Besides, the chiral media are considering as essential materials for radioabsorbing coatings for UHF devices.

1.2. Segnetomagnetic matters

Even in the past century it was marked that the bodies containing non-symmetrical moleculae may be polarized in the magnetic field and be magnetized in the electric one [3]. Later it was spoken out the assumption about existing of the substances with the polarization and magnetizing are caused by means of the electric field influence only. In the beginning of the sixties in the USSR it was obtained the segnetoelectrics with magnetic order which were called as segnetomagnetics. In foreign literature same matters are called as ferroelectrics with magnetic order.

The system of the material equations (3) for segnetomagnetics is often rewrote for the polarization and magnetizing vectors:

$$\overline{P} = \hat{\kappa}^{e}\overline{E} + \hat{\kappa}^{em}\overline{H}, \overline{M} = \hat{\kappa}^{me}\overline{E} + \hat{\kappa}^{m}\overline{H},$$

where $\hat{\kappa}^{me}, \hat{\kappa}^{em}$ - are tensors of the magnetoelectric and electromagnetic susceptibilities. The bibliography of the segnetomagnetic research up to 1989 is contained in two books [3, 4] where more than 1100 papers have been shown. A major attention of physicists and chemists is concentrated on the search of the matters with the sufficient values of the magnetoelectric and electromagnetic susceptibilities. Among possible technical applications of the devices in which the electrical field controls magnetic characteristics or magnetic field changes the electrical parameters were point out the optical switchers, phase shifters, magnetoelectric converter, etc.

The important way of creation of the materials with an effective electric and magnetic subsystems interaction is using of the composite structures from ferrit and segnetoelectric films [4].

1.3. Inhomogeneous media with wave constant velocity

There are existing a great number of the papers on electromagnetic waves investigation in the inhomogeneous media with continuos refraction coefficient $n = \sqrt{\varepsilon_r \mu_r}$. A Helmholz's equation with varying wave number $k = \omega n / c_0$ is considered during the waves types analysis. Medium is usually considered as non-magnetic one ($\mu_r = 1$), and variation of $n = n(x, y, z)$ is owed to non-constancy of permittivity ε_r.

Some waveguide systems with inhomogeneous filling are considered in monograph [5]. If we guess that $\varepsilon_r(x,y,z)\mu_r(x,y,z) = \text{const}$, (by using condition (5)) then we may use the constant wave number in the Helmholz's equation and the analysis of the E,H-waves becomes simpler. It gives a possibility to build an algorithm of the medium synthesis according to the nessesary wave impedance dependence $Z_C = \sqrt{\mu/\varepsilon}$. So due to no information about the real material created under equation (5) realization in work [5], that applied aspects of these results aren't clear.

1.4. Some media with special properties

The investigation on problem of the creation of some media with the special properties are closed to considering problem of the binary media description and creation. The methods of creation of the ferromagnetic materials by means of the magnetized and isolating particles mixture have almost one hundred years history [9-13].

The essential reduce of the energy losses is provided in magnetodielectrics or ferrits are the most known class of the high frequency magnetic materials. The investigations on production of the dielectrics with new properties are conducted parallelly [14-18].

The greatest number of works is doing now for the investigation and the utilization of the hybrid properties of the materials and the affections on them. Let us note only few of these directions. It is possible to affect on matter optical properties with the help of outer magnetic field [19, 20]. Devices are using the magnetostatic waves in iron-ittrij garnet will be useful for microwave engineering [21]. The important applications of the magnetic liquids take place at lower frequencies [22, 23].

A lot of papers are devoted the nonlinear properties matter application for wave processes transformation at very high frequencies including optical band [24-28].

The problems of bi-isotropic (chiral) media [1, 2, 29-32] and segnetomagnetics [3,4,33-35] researches are more closed to the problems of the isoimpedance electromagnetic media creation.

In order to develop works on artificial isoimpedance media, one can use the results on artificial dielectrics and magnetodielectrics realization [36-43]. Before inhomogeneous isoimpedance media will be created, it is necessary to come throw a stage of homogeneous media creation with dielectric and magnetic properties combination. The ferromagnetism phenomena is absent on high frequencies [44,45], therefore the magnetosoft materials may exist when we use the frequencies no more then few hundreds MHz [9-11]. The known method of the compositional materials fabrication is method of their creation from plates, rods [46-50] and a transition to smooth inhomogeneous media [51,52]. It is important to research the powdery ferromagnetics and dielectrics and it will be useful the results of powdery dielectric application in antenna engineering [53] and some ideas on dusty media creation with combinational properties [38,54].

2.1. Globally plane and sphere waves

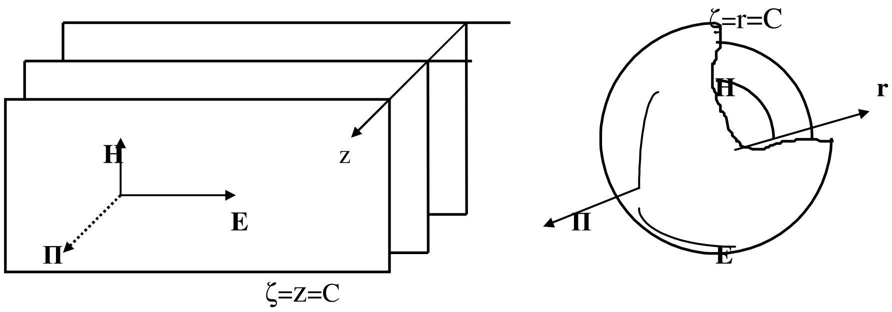
The traditional representations of the plane and sphere waves with transverse intensities

$$E_{\perp} = E_m e^{j(\omega t - k\zeta)}, H_{\perp} = E_m Z_c^{-1} e^{j(\omega t - k\zeta)} \qquad (2.1)$$

are corresponded to plane-parallel fronts when $\zeta = z$ (Fig.2.1,a) or to sphere-parallel fronts when $\zeta = r = \sqrt{x^2 + y^2 + z^2}$ (Fig.2.1,b). The energy propagation takes place in the homogeneous medium with wave impedance

$$Z_c = \sqrt{\mu / \varepsilon} = Z_0 \sqrt{\mu_r / \varepsilon_r} \qquad (2.2)$$

along the parallel straights (z) or along the divergent straights (r-rays).



a) b)

Fig. 2.1

The phase velocity is equal to

$$v = \omega / k = 1/\sqrt{\mu\varepsilon} = c_o / \sqrt{\mu_r \varepsilon_r} = c_o / n . \qquad (2.3)$$

If the longitudinal components are equal to zero $(E_\zeta = 0, H_\zeta = 0)$, in the electromagnetic wave that the equations (2.1) are corresponded to transverse type (T) wave. By $E_\zeta \neq 0, H_\zeta = 0$ or $H_\zeta \neq 0, E_\zeta = 0$ we have the electrical and magnetic wave types for which we guess that k in formulae (2.1) as longitudinal wave number and to use impedance Z_c^E or Z_c^H instead of magnitude (2.2).

Approaching the consideration of the waves in the inhomogeneous media we mark the cases when the intensities representations (2.1) are justified also.

According to well known geometrical optics method the equations (2.1) give the local plane representation for the wave in medium with slow refraction coefficient n(x,y,z) variation.

The author develops other direction which begins from a question: what are media where wave with intensities (2.1) will has non-local but global plane or sphere fronts ? With account of the demand of the orthogonal disposition $E_{\perp}, H_{\perp}$ to unit vector $\overline{\zeta}_0$ it needs to consider a problem with the utilization of the orthogonal curvilinear coordinates ξ, η, ζ. Therefore from infinite number of situations with $\zeta = C$ as planes and spheres it is necessary to select only cases when surfaces $\xi = C, \eta = C, \zeta = C$ (where $\zeta = C$ are planes and spheres) perform three-orthogonal surfaces system.

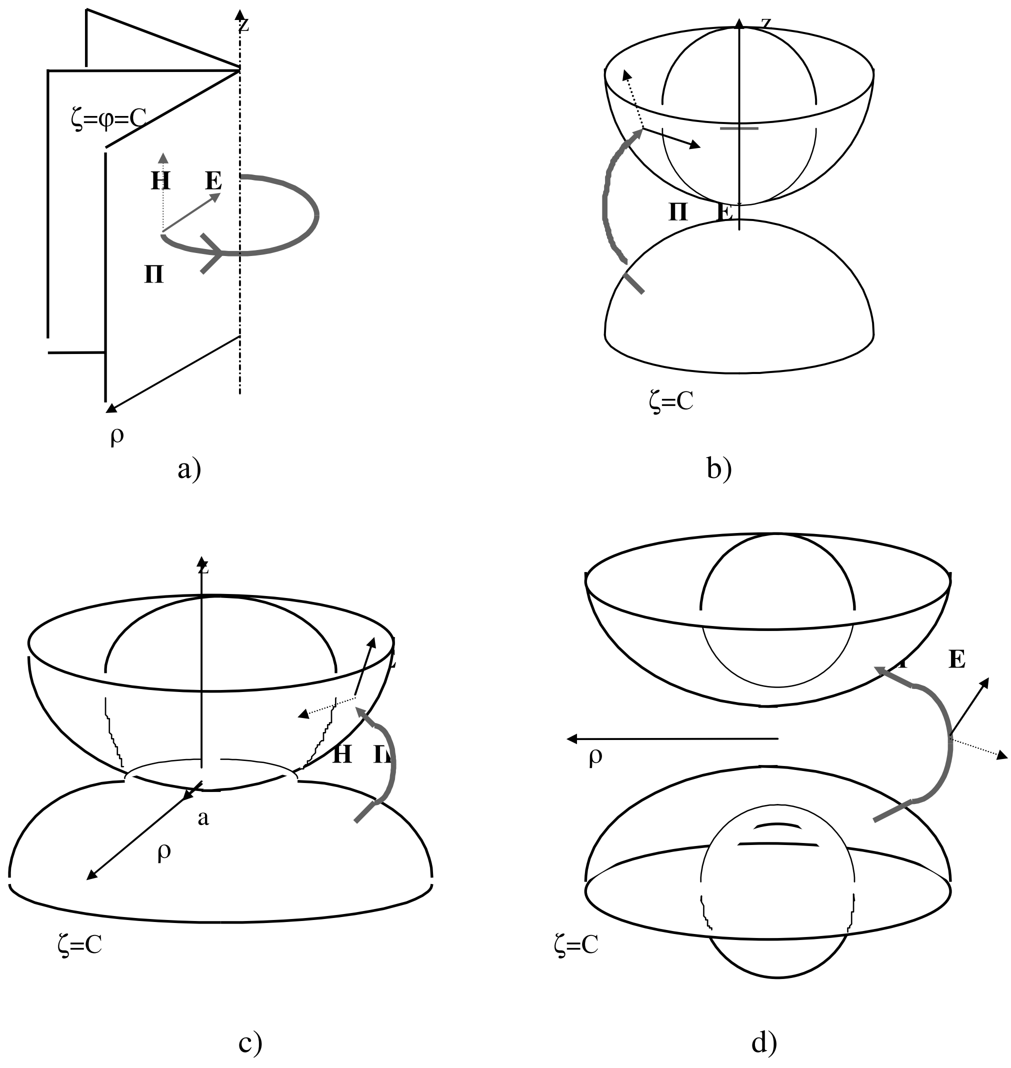


Fig. 2.2

The problem in given geometrical recognition has been investigated else in [55,56] where was shown that the plane or spherical basics make four new families shown on Fig. 2.2. in addition to two families represented on Fig. 2.1. The plane-base (PB) and the sphere-base (SB) coordinate systems are described with details in [7,55,56]. The general research of global plane (sphere) waves in the isoimpedance inhomogeneous media was made later in [6-8,57] where terms neoclassical or circular waves were used.

As was found to that all six classes of global plane (sphere) waves demand for their existence of fulfillment as the isoimpedance medium condition

$$\sqrt{\mu / \varepsilon} = Z_c = \text{const}, \tag{2.4}$$

so and the condition of matching with metrical coefficient (Lame's one) for phase front families $\zeta = C$:

$$\varepsilon_r(\xi, \eta, \zeta) = \mu_r(\xi, \eta, \zeta) = h_{\zeta C} / h_\zeta, \tag{2.5}$$

where $h_{\zeta C}$ - numerical value of Lame's coefficient in a some point of space.

The waves with plane-parallel and sphere-parallel fronts (Fig.2.1,a,b) are observed in the homogeneous medium where conditions (2.4),(2.5) are $Z_C = Z_0, \varepsilon_r = \mu_r = h_\zeta = h_{\zeta C} = 1$. The waves with plane-axis (Fig.2.2,a), sphere-point (Fig.2.2,b), sphere-axis (Fig.2.2,c), bi-spherical (Fig.2.2,d) fronts take place in the inhomogeneous isoimpedance media where equation (2.5) is appropriately:

$$\text{PBII}.\ \varepsilon_r = \mu_r = a / \rho, \rho = \sqrt{x^2 + y^2}, \tag{2.6}$$

$$\text{SBII}.\ \varepsilon_r = \mu_r = a^2 / r^2, r^2 = x^2 + y^2 + z^2, \tag{2.7}$$

$$\text{SBIII}.\ \varepsilon_r = \mu_r = c^2 / \sqrt{(r^2 + a^2)^2 - 4\rho^2 a^2}, \tag{2.8}$$

$$\text{SBIV}.\ \varepsilon_r = \mu_r = c^2 / \sqrt{(r^2 + a^2)^2 - 4z^2 a^2}. \tag{2.9}$$

On shown figures double pointers correspond to the Pointing's energy vector lines, i.e. to the energy flows. The ability of choice of the different constants a, c in formulae will be considered later. Each of six global (sphere) waves classes has four subclasses which according to known terminology are called T,E,H,EH types of the waves. The calculating formulae for transverse intensities components in E-wave are obtained in [7,8,57] from the Maxwell's equations in PB, SB coordinate systems of the following form:

$$E_\xi^E / Z_c^E = H_\eta^E = -j\omega\varepsilon_0\sigma U'_\xi, H_\xi^E = j\omega\varepsilon_0\sigma U'_\eta = -E_\eta^E / Z_c^E, \quad (2.10)$$

where $Z_c^E = \beta/\omega\varepsilon_0, 1/\sigma = h_{\zeta C} h(k_0^2 - \beta^2) = h_{\zeta C} h\gamma^2, U = h_\zeta E_\zeta,$ (2.11)

or for Í-wave:

$$E_\xi^H / Z_c^H = H_\eta^H = -j\beta\sigma V'_\eta, -E_\eta^H / Z_c^H = H_\xi^H = -j\beta\sigma V'_\xi, \quad (2.12)$$

where $Z_c^H = \omega\mu_0 / \beta, V = h_\zeta H_\zeta.$ (2.13)

The functions U,V are determining according to (2.11), (2.13) the field vectors longitudinal components and according to (2.10), (2.12) transverse components, have the view:

$$U = u(\xi,\eta)e^{j(\omega t - h_{\zeta C}\beta\zeta)}, V = v(\xi,\eta)e^{j(\omega t - h_{\zeta C}\beta\zeta)}, \quad (2.14)$$

where $u(\xi,\eta)$ or $v(\xi,\eta)$ are two-dimentional equation

$$u''_\xi + u''_\eta + h^2\varepsilon_r^2\gamma^2 u = 0. \quad (2.15)$$

solutions. Now it therefore remains only to recognize the boundary problem for equation (2.15), including the data about guiding conductors, to find the longitudinal wave number β and functions u,v in order to have all components of wave intensity vectors from (2.10)-(2.14).

The only change of the constant nearby ζ takes place in phase multiplicator (2.14) during the generalization of representation (2.1) for 6×4 variants of global plane (sphere) waves.

The circular waves also exist in the inhomogeneous anisotropic media if for components of tensors $\hat{\varepsilon}, \hat{\mu}$, from the material equations of media

$$\overline{D} = \hat{\varepsilon}\overline{E} = \sum_{n=1}^{3} \vec{x}_n^0 \sum_{\nu=1}^{3} \varepsilon_{n\nu} E_\nu, \overline{B} = \hat{\mu}\overline{H} = \sum_{n=1}^{3} \vec{x}_n^0 \sum_{\nu=1}^{3} \mu_{n\nu} H_\nu,$$

the relations

$$h_3\varepsilon_{n\nu} = h_{3C}\varepsilon_{n\nu}^C, h_3\mu_{n\nu} = h_{3C}\mu_{n\nu}^C; n,\nu = 1,2,3,$$

$$\varepsilon_{31}^C = \varepsilon_{32}^C = 0, \mu_{31}^C = \mu_{32}^C = 0, \quad (2.16)$$

are valid in the case when $\varepsilon_{n\nu}^{C}, \mu_{n\nu}^{C}$ are constants. If these numbers no depend on frequency ω, one can put $\beta = \omega\sqrt{\varepsilon\mu}$ and take $\beta = k_0 = \omega\sqrt{\varepsilon_0\mu_0}$ without the generalization limitation. The requirement of the Maxwell's equations system compatibility leads to relationship between numbers $\varepsilon_{n\nu}^{C}, \mu_{n\nu}^{C}$:

$$\frac{\mu_{22}^{C}}{\mu_{11}^{C}} = \frac{\varepsilon_{22}^{C}}{\varepsilon_{11}^{C}}, \frac{\mu_{21}^{C}}{\mu_{11}^{C}} = \frac{\varepsilon_{12}^{C}}{\varepsilon_{11}^{C}}, \frac{\mu_{12}^{C}}{\mu_{11}^{C}} = \frac{\varepsilon_{21}^{C}}{\varepsilon_{11}^{C}}, \mu_0\varepsilon_0 = \varepsilon_{11}^{C}\mu_{22}^{C} - \varepsilon_{12}^{C}\mu_{12}^{C}. \tag{2.17}$$

The relations (2.16), (2.17) for the plane-parallel and sphere-parallel T-waves were obtained earlier [58].

The circular waves have a lot of properties of the waves in homogeneous media. So, for circular T-waves the known properties of usual T-waves are observed: a) the frequency independence of force lines structure, b) the impedance independence from coordinate of point observation, c) the real character of impedance and coincidence on the phase electrical and magnetic fields intensities, d) the ability of transmission line theory application with voltage, current, inductances, capacities introduction, etc.

The phase velocity of circular wave is calculated similarly to (2.3) with take account of (2.14):

$$v = h_\zeta \zeta_t' = h_\zeta \omega / h_{\zeta C}\beta = \omega / \beta\varepsilon_r. \tag{2.18}$$

The energy transmission velocity also is different in different points:

$$v_э = \frac{\Pi_{-p}}{w_{-p}} = \frac{\mathrm{Re}(\overline{E}\times\overline{H}^*)/2}{(\varepsilon|\overline{E}|^2 + \mu|\overline{H}|^2)/4} = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c_0 h_\zeta}{h_{\zeta C}} \le c_0. \tag{2.19}$$

2.2. Isoimpedance media and bodies

Let us now consider the properties of those isoimpedance media which due to relations (2.6)-(2.9) provide the plane or sphere character of wave front in the total variety of points on surface $\zeta = C$ (Fig.2.2). As theoretically so as practically it is convenient to describe four variants of isoimpedance media with the help of the surfaces of the equal magnitudes permeabilities.

2.2.1. For inhomogeneous medium with parameters (2.6) the circle cylinder surfaces $\rho = C$ are ones of constant values of ε_r, μ_r. Choice of some radius **a** means that we have the decelerating medium with $\varepsilon_r = \mu_r > 1$ when $\rho < a$ and the accelerating one when $\rho > a$. The continuous reverse proportional relation (2.6) may be realized in the stratified magnetodielectric with cylinder layers of constant values $\varepsilon_r = \mu_r$. The half-planes $\zeta = \mathrm{arctg}(y/x) = C$ are orthogonal to surfaces $\varepsilon_r = \mu_r = C$ as the phase fronts of plane-axis waves (Fig.2.2,a).

2.2.2. The medium, characterized by functions (2.7), has the concentric spheres **r=C** as the surfaces of the equal values $\varepsilon_r = \mu_r = C$. The step-stair realization of this medium is consist of sphere areas. In the points when **r<a**, the medium is decelerating (n>1) and accelerating (n<1) when **r>a** it is. For sphere-point waves (Fig.2.2, b) phase fronts are spheres $\zeta = z / r^2 = C$, which are not orthogonal to the spheres of the equal values $\varepsilon_r = \mu_r = a^2 / r^2 = C$.

2.2.3. We have possibility to take constants **a,c** in the relation (2.8) so that demarcation surface $\varepsilon_r = \mu_r = 1$ becomes having some geometrical variants. For surface $\varepsilon_r = \varepsilon_{rc}$ we have equation

$$(\rho^2 + z^2)^2 - 2a^2(\rho^2 - z^2) = c^4 / \varepsilon_{rc}^2 - a^4, \tag{2.20}$$

which determines the known Cassini's curves families (Fig.2.3) on the plane ρ, **Z**.

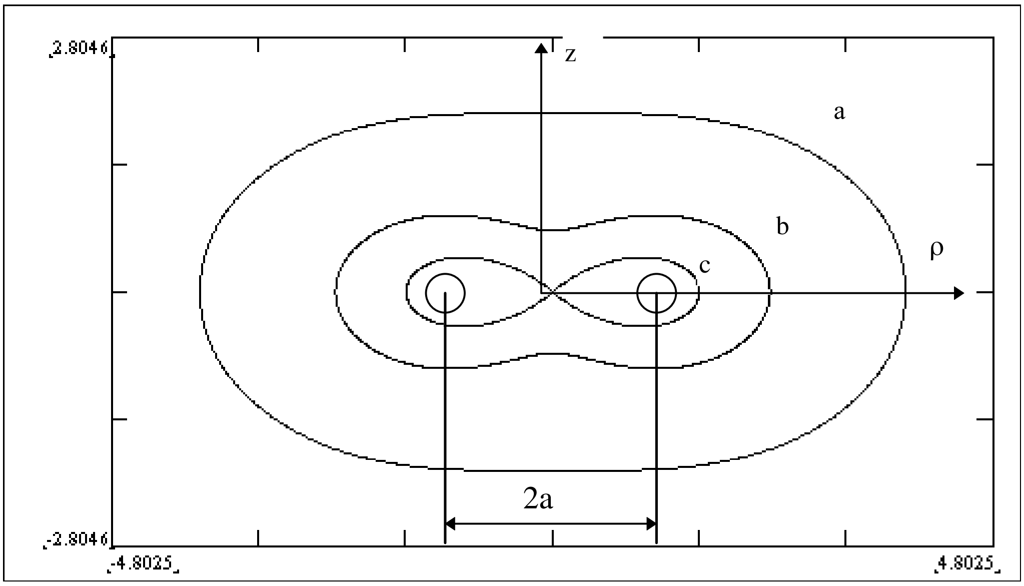


Fig. 2.3

Surfaces $\varepsilon_r = \varepsilon_{rc}$ are created with the help of Cassini's curves rotation around axis z, i.e. they are surfaces of rotation. Four different forms of Cassini's curves are shown at Fig.2.3 that allows to choose the demarcation surface $\varepsilon_r = \mu_r = 1$ represented in four views: a) oblate ellipsoidal when $c > a\sqrt{2}$, b) ellipsoidal with recess by $a < c < a\sqrt{2}$, c) ellipsoidal with minimum recess (point $\rho = z = 0$) by c=a, d) like thoroid when c<a. Shown on Fig.2.3 points M in cases a)-c) have coordinates $z = 0, \rho = a\sqrt{1 + c^2 / a^2}$, and in case d) coordinates are $z = 0, \rho = a\sqrt{1 - c^2 / a^2}$. The isoimpedance medium, located inside surface $\varepsilon_r = \mu_r = 1$, is decelerating (n>1), and located outside is accelerating (n<1). We note that the phase fronts $\zeta = C$ of the sphere-axis waves (Fig. 2.2,c) are not orthogonal to the surfaces $\varepsilon_r = \mu_r = C$.

2.2.4. The medium with permeabilities from (2.9) has surfaces of the constant value permeabilities with equation

$$(z^2 + \rho^2)^2 - 2a^2(z^2 - \rho^2) = c^4 / \varepsilon_{rc}^2 - a^4. \quad (2.21)$$

Obviously, in the equations (2.20), (2.21),we need to make the substitution of ρ, z. The surfaces $\varepsilon_r = \varepsilon_{rc}$ are formed by means of Cassini's curves rotation, shown on Fig.2.3, corresponding to the horizontal axis which is axis **z** after exchange of the variables. Now surface $\varepsilon_r = \mu_r = 1$ may have four following views: a) a lengthen ellipsoidal if $c > a\sqrt{2}$, b) a lengthen ellipsoidal with waist when $a < c < a\sqrt{2}$, c) two dropview surfaces with common point $\rho = z = 0$ if c=a, d) two separate dropview surfaces when c<a. The shown demarcation surface divides total space on decelerating inside medium and accelerating outside one. The phase fronts of the bi-spherical waves (Fig.2.2,d) are not orthogonal to surfaces $\varepsilon_r = \mu_r = C$, shown on Fig.2.3.

We can make “separations” from infinite inhomogeneous matter and fill the remain part of space with an air. If it is made over surface $\varepsilon_r = \mu_r = 1$, that the continuation of permeabilities on boundary is provided. We have isoimpedance decelerating body by means of leaving of the inhomogeneous material inside surface $\varepsilon_r = \mu_r = 1$. If, on the contrary, an air is inside demarcation surface, we have cavity in the accelerating inhomogeneous medium. It's possible to have some intermediate variants: the air cavity in decelerating-accelerating medium or the decelerating-accelerating coating in an air.

The electromagnetic field in the isoimpedance body of finite size will be a circular wave when the waveguiding conductors are used additionally.

2.3. T-waves in the inhomogeneous media

The T-waves with plane-parallel phase fronts which are used in all feeders: multiconductors lines, coaxial cables, etc. are known mostly. The waves with sphere-parallel fronts are guided with multicones conductors with divergent (ray) currents [56,59]. Let us now consider in greater detail four classes of T-waves in the isoimpedance inhomogeneous media which were described above.

The PB, SB coordinate systems application, where $h_\xi = h_\eta = h$, allows to represent Maxwell's equations in convenient form [7,57], we have equations for T-wave $(E_\zeta = 0, H_\zeta = 0, \beta = k_0 = \varpi\sqrt{\mu_0\varepsilon_0})$:

$$(hE_\eta)'_\xi = (hE_\xi)'_\eta, (hE_\xi)'_\xi = -(hE_\eta)'_\eta, E_\xi = Z_0 H_\eta, E_\eta = -Z_0 H_\xi. \quad (2.22)$$

The intensities components are determined with the help of the analytical function of complex variable $W(\xi + i\eta)$:

$$h(E_\xi - iE_\eta) = W(\xi + i\eta)e^{-jk_0 h_{\zeta C}\zeta}. \quad (2.23)$$

2.3.2. The simplest circular wave is one rotating along coordinate $\zeta = \varphi$ in the isoimpedance medium with permeabilities in (2.6). If the indicated material fills a space between two coaxial metal cylinders with radii $\rho = \rho_1, \rho = \rho_2$, the field intensities are equal to

$$E = E_\rho = -Z_0 H_z = U(\rho_2 - \rho_1)^{-1} e^{-jk_0\rho_2\varphi}, \quad (2.24)$$

where U is voltage between two conductors. Formula (2.24) is written with using of the formulas (2.22), (2.23), accounting the equations $\xi = z, \eta = \rho, h = 1$. In accordance with formulas (2.18), (2.19), the linear phase velocity and the velocity of energy transmission are $v = v_э = c_0\rho/\rho_2$. They are maximum, if

$\rho = \rho_2$, and minimum, if $\rho = \rho_1$. As is well known, the expression $\varphi = \mathrm{arctg}(y/x)$, is the uniquely determined function only in the case when $0 < \varphi < 2\pi$. Practically a circular wave with intensities (2.24) may be realized, if to take energy from source which is coupled with half-plane $\varphi = 0$. Further the wave transmits this energy along circle toward to the resisting wall coinciding with half-plane $\varphi = 2\pi$.

Consider now the circular T-wave followed the currents in thin wire winding immersing in the isoimpedance medium with perameabilities (2.6).

Two loops with radii ρ_1 and ρ_2, placed in planes $z = z_1$ and $z = z_2$ are represented at Fig. **2.4,a**.

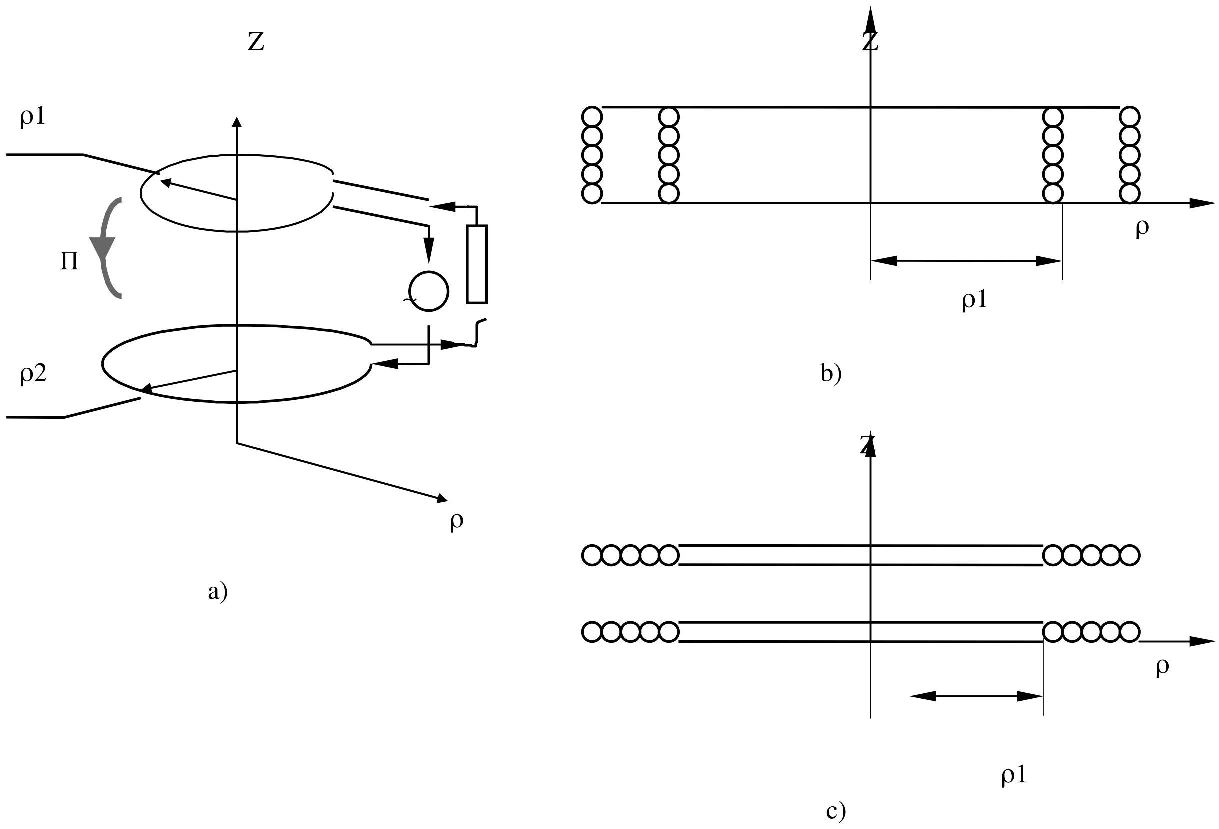


Fig. 2.4

The circular wave is running in direction from generator to load, and an influence on the field of the opposite directed and nearly placed currents in the generator and load may be neglected. In accordance with (2.23), we have equations for field intensities:

$$E_z = Z_0 H_\rho = E_0 \rho_1 \{(z - z_1)\left[\frac{1}{(z - z_1)^2 + (\rho - \rho_1)^2} - \frac{1}{(z - z_1)^2 + (\rho + \rho_1)^2}\right] -$$

$$- (z - z_2)\left[\frac{1}{(z - z_2)^2 + (\rho - \rho_2)^2} - \frac{1}{(z - z_2)^2 + (\rho + \rho_2)^2}\right]\} e^{-jk_o a\varphi}, \qquad (2.25)$$

$$E_\rho = -Z_0 H_z = E_0 \rho_1 [\frac{\rho - \rho_1}{(z - z_1)^2 + (\rho - \rho_1)^2} - \frac{\rho + \rho_1}{(z - z_1)^2 + (\rho + \rho_1)^2} -$$

$$- \frac{\rho - \rho_2}{(z - z_2)^2 + (\rho - \rho_2)^2} + \frac{\rho + \rho_2}{(z - z_2)^2 + (\rho + \rho_2)^2}] e^{-jk_o a\varphi}, \qquad (2.26)$$

where the radius **a** corresponds to cylindrical surface which separate the decelerating area $(\rho < a)$ and the accelerating area $(\rho > a)$ in the infinite isoimpedance medium. In writing formulas (2.25),(2.26) we have taken into account formula (2.23) for $\rho \to 0$ when we have the perfect conductor filament $(\varepsilon \to \infty)$, where, according to (2.25),

$$E_z = 0, E_\rho = -2E_0 \rho_1 \left[\frac{\rho_1}{(z - z_1)^2 + \rho_1^2} - \frac{\rho_2}{(z - z_2)^2 + \rho_2^2}\right] e^{-jk_o a\varphi}.$$

The fields, creating by currents of two cylindrical (Fig.2.4,b) or plane (Fig.2.4,c) windings from **w** turns, are finding with the help of formulae (2.25),(2.26). We have at first case:

$$E = \sum_{n=1}^{w} e^{-jk_o a\varphi_n} E_{zn} = e^{-jk_o a\varphi} \sum_{n=1}^{w} e^{-jk_o a(n-1)2\pi} E_{zn},$$

$$E_\rho = e^{-jk_o a\varphi} \sum_{n=1}^{w} e^{-jk_o a(n-1)2\pi} E_{\rho n}, \text{where} \qquad (2.27)$$

$$E_{zn} = E_0 \rho_1 (z - z_n) \sum_{\nu=1}^{2} \left[\frac{(-1)^{\nu-1}}{(z - z_n)^2 + (\rho - \rho_\nu)^2} - \frac{(-1)^{\nu-1}}{(z - z_n)^2 + (\rho + \rho_\nu)^2}\right]$$

$$E_{\rho n} = E_0 \rho_1 \sum_{\nu=1}^{2} \left[\frac{(-1)^{\nu-1}(\rho - \rho_\nu)}{(z - z_n)^2 + (\rho - \rho_\nu)^2} - \frac{(-1)^{\nu-1}(\rho + \rho_\nu)}{(z - z_n)^2 + (\rho + \rho_\nu)^2}\right], \qquad (2.28)$$

where $z_n = nb$ and number **b** is wire diameter. It was considered in (2.27), (2.28) that the angle coordinate for a turn with number **n** is $\varphi_n = \varphi + 2\pi(n-1)$ where $0 < \varphi < 2\pi$ corresponds to the first turn.

The phasing mode is of interest in its own right when radius **a** of surface $\varepsilon_r = \mu_r = 1$ is chosen according to condition of the "matching" with wavelength $\lambda_0 = c_0 / f$:

$$a = m\lambda_0 / 2\pi. \qquad (2.29)$$

In the case of fulfillment of the equation (2.29), the intensities are maximum because of summation of the uniphase (real) summands (2.28) in the (2.27).

The plane windings application (Fig.2.4,c) is accompanied with formulae (2.27) where, instead of formula (2.28), it is necessary to take

$$E_{zn} = E_0\rho_1 e^{-jk_o a\varphi}\sum_{\nu=1}^{2}\left[\frac{(-1)^{\nu-1}(z-z_\nu)}{(z-z_\nu)^2+(\rho-\rho_n)^2} - \frac{(-1)^{\nu-1}(z-z_\nu)}{(z-z_\nu)^2+(\rho+\rho_n)^2}\right],$$

$$E_{\rho n} = E_0\rho_1 e^{-jk_o a\varphi}\sum_{\nu=1}^{2}\left[\frac{(-1)^{\nu-1}(\rho-\rho_n)}{(z-z_\nu)^2+(\rho-\rho_n)^2} - \frac{(-1)^{\nu-1}(\rho+\rho_n)}{(z-z_\nu)^2+(\rho+\rho_n)^2}\right] \qquad (2.30)$$

In the formulae (2.30) we need to consider the relation $\rho_n = \rho_1 + (n-1)b$.

2.3.3. The sphere-point T-waves may be observed in medium with permeabilities (2.7). If coordinates SBII [56]

$$\xi = x/r^2, \eta = y/r^2, \zeta = z/r^2, h = h_\zeta = r^2 \qquad (2.31)$$

are used, one of simplest waves is T-wave which according (2.23) has intensities

$$E_\xi = Z_0 H_\eta = E_0 a^2 r^{-2} e^{-jk_o a^2\zeta} = E_0 a^2 r^{-2} e^{-jk_o a^2 z/r^2}. \qquad (2.32)$$

The phase fronts are spheres $\zeta = C$ tangenting each other in the point x=y=z=0 (Fig.2.2,b). In accordance with (2.18), (2.19) we have for the velocities $v = v_э = c_0/\varepsilon_r = c_0 r^2/a^2$. Poiting's energy vector lines are circles which are started in point r=0 when z<0 and are finished in same point but when z>0. Since, according to (2.32), the electrical field intensity wave vector is orthogonal to surface $\xi = x/r^2 = C$, that the complete metallization of two these surfaces doesn't affect on the T-wave structure. Hereby, the T-wave will propagate in the screening volume between two spheres $x/r^2 = C_1$ and $x/r^2 = C_2$, which are tangented in the point x=y=z=0 geometrically(but not electrically).

One more example of the sphere-point T-wave we have by using of another SBII class coordinate variant [56], namely:

$$\xi = \ln(a\rho / r^2), \eta = \mathrm{arctg}(y/x), \zeta = z/r^2, h = \rho, h_\zeta = r^2. \qquad (2.33)$$

Surfaces $\xi = C$ are thoroidal ones without hole, immersing each in other so that their common point is x=y=z=0. We have relations for intensities: $E_\xi = Z_0 H_\eta = E_0 a\rho^{-1} e^{-jk_o a^2 z/r^2}$.

2.3.4. The sphere-axis T-waves, transmitted an energy around circle line $\rho = a$ (Fig.2.2,c), may exist in the medium with permeabilities (2.8). Let us use one of SBIII coordinate variant:

$$\xi = \mathrm{Arch}[(r^2 + a^2)/2a\rho], \eta = \mathrm{arctg}(y/x), \cos\zeta = (a^2 - r^2)/\sqrt{(a^2 + r^2)^2 - 4a^2\rho^2}$$

$$h = \rho = a/\mathrm{sh}\xi(\mathrm{cth}\xi - \cos\zeta), h_\zeta = h\,\mathrm{sh}\xi = \sqrt{(a^2 + r^2)^2 - 4a^2\rho^2}/2a. \qquad (2.34)$$

In space between perfect conducting thoroids $\xi = C_1, \xi = C_2$ along lines ζ, i.e. along small radius circles, T-wave is rotating, and it has intensities

$$E_\xi = Z_0 H_\eta = E_0 a\rho^{-1} e^{-jk_o\zeta c^2/2a}, \qquad (2.35)$$

where constant c^2 corresponds to formulae (2.8),(2.20). We have for velocities $v = v_э = c/\varepsilon_r = c_0\sqrt{(r^2 + a^2)^2 - 4a^2\rho^2}/c^2$. Since the consideration of equation (2.20) it was explained that there are exist four variants of values $-^2/a^2$, to which four variants of values $\varepsilon_r(\rho, z) = \mu_r(\rho, z)$ are correspond to the matter filling a space between the thoroids.

It is interesting to excite sphere-axis T-wave with the help of two thoroidal windings, each of them has **w** turns. The turns placement planes are specify with the help of the angle coordinate η from (2.34) as the relation $\eta = \varphi_n = \varphi_1 + (n-1)\Delta\varphi$, where magnitude $\Delta\varphi$ determines wire ratio diameter. Taking into account the demands of symmetry by coordinate ξ and periodical behavior to coordinate η, we have equation , according (2.23):

$$E_\xi - iE_\eta = Z_0(H_\eta + iH_\xi) = E_0 e^{-jk_o c^2\zeta/2a} a\rho^{-1} \times \qquad (2.36)$$

$$\times \sum_{n=1}^{w}\sum_{\nu=1}^{2}(-1)^\nu\{-\mathrm{cth}[\xi - \xi_\nu + i(\eta - \eta_n)] + \mathrm{cth}[\xi + \xi_\nu + i(\eta - \eta_n)]\}.$$

The windings occupy a sector of angles from φ_1 to $\varphi_1 + (w-1)\Delta\varphi$ becoming in all thoroidal windings, when $\varphi_1 = \Delta\varphi, w\Delta\varphi = 2\pi$.

2.3.5. At last, bi-spherical T-waves in medium with permeabilities (2.9) are analyzed with the help of SBIV class coordinates:

$$\xi = \mathrm{Arsh}\frac{r^2 - a^2}{2a\rho}, \eta = \arccos\frac{x}{\rho}, \mathrm{ch}\zeta = \frac{a^2 + r^2}{\sqrt{(r^2 - a^2)^2 + 4a^2\rho^2}},$$

$$h = a / \mathrm{ch}\xi(\mathrm{ch}\zeta - \mathrm{th}\xi), h_\zeta = a /(\mathrm{ch}\zeta - \mathrm{th}\xi). \qquad (2.37)$$

The simplest T-wave transmits an energy along parts of circles $\zeta = \mathrm{var}$ from point x=0, y=0, $z = -a$ to point x=0, y=0, z=a. The field intensities are $E_\xi = Z_0 H_\eta = E_0 \mathrm{ch}\xi(\mathrm{ch}\zeta - \mathrm{th}\xi) e^{-jk_0 c^2 \zeta / 2a}$ where constant c^2 is corresponded to equations(2.9),(2.21).

2.4. Electrical and magnetic waves

2.4.1. The electrical and magnetic waves with plane-parallel fronts are widely used in the microwave waveguides. The sphere-parallel phase fronts are observed for E,H-waves with small radial intensities components radiating by all antennas. Let us now consider four classes of E,H-waves in the isoimpedance media with permeabilities (2.6)-(2.9). The general view formulae (2.10)-(2.14) are justified for all cases, it is necessary only to apply the variable separation method to equation (2.15) in order to have formulae-solutions.

According to variable separation method the equation (2.15) solution is finding as series

$$u(\xi, \eta) = \sum_m \varphi_m(\xi) \psi_m(\eta),$$

that leads to two separate ordinary differential equations

$$\varphi''_\xi + [p(\xi) + m^2]\varphi = 0, \qquad (2.38)$$

$$\psi''_\eta + [q(\eta) - m^2]\psi = 0, \qquad (2.39)$$

if medium and PB,SB coordinate systems variant allow to separate the variables in coefficient $\gamma^2 \varepsilon_r^2 h^2 = \gamma^2 h^2 h_{\zeta C}^2 / h_\zeta^2 = p(\xi) + q(\eta)$.

2.4.2. In coordinates PBII, when $\xi = z, \eta = \rho, h^2 = 1$, and for medium with permeabilities (2.6) we have $p(\xi) = 0, q(\eta) = \gamma^2 a^2 / \eta^2$, hence equation (2.38) solution is $\varphi_m = \exp(\pm jmz / b)$, and equation (2.39) acquires a view

$$\eta^2 \psi''_\eta + (\gamma^2 a^2 - m^2 \eta^2 / b^2)\psi = 0, \qquad (2.40)$$

where unitless character of number **m** is provided with the help of constant **b**. The equation (2.40) solutions are elementary functions [60] for proper transverse wave number γ magnitude. So, for $a^2\gamma^2 = n(1-n)$, where **n**-natural number, we have

$$\psi_m = \rho^n \left(\frac{1}{\rho} \frac{d}{d\rho} \right)^n \left(C_1 e^{m\rho/b} + C_2 e^{-m\rho/b} \right). \qquad (2.41)$$

If $a^2\gamma^2 = -n(1+n)$, that

$$\psi_m = \rho^{n+1} \left(\frac{1}{\rho} \frac{d}{d\rho} \right)^{n+1} \left(C_1 e^{m\rho/b} + C_2 e^{-m\rho/b} \right)$$

The simplest E,H-waves are ones which have intensities non depending from coordinate z, that take place for m=0. In this case equation (2.40) solutions are described by expressions

$$\psi = \sqrt{\rho} \begin{cases} C_1 \cos(\kappa \ln \rho / b) + C_2 \sin(\kappa \ln \rho / b), \kappa^2 = \gamma^2 - 1/4 > 0, \\ C_1 \rho^\kappa + C_2 \rho^{-\kappa}, \kappa^2 = 1/4 - \gamma^2 > 0, \\ C_1 + C_2 \ln(\rho / b), \gamma^2 = 1/4. \end{cases} \qquad (2.42)$$

For example, let us show the calculating relations for circular E,H-waves in coaxial resonator between two perfect conducting cylinders $\rho = \rho_1, \rho = \rho_2$. A boundary condition for electrical waves is $\psi = 0$ for $\rho = \rho_1, \rho = \rho_2$. The simplest E-waves, non depending from coordinate z, in accordance with (2.10),(2.11),(2.40),(2.41), are specified with formulae:

$$E_\varphi = \rho^{-1/2} \sin[\theta(\rho)] e^{-j\beta\rho_2\varphi}, \theta(\rho) = n\pi \ln(\rho/\rho_1) / \ln(\rho_2/\rho_1),$$

$$E_\rho = -\frac{j\beta\rho_2}{\gamma^2} \frac{\partial(\rho E_\varphi)}{\partial\rho}, H = \frac{j\varpi\varepsilon_0\rho_2}{\gamma^2} \frac{\partial(\rho E_\varphi)}{\partial\rho}.$$

The boundary conditions give for transverse and longitudinal wave numbers:

$$\gamma = 2\pi\rho_2 / \lambda_{cr}, \beta = \sqrt{k_0^2 - 4\pi^2 / \lambda_{cr}^2}, \qquad (2.43)$$

where critical wavelength for some **n** (**n**=1,2,...) is number

$$\lambda_{cr} = 2\pi\rho_2 / \sqrt{1/4 + [n\pi/\ln(\rho_2/\rho_1)]^2} . \qquad (2.44)$$

Since consideration of the circular waves in channel waveguides, corresponding to PBII, SBIII classes coordinates, the variation area of variable ζ must be finite $(0 \le \zeta \le 2\pi)$. As untraditional condition we have a demand of circular wave auto-phasing in view of periodicity condition $\beta h_{\zeta C}(\zeta + 2\pi) = \beta h_{\zeta C} + 2\pi$, which for considering E-waves gives

$$\beta\rho_2 = 1. \qquad (2.45)$$

With account (2.43), (2.44) from (2.45) we have for frequency

$$f = c_0\sqrt{(2\pi\rho)^{-2} + \lambda_{cr}^{-2}} . \qquad (2.46)$$

It is not difficult to see that wavelength $\lambda_0 = -_0 / f$ for auto-phasing frequency (2.46) satisfy the condition $\lambda_0 < \lambda_{cr}$.

For paraboloidal coordinate system from class PBII, specifying with formulae $(\xi + i\eta)^2 = 2(z + i\rho), \zeta = \mathrm{arctg}(y/x)$, we obtain
$h_{\zeta C}^2 h^2 / h_\zeta^2 = a^2(1/\xi^2 + 1/\eta^2), p(\xi) = \gamma^2 a^2/\xi^2, q(\eta) = \gamma^2 a^2/\eta^2$,

hence both equations (2.38),(2.39) have a view likes the equation (2.40). As for expression $\varphi(\xi)$ finding so as for $\psi(\eta)$, we can use formulae (2.41),(2.42). The boundary surfaces for the E,H waves are paraboloids of rotation $\xi = C$ or $\eta = C$

Third coordinate system from class PBII, introducing with the help of relations $(z + i\rho)/a = \sin(\xi + i\eta), \zeta,$ has the relation

$$h_{\zeta C}^2 h^2 / h_\zeta^2 = a^2(1/\cos^2\xi + 1/\mathrm{sh}^2\eta),$$

therefore equations (2.38),(2.39) acquire a view:

$$\varphi_\xi'' + (m^2 + \gamma^2 a^2/\cos^2\xi)\varphi = 0, \psi_\eta'' + (-m^2 + \gamma^2 a^2/\mathrm{sh}^2\eta)\psi = 0. \qquad (2.47)$$

In some cases the equations (2.47) solutions are writing as simple expressions [60]. So, if transverse number γ is chosen from condition $\gamma^2 a^2 = n(1-n)$, where **n**-natural number, we have

$$\varphi_m = \cos^n\xi\left(\frac{1}{\cos\xi}\frac{d}{d\xi}\right)^n\left(C_1 e^{\xi\sqrt{-m}} + C_2 e^{-\xi\sqrt{-m}}\right). \qquad (2.48)$$

Note, that the coordinate surfaces $\xi = C$ are hyperboloids of rotation and $\eta = C$ are lengthen ellipsoids of rotation.

One more coordinate system from class PBII, when $(\rho + iz)/a = \sin(\xi + i\eta)$, determines surfaces $\xi = C$ as hyperboloids of rotation, and $\eta = C$ are oblate ellipsoids of rotation. The coefficients in equation (2.5) are $\gamma^2 h_{\zeta C}^2 h^2 / h_\zeta^2 = \gamma^2 a^2 (1/\sin^2\xi - 1/ch^2\eta)$. Hereby obtained equations (2.38), (2.39) are similar by view to equations (2.47) that allows to use formulae (2.48).

2.4.3. The sphere-point E,H-waves research is making with coordinates SBII participation specifying by means of formulae (2.31),(2.33). In first case $h^2/h_\zeta^2 = 1, h_{\zeta C}^2 = a^2$, hence equations (2.38),(2.39) are

$$\varphi''_\xi + (\gamma^2 a^2 + m^2)\varphi = 0, \psi''_\eta - m^2\psi = 0. \quad (2.49)$$

The equations (2.49) have constant coefficients, therefore the solutions are exponential functions. According to coordinates (2.33) we have $h_{\zeta C}^2 h^2 / h_\zeta^2 = a^4\rho^2 / r^4 = a^2 e^{2\xi}$, and the equation (2.38) is the following:

$$\varphi''_\xi + (\gamma^2 a^2 e^{2\xi} + m^2)\varphi = 0, \quad (2.50)$$

but equation for $\psi(\eta)$ looks like as in formulae (2.49). For m=0, the equation (2.50) solutions are expressing with the help of the elementary functions, and for $m \neq 0$ it is necessary to use Bessel's functions [60].

2.4.4. The class of SBIII coordinates, given by formulae (2.34), is used for the sphere-axis E,H-waves analysis. As $h^2/h_\zeta^2 = 1/sh^2\xi, h_{\zeta C} = c^2/2a$ the equations (2.38),(2.39) are:

$$\varphi''_\xi + (m^2 + \gamma^2 c^4 / 4a^2 sh^2\xi)\varphi = 0, \psi''_\eta - m^2\psi = 0. \quad (2.51)$$

The choice of constant c^2/a^2 may be different that was explained for formulae (2.8),(2.20). The first equation from (2.51) is similar to second equation from (2.47).

2.4.5. In class SBIV coordinates the bi-spherical E,H-waves are specified. With account of relations $h^2/h_\zeta^2 = 1/ch^2\xi$, $h_{\zeta C} = c^2/2a$ equations (2.38),(2.39) are obtained in view

$$\varphi''_{\xi} + (m^2 + \gamma^2 c^4 / 4a^2 ch^2\xi)\varphi = 0, \psi''_{\eta} - m^2\psi = 0. \qquad (2.52)$$

The equations (2.52) analysis is similar to equation (2.51) one.

Therefore, at least, for shown coordinate systems variants (four from class PBII, two from class SBII, one from classes SBIII, SBIV) analysis of E,H-waves in corresponding isoimpedance media we may do entirely with the help of (2.10)-(2.14) because variables separation method is applied to equation (2.15).

2.5.Media with factorizied permittivity/permeability ratio

2.5.1. The generalization of relations (2.4)-(2.9) is the following equations for permeability and perrmittivity:

$\mu / \varepsilon = A(\zeta)B(\xi, \eta)$, (2.53)

$$\varepsilon = \alpha^e(\zeta)\beta^e(\xi,\eta) / h_{\zeta}(\xi,\eta,\zeta), \mu = \alpha^m(\zeta)\beta^m(\xi,\eta) / h_{\zeta}, \qquad (2.54)$$

which we shall consider in six classes of PB,SB coordinate systems. In accordance with (2.54), in classes of the PBI,PBII,SBI coordinates we have factorization for permittivity and permeability separately. It is not justified for the media, describing in SBII-SBIV coordinates, due to impossibility to do factorization of Lame's coefficient $h_{\zeta}(\xi,\eta,\zeta)$. Shown media allow the existence of new wave variants that below will be represented as generalization of results for global plane and sphere waves.

If to determine any wave type impedance as electrical and magnetic fields intensities transverse components ratio, the considering media may be called ones with factorizied impedances. It take place as due to relation (2.53) so due to Lame's coefficients property $h_{\xi} = h_{\eta} = h$ for transverse coordinates of PB,SB systems.

The reference of these media to binary ones is owed to relation(2.53) which will be further specified when functions $\alpha^{e,m}(\zeta), \beta^{e,m}(\xi,\eta)$ will be determined on dependence of propagating wave type.

Let us now consider the general investigation of classical problem about possibility of scalarization of the electrodynamical vector equations.

2.5.2. The scalarization problem is one of transformation of Maxwell's equations system into separate equations for field vectors coordinates components which for homogeneous media had been considered by Abraham, Bromwhich, Debau [64]. Let us research the problem for generalized media with permeabilities (2.54). We are starting from Maxwell's equations system, which is wrote for calculating intensities vectors components $E_\nu, H_\nu (\nu = \xi, \eta, \zeta)$, which linearly depend on physically existing components E_ν, H_ν:

$E_\nu = h_\nu E_\nu, H_\nu = h_\nu H_\nu$,

where h_ν-Lame's coefficients $(h_\xi = h_\eta = h = p(\xi, \eta) h_\zeta$). Namely:

$$\frac{\partial H_\zeta}{\partial \eta} - \frac{\partial H_\eta}{\partial \zeta} - j\omega\kappa^e E_\xi = 0, \qquad \frac{\partial H_\xi}{\partial \zeta} - \frac{\partial H_\zeta}{\partial \xi} - j\omega\kappa^e E_\eta = 0,$$

$$\frac{\partial H_\eta}{\partial \xi} - \frac{\partial H_\xi}{\partial \eta} - j\omega p^2 \kappa^e E_\zeta = 0, \quad \frac{\partial E_\zeta}{\partial \eta} - \frac{\partial E_\eta}{\partial \zeta} + j\omega\kappa^m H_\xi = 0,$$

$$\frac{\partial E_\xi}{\partial \zeta} - \frac{\partial E_\zeta}{\partial \xi} + j\omega\kappa^m H_\eta = 0, \frac{\partial E_\eta}{\partial \xi} - \frac{\partial E_\xi}{\partial \eta} + j\omega p^2 \kappa^m H_\zeta = 0,$$

$$\begin{aligned} &\left(\kappa^e E_\xi\right)'_\xi + \left(\kappa^e E_\eta\right)'_\eta + p^2 \left(\kappa^e E_\zeta\right)'_\zeta = 0, \\ &\left(\kappa^m H_\xi\right)'_\xi + \left(\kappa^m H_\eta\right)'_\eta + p^2 \left(\kappa^m H_\zeta\right)'_\zeta = 0, \end{aligned} \tag{2.55}$$

where, for permittivity and permeability of medium, formulae (2.54) were taken into account and also denotations are used:

$$\kappa^e = h_\zeta \varepsilon = \alpha^e(\zeta)\beta^e(\xi, \eta), \kappa^m = h_\zeta \mu = \alpha^m(\zeta)\beta^m(\xi, \eta). \tag{2.56}$$

The scalarization procedure will be discovered the most evident after creation from transverse components E_ξ, E_η and H_ξ, H_η the complex-spatial transverse intensities (binary ones) $E = E_\eta + iE_\xi, H = H_\eta + iH_\xi$ which are functions of longitudinal coordinate ζ and complex variables $\gamma = \xi + i\eta, \bar{\gamma} = \xi - i\eta$. Let us collect from eight equations (2.55) the four systems of pairs:

$$\frac{\partial E_\eta}{\partial \xi} - \frac{\partial E_\xi}{\partial \eta} = -j\omega\kappa^m p^2 H_\zeta, \frac{\partial(\kappa^e E_\xi)}{\partial \xi} + \frac{\partial(\kappa^e E_\eta)}{\partial \eta} = -p^2 \frac{\partial(\kappa^e E_\zeta)}{\partial \zeta}, \tag{2.57}$$

$$\frac{\partial H_\eta}{\partial \xi} - \frac{\partial H_\xi}{\partial \eta} = j\omega\kappa^e p^2 E_\zeta, \frac{\partial(\kappa^m H_\xi)}{\partial \xi} + \frac{\partial(\kappa^m H_\eta)}{\partial \eta} = -p^2 \frac{\partial(\kappa^m H_\zeta)}{\partial \zeta}, \tag{2.58}$$

$$\frac{\partial E_\eta}{\partial \zeta} - j\omega\kappa^m H_\xi = \frac{\partial E_\zeta}{\partial \eta}, \frac{\partial E_\xi}{\partial \zeta} + j\omega\kappa^m H_\eta = \frac{\partial E_\zeta}{\partial \xi}, \tag{2.59}$$

$$\frac{\partial H_\eta}{\partial \zeta} + j\omega\kappa^e E_\xi = \frac{\partial H_\zeta}{\partial \eta}, \frac{\partial H_\xi}{\partial \zeta} - j\omega\kappa^e E_\eta = \frac{\partial H_\zeta}{\partial \xi}. \tag{2.60}$$

With using of known complex derivation symbols

$$2\partial/\partial\gamma = \partial/\partial\xi - i\partial/\partial\eta, 2\partial/\partial\bar{\gamma} = \partial/\partial\xi + i\partial/\partial\eta,$$

we exchange each pair from (2.57)-(2.60) with one complex equation:

$$2E'_{\bar{\gamma}} + (\ln\kappa^e)'_{\bar{\gamma}}E - (\ln\kappa^e)'_\gamma\bar{E} = -j\omega\kappa^m p^2 H_\zeta - ip^2(\kappa^e E_\zeta)'_\zeta/\kappa^e, \tag{2.61}$$

$$2H'_{\bar{\gamma}} + (\ln\kappa^m)'_{\bar{\gamma}}H - (\ln\kappa^m)'_\gamma\bar{H} = j\omega\kappa^e p^2 E_\zeta - ip^2(\kappa^m H_\zeta)'_\zeta/\kappa^m, \tag{2.62}$$

$$E'_\zeta + ij\omega\kappa^m H = 2i(E_\zeta)'_\gamma, \tag{2.63}$$

$$H'_\zeta - ij\omega\kappa^e E = 2i(H_\zeta)'_\gamma. \tag{2.64}$$

Consequently, the scalarization problem is recognized as problem of Maxwell's equations system (2.61)-(2.64) transformation in separate equations for four intensities calculating components E_ζ, H_ζ, E, H with account, if it will be need, the boundary conditions. It is possible to recognize a problem variant when it is sufficient to have the separate equations for E_ζ, H_ζ, assuming presence of function E_ζ, as known solution, in the equation for E.

2.5.3. Let us, at first, make the equations (2.61)-(2.64) research for T-waves when $E_\zeta = 0, H_\zeta = 0$. From (2.61),(2.62) we have the system

$$2E'_{\bar{\gamma}} + (\ln\kappa^e)'_{\bar{\gamma}}E - (\ln\kappa^e)'_\gamma\bar{E} = 0, 2H'_{\bar{\gamma}} + (\ln\kappa^m)'_{\bar{\gamma}}H - (\ln\kappa^m)'_\gamma\bar{H} = 0, \tag{2.65}$$

and from (2.63),(2.64)we obtain:

$$E'_\zeta + ij\omega\kappa^m H = 0, H'_\zeta - ij\omega\kappa^e E = 0. \tag{2.66}$$

The general expressions (2.56) will be used after analysis of a simpler ones.

a). At first, they have to be the constants: $\kappa^e = \varepsilon_0 h_{\zeta C}, \kappa^m = \mu_0 h_{\zeta C}$. With these values the equations (2.65),(2.66) solutions are described with the help of formula $E = iZ_0 H = e^{-jk_0 h_{\zeta C}\zeta} W(\gamma)$ which determines all six classes of T-waves in homogeneous and inhomogeneous isoimpedance media, when $\varepsilon_r = \mu_r = h_{\zeta C}/h_\zeta$.

b). Let us consider auxiliary functions κ^e, κ^m which are depended from the longitudinal coordinate ζ only: $\kappa^e = \kappa^e(\zeta), \kappa^m = \kappa^m(\zeta)$. The electrical and magnetic fields dependence from transverse coordinates will be same since

$$E = iZ(\zeta)H = W(\gamma)L(\zeta) = Z(\zeta)[M(\zeta)W(\gamma)], \quad (2.67)$$

where $Z = L(\zeta)/M(\zeta) = E/iH$ performs a role of medium impedance for T-wave. Substitution of (2.67) in (2.66) leads to two differential equations of second order:

$$(L'_\zeta/\kappa^m)'_\zeta + \omega^2\kappa^e L = 0, (M'_\zeta/\kappa^e)'_\zeta + \omega^2\kappa^m M = 0. \quad (2.68)$$

These equations will have varying coefficients if at least one of functions κ^e, κ^m is not constant. Note that in literature [46,47] waves in the inhomogeneous media are described with Cartesian or spherical coordinates only, when $\zeta = z$ or $\zeta = r$, and a medium has only inhomogeneous permittivity $\varepsilon_r = \kappa^e(\zeta)/\varepsilon_0$.

Especially we consider the isoimpedance medium with parameters

$$\varepsilon_r = \mu_r = \kappa^e(\zeta)/\varepsilon_0 h_\zeta = \kappa^m(\zeta)/\mu_0 h_\zeta. \quad (2.69)$$

The relations (2.69) are more general than equations (2.6)-(2.9). Hereby from system (2.68) we obtain one equation:

$$(L'_\zeta/\kappa^e)'_\zeta + [\omega^2\mu_0\kappa^e(\zeta)/\varepsilon_0]L = 0. \quad (2.70)$$

According to (2.70), a dependence on the longitudinal coordinate ζ for new T-waves in the isoimpedance medium may be taken arbitrarily differing from function $\exp(-jk_0 h_{\zeta C}\zeta)$. It is necessary to give desired function $L = L(\zeta)$ for (2.67), and than we consider equation (2.70) as nonlinear differential equation of first order for $\kappa^e(\zeta)$ which will be used in (2.69) during binary material realization. Phase fronts $\zeta = C$ (Fig.2.1,2.2) are caused by previous relations $\zeta = \zeta(x, y, z)$ but field intensities are non- exponential functions of variable ζ.

c) Let the relations $\kappa^e = \kappa^e(\xi, \eta), \kappa^e\kappa^m = \varepsilon_0\mu_0 h^2_{\zeta C}$ take place and medium parameters are equal:

$$\varepsilon_r = \kappa^e(\xi,\eta)/\varepsilon_0 h_\zeta(\xi,\eta,\zeta), \mu_r = \varepsilon_0 h^2_{\zeta C}/\kappa^e(\xi,\eta)h_\zeta(\xi,\eta,\zeta). \quad (2.71)$$

The fields intensities are obtaining in accordance with formula

$$E = e^{-jk_0 h_{\zeta C}\zeta} W(\gamma,\bar{\gamma}) = iZ(\xi,\eta)H, \tag{2.72}$$

where impedance Z depends on transverse coordinates ξ, η only:

$$Z = h_{\zeta C}\sqrt{\varepsilon_0\mu_0} / \kappa^e(\xi,\eta) = \kappa^m / h_{\zeta C}\sqrt{\varepsilon_0\mu_0} = Z_0\sqrt{\mu_r/\varepsilon_r}. \tag{2.73}$$

The complex potential $W = W(\gamma,\bar{\gamma})$ is generalized analytical function of two complex variables $\gamma,\bar{\gamma}$ satisfying the equation

$$2W'_{\bar{\gamma}} + (\ln\kappa^e)'_{\bar{\gamma}}W - (\ln\kappa^e)'_{\gamma}\overline{W} = 0. \tag{2.74}$$

Therefore, one taken real variable function $\kappa^e = \kappa^e(\xi,\eta)$ determines according to (2.71) binary medium parameters. Appropriate T-wave is described with formulae (2.72), (2.74) having according to (2.73) the transverse-inhomogeneous impedance.

d). The great variety of T-waves variants is possible in medium which has the parameters with arbitration for two functions:

$\varepsilon_r = \alpha(\zeta)\beta(\xi,\eta)/\varepsilon_0 h_\zeta, \mu_r = \alpha\varepsilon_0 h_{\zeta C}^2 / h_\zeta\beta$. For intensities E, H and impedance Z we have relationships

$E = L(\zeta)W(\gamma,\bar{\gamma}) = iZ(\xi,\eta)H$, $Z = h_{\zeta C}\sqrt{\varepsilon_0\mu_0}/\beta(\xi,\eta)$, where

$L = \exp[-jk_0 h_{\zeta C}\int_0^{\zeta}\alpha(\zeta)d\zeta]$ and generalized analytical function $W(\gamma,\bar{\gamma})$ is solution of the equation $2W'_{\bar{\gamma}} + (\ln\beta)'_{\bar{\gamma}}W - (\ln\beta)'_{\gamma}\overline{W} = 0$.

2.5.4. Let us pass to consideration of E,H-waves in the infinite media starting from known results. For the homogeneous medium $\varepsilon_r = \mu_r = 1$, and application of arbitrary cylinder or conical coordinates (PBI,SBI) is accompanied with independance κ^e, κ^m from ξ, η. The equations (2.61)-(2.64) became essentially simpler, and we have traditional technique of E,H,EH-waves investigation. Note that a using of common relation $h = h_\zeta p(\xi,\eta)$ for all six coordinate systems classes are corresponded the choice of the relation $\zeta = \ln(r/r_0), h_\zeta = r$ in the conical coordinates.

Abraham's potentials [64] are appropriated to fields, non-depending on coordinate ζ, and to coordinate systems, all Lame's coefficients of which also don't depend on ζ. Last condition take place for cylinder coordinates (PBI) and coordinates of rotation (PBII) only. Deriving (2.61), (2.62) by γ and substituting (2.63) in (2.62) and (2.64) in (2.61) we have separate equations for E, H:

$$4[E'_{\bar{\gamma}}/\mu h_\zeta]'_\gamma + 2\{[(\varepsilon h_\zeta)'_{\bar{\gamma}}E - (\varepsilon h_\zeta)'_\gamma \overline{E}]/\varepsilon\mu h_\zeta^2\}'_\gamma + \omega^2\mu\varepsilon h_\zeta E = 0 \qquad (2.75)$$

$$4[H'_{\bar{\gamma}}/\varepsilon h_\zeta]'_\gamma + 2\{[(\mu h_\zeta)'_{\bar{\gamma}}H - (\mu h_\zeta)'_\gamma \overline{H}]/\varepsilon\mu h_\zeta^2\}'_\gamma + \omega^2\mu\varepsilon h_\zeta H = 0. \qquad (2.76)$$

The equations (2.75), (2.76) generalize Abraham's results for fields in the transverse-inhomogeneous media with $\varepsilon = \varepsilon(\xi,\eta), \mu = \mu(\xi,\eta)$.

New variants of scalarization problem solutions take place if to use the formulae (2.56) when are valid the relation

$$\beta^e\beta^m = h_{\zeta C}^2 = \text{const}. \qquad (2.77)$$

Deriving (2.63) and taking into account (2.61),(2.62),(2.77) we have :

$$4(E_\zeta)''_{\gamma\bar{\gamma}} + \omega^2\alpha^m\alpha^e h_{\zeta C}^2 p^2 E_\zeta + p^2[(\alpha^e E_\zeta)'_\zeta/\alpha^e]'_\zeta +$$
$$+ (\ln\beta^e)'_\xi(E_\zeta)'_\xi + (\ln\beta^e)'_\eta(E_\zeta)'_\eta = 0. \qquad (2.78)$$

Similarly, from (2.64),(2.61),(2.62),(2.77) we have equation for H:

$$4(H_\zeta)''_{\gamma\bar{\gamma}} + \omega^2\alpha^m\alpha^e h_{\zeta C}^2 p^2 H_\zeta + p^2[(\alpha^m H_\zeta)'_\zeta/\alpha^m]'_\zeta +$$
$$+ (\ln\beta^m)'_\xi(H_\zeta)'_\xi + (\ln\beta^m)'_\eta(H_\zeta)'_\eta = 0. \qquad (2.79)$$

Additional analysis shows that the equations (2.78),(2.79) are justified not only with fulfillment of condition (2.77) but and from relations:

$$\beta^e\beta^m = f(\xi), E_\eta = 0, H_\eta = 0.$$

The scalarization procedure variants variety according to shown formulae is very great. At first, it is caused by possibility of application of any variants from six PB,SB coordinate systems, i.e. of six infinite collections of variables ξ,η,ζ. At second, beside fields analysis for homogeneous media, one can to research fields in the inhomogeneous media having the representation (2.54) for parameters which by using of appropriate PB,SB systems are the following:

$$\text{PBI}.\ \varepsilon = \alpha^e(z)\beta(x,y), \mu = \alpha^m(z)/\beta(x,y),$$

$$\text{PBII}.\ \varepsilon = \alpha^e(\varphi)\beta(\rho,z)h_{\zeta C}/\rho, \mu = \alpha^m(\varphi)h_{\zeta C}/\rho\beta(\rho,z),$$

$$\text{SBI}.\ \varepsilon = \alpha^e(r)h_{\zeta C}\beta(\theta,\varphi)/r, \mu = \alpha^m(r)h_{\zeta C}/r\beta(\theta,\varphi),$$

$$\text{SBII} - \text{SBIV}.\ \varepsilon = \alpha^e(\zeta)\beta(\xi,\eta)h_{\zeta C}[\vartheta(\zeta) + \sigma(\xi,\eta)],$$

$$\mu = \alpha^{m}(\zeta)h_{\zeta C}[\vartheta(\zeta) + \sigma(\xi,\eta)]/\beta(\xi,\eta), \tag{2.80}$$

where ϑ, σ - the concrete functions [56].

The equations for transverse components, in contrast to (2.78),(2.79), don't become in general case the separate ones. For example, for transverse components we have:

$$4(\beta^{э}E'_{\gamma}/p^{2})'_{\gamma} + \beta^{э}\alpha^{“}(E'_{\zeta}/\alpha^{“})'_{\zeta} + 2[(E\beta^{э\prime}_{\bar{\gamma}} - \bar{E}\beta^{э\prime}_{\gamma})/p^{2}]'_{\gamma} +$$
$$+ h^{2}_{\zeta C}\omega^{2}\kappa^{э}\alpha^{“}E = 2i\{\alpha^{“}\beta^{э}[(E_{\zeta})'_{\gamma}/\alpha^{“}]'_{\zeta} - [\beta^{э}(\alpha^{э}E_{\zeta})'_{\zeta}]'_{\gamma}/\alpha^{э}\}, \tag{2.81}$$

where in right part the longitudinal component is present as known solution of equation (2.78). But if

$$\beta^{e} = \beta^{m} = h_{\zeta C}, \alpha^{e}\alpha^{m} = \varepsilon_{0}\mu_{0}, \tag{2.82}$$

the equations for E, H also will be separate ones. Note that to earlier investigated circular waves the equations (2.82) are corresponded when $\alpha^{e} = \varepsilon_{0}, \alpha^{m} = \mu_{0}$.

Let us see the most important cases when all calculating intensities are faxtorizied functions relatively to longitudinal ζ and transverse ξ, η coordinates. The representation

$$E_{\zeta} = L_{\zeta}(\zeta)T_{\zeta}(\xi,\eta), H_{\zeta} = L^{“}_{\zeta}(\zeta)T^{“}_{\zeta}(\xi,\eta) \tag{2.83}$$

for longitudinal components is allowed by equations (2.78),(2.79). Substitution (2.83) in (2.61)-(2.64) gives the factorization for transverse components:

$$E = L(\zeta)T(\xi,\eta), H = L^{“}(\zeta)T^{“}(\xi,\eta),$$

if functions α^{e}, α^{m} are interrelated:

$$\alpha^{e}(\zeta)\alpha^{m}(\zeta) = \varepsilon_{0}\mu_{0}. \tag{2.84}$$

With account (2.84) one can to obtain from (2.63),(2.64) a system of algebraic equations for T, T^{M} finding if functions T_{ζ}, T^{M}_{ζ} are known. Similarly, from (2.61),(2.62) we have system of algebraic equations for finding of T_{ζ}, T^{M}_{ζ}, if functions T, T^{M} are known. Hence, there are possible to use two algorithm of field vectors components finding: longitudinal-transverse sequence and transverse-longitudinal sequence. According to first of them initially the longitudinal components must be find as a solution of boundary problem for (2.78),(2.79), and then from (2.63),(2.64) we have transverse components. According to second algorithm it is necessary to find transverse components as solutions of equations

$$4(E'_{\bar{\gamma}}/p^2)'_{\gamma} + \alpha^m (E'_{\zeta}/\alpha^m)'_{\zeta} + \omega^2 \varepsilon_0 \mu_0 h^2_{\zeta C} E = 0, \quad (2.85)$$

$$4(H'_{\bar{\gamma}}/p^2)'_{\gamma} + \alpha^e (H'_{\zeta}/\alpha^e)'_{\zeta} + \omega^2 \varepsilon_0 \mu_0 h^2_{\zeta C} H = 0, \quad (2.86)$$

which are coming from (2.81),(2.82), and to obtain longitudinal components E_{ζ}, H_{ζ} from (2.61),(2.62). First algorithm action area is more broad because it is accompanied with conditions (2.77),(2.84) which give more functions β^e, β^m than conditions (2.82), working for second algorithm. It is necessary to take into account boundary conditions equations.

2.5.6. We are going to account of boundary conditions: for surface of two magnetodielectrics separation

$$\vec{n} \times (\overline{E}^+ - \overline{E}^-) = 0, \vec{n} \times (\overline{H}^+ - \overline{H}^-) = 0, \quad (2.87)$$

or for perfect conductor surface

$$\text{h} \times \overline{E} = 0. \quad (2.88)$$

It is necessary to consider as boundary $\zeta = C$, which is plane or sphere, so six infinite collections of surfaces $\xi = C$. In problem with perfect conductor the boundary condition (2.87) for $\zeta = C$ is $E_{\Gamma} = 0$, which according to (2.57) is accompanied with equation $H_{\zeta\Gamma} = 0$. Besides, we have from (2.64) $H'_{\zeta} = 0$ and from (2.61) also $(\alpha^e E_{\zeta})'_{\zeta} = 0$. Each of equations (2.78),(2.79),(2.85),(2.86) will have own boundary condition.

For conjunction problem from conditions (2.87) and Maxwell's equations we have also separate boundary continuation equations as the relations: $E^+ = E^-, H^+ = H^-, \mu^+ H^+_{\zeta} = \mu^- H^-_{\zeta}, \varepsilon^+ E^+_{\zeta} = \varepsilon^- E^-_{\zeta}$. For shown problems both algorithms of fields analysis are equal.

Let us come to great variety of problems with boundaries $\xi = C$ from PB,SB coordinate systems. For perfect conductor from (2.88),(2.57)-(2.60) we have: $H_{\xi} = 0, (H_{\eta})'_{\xi} = 0, E_{\eta} = 0, (\beta^e E_{\xi})'_{\xi} = 0; E_{\zeta} = 0, (H_{\zeta})'_{\xi} = 0$.

The longitudinal-transverse sequence algorithm of field analysis is more used in comparison with the transverse-longitudinal one only due to weak application of complex spatial intensities and generalized analytical variables $\gamma, \bar{\gamma}$ functions technique. The conjunction problem investigation shows that the transverse-longitudinal sequence algorithm is more convenient than second one because transverse components are accompanied with independent boundary conditions but boundary equations for longitudinal components contain else transverse components.

CHAPTER 3. REALIZATION AND APPLICATION OF THE ISOIMPEDANCE MATERIALS

3.1. Metal-air realization of magnetodielectrics

3.1.1. The medium permittivity and permeability may be determined by means of two methods: a) quasi static, b) wave. According to first of them, one finds a matter polarization **P** in the electrical field and a magnetizing **M** in the magnetic field, after all we have:

$$\varepsilon_r = 1 + P / E\varepsilon_0 \ , \ \mu_r = 1 + M / H\mu_0 . \tag{3.1}$$

According to second method, it is assumed that wave is propagating in the medium along coordinate ζ , having for intensities transverse components the representations:

$$E_\perp = E_m(\xi,\eta)e^{j(\omega t - \beta\zeta)}, \ H_\perp = E_m Z_c^{-1} e^{j(\omega t - \beta\zeta)}, \tag{3.2}$$

where β- longitudinal wave number, ξ,η- transverse coordinates, Z_C- wave impedance of media for this wave. Particularly, in the homogeneous medium a wave is running along straight-line z. Relations

$$Z_c = Z_0 = \sqrt{\mu_0 / \varepsilon_0}, \ \omega/\beta = \omega/k_0 = 1/\sqrt{\mu_0\varepsilon_0} , \tag{3.3}$$

acting for field in vacuum, may be remained and for field (3.2) in considering medium so that relations between parameters are given:

$$\sqrt{\mu / \varepsilon} = Z_c, \ \sqrt{\mu\varepsilon} = \beta / \omega . \tag{3.4}$$

From (3.2)-(3.4) we obtain the calculating formulae:

$$\varepsilon_r = n / z_c, \quad \mu_r = n z_c , \tag{3.5}$$

where refraction coefficient n and ratio impedance z_c will be known:

$$n = c_0\beta / \omega, \ z_c = E_\perp / H_\perp Z_0, \tag{3.6}$$

if to find the field (3.2).

In special cases only, the influence on medium with the help of static fields or of wave (3.2) may give a coincidence of results, has been obtained with the help of (3.1) and (3.5).

In accordance with two methods of measurement, there are two techniques of artificial creation of magnetodielectrics (MD) with $\varepsilon_r \neq 1, \mu_r \neq 1$. The First of them is based on representation about electrical and magnetic dipoles which may be realized as discrete conducting elements (small plates, loops) [37-43,61]. The second method deals with the investigation of waves guiding by metal strips, waveguides and so on. The quasi static and wave techniques of media realization we shall consider further separately with regard of the media classification given in the Table 1.

In rows 5,6 as homogeneous so inhomogeneous media are assumed to be the isoimpedance ones, i.e. $\varepsilon_r(x,y,z)=\mu_r(x,y,z)$. The rows 7,8 are correspond to media where wave may to have constant velocity [5], when $\varepsilon_r\mu_r = 1$.

Table 1.

№	Medium	ε_r	μ_r	n	z_c
1	Decelerating dielectric	>1	1	>1	<1
2	Accelerating dielectric	<1	1	<1	>1
3	Accelerating magnetic	1	<1	<1	<1
4	Decelerating magnetic	1	>1	>1	>1
5	Decelerating MD	>1	>1	>1	1
6	Accelerating MD	<1	<1	<1	1
7	MD with small impedance	>1	<1	1	<1
8	MD with great impedance	<1	>1	1	>1

The interest to metal-air MD realization based on the property of the good conducting metals having the electrical current without delay in total frequency band from beginning to 10^{15} Hz which contains visible light area also. It takes place due to unique small mass of electron and its mobility in metal.

3.1.2. Let us consider the quasi static technique of media realizations for cases given in the Table 1.

1. Decelerating dielectric $(\varepsilon_r > 1, \mu_r = 1)$ realization with the help of small dimension metal bodies (spheres, rods, disks and so on) are known else from twenties years. The results of calculations ε_r, when different configuration elements have been used, are represented in [37,61]. In some cases it is necessary to take into account the effect of alternating magnetic field action which leads to reduction of equivalent permeability $(\mu_r < 1)$.

2. The quasi static method may to used for accelerating dielectric realization $(\varepsilon_r < 1, \mu_r = 1)$ also. It is necessary to describe this procedure in detail because the appropriate information in literature is absent. Let there be given electrically short metal rod with length $l << \lambda$ is placed in the electrical field of capacitor (Fig.3.1,a).

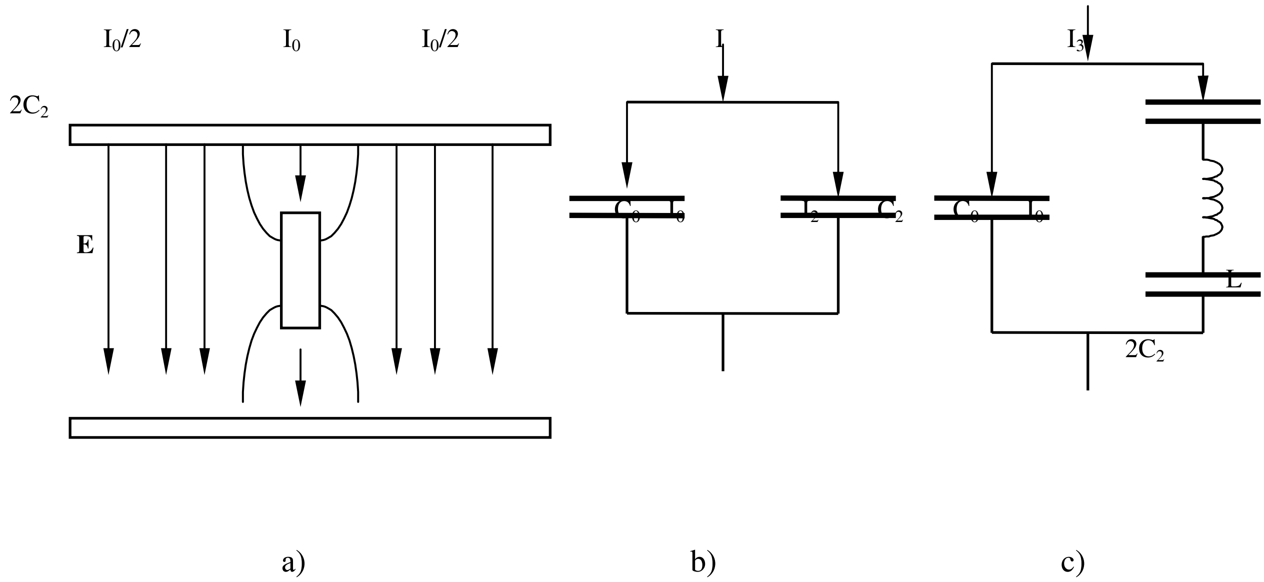


Fig. 3.1

The current through capacitor consist of the current $I_0 = j\omega C_0 U$, non-depending from presence or absence of rod, and the current $I_2 = j\omega C_2 U$ which is equal to displacement current in area of rod position (Fig.3.1,b). When the rod was absent we have instead of I_2 current $I_1 = j\omega C_1 U$ where $C_1 < C_2$. Therefore, application of rod is equal to the increasing of ε_r. These consideration else are correspond to above mentioned case of decelerating dielectric.

Let us divide the rod at two parts and inset between them lumped inductance L (Fig.3.1,c). Instead of current I_2 the current $I_3 = j\omega U C_2 (1 - \omega^2 / \omega_0^2)$ will flow, where $\omega_0 = 1/\sqrt{LC_2}$. The current I_3 remains capacitive one on frequencies $\omega < \omega_0$ but will be inductance one if inequality $\omega > \omega_0$ is provided. Hence for full current of capacitor by $\omega > \omega_0$ we shall have difference $|I_0| - |I_3|$.Therefore, accelerating dielectric creation consist of application of great number of small rods with additional inductances L which for $\omega > \omega_0$ provide for equivalent permittivity an implementation of inequality $\varepsilon_r < 1$, i.e. $n = c_o / v < 1$.

3. The accelerating magnetic must to have $\varepsilon_r = 1$, $\mu_r < 1$, that is provided with help of small short-circuited turns from perfect conducting metal. According to Faraday's law, induced emf causes a current which creates magnetic field with opposite direction relatively to primary magnetic field.

4. The decelerating magnetic $(\mu_r > 1, \varepsilon_r = 1)$ may be created with the help small turns, each of them is loaded with lumped capacity C. The resonance frequency of this loop $\omega_0 = 1/\sqrt{LC}$ is used in condition $\omega > \omega_0$ when current in the loop corresponds to above shown case of the accelerating magnetic. If, on the contrary, to provide $\omega < \omega_0$, the current in loop will change its direction at opposite one, and magnetic will become decelerating one.

5. Decelerating magnetodielectric $(\varepsilon_r > 1, \mu_r > 1)$ may be created by means of combination of metal elements which have been described above for decelerating dielectric and decelerating magnetic realizations (variants 1 and 4). It is necessary to take into account earlier shown condition $\omega < \omega_0$.

6. Accelerating magnetodielectric $(\varepsilon_r < 1, \mu_r < 1)$ is made with application of elements corresponding to variants 2,3.

7,8. Magnetodielectric with small or great impedance will be realized if to use the combinations of elements 1,3 or 2,4 appropriately.

3.1.3. Let us come to consideration of wave method of magnetodielectrics realization.

1. It is known that the decelerating dielectric realization is possible with using of unlimited length metal strips which have been placed normally to wave moving direction and to vector $\overline{E}$. Besides approximate formulae [37,61] there are known [62] the rigorous analysis results of the electromagnetic wave diffraction by array from parallel strips. The assumption $\mu_r = 1$ is justify if in accordance with (3.5) the relation $z_c = 1/n$ took place.

2. The accelerating dielectric is formed from metal parallel plates along which a wave is running as guided H-wave in the waveguide [37,61]. Herein $v = c_o / \sqrt{1-(\lambda/\lambda_{cr})^2}$, $Z_c^H = Z_0 / \sqrt{1-(\lambda/\lambda_{cr})^2}$, that gives from (3.5),(3.6) values $\mu_r = 1, \varepsilon_r = 1-(\lambda/\lambda_{cr})^2 < 1$. Besides everything, it is important to maintain the unimode regime in waveguide.

3. If in above mentioned systems of plates to excite currents corresponding to E-wave in waveguide, we have accelerating magnetic. Really, for E-wave equations are: $v = c_o / \sqrt{1-(\lambda/\lambda_{cr})^2}, Z_c^E = Z_0\sqrt{1-(\lambda/\lambda_{cr})^2}$, i.e. $n = z_c$, that in accordance with (3.5),(3.6) gives $\varepsilon_r = 1, \mu_r = 1-(\lambda/\lambda_{cr})^2 < 1$.

4. For creation of the decelerating magnetic it is necessary to add to the considered plates system the transverse ridges creating the multi-ridge and multi-waveguide arrays. With proper conditions implementation, knowing for ridge impedance surface, the decelerating surface E-wave is satisfied the relations $v = c_o\psi, \psi < 1, z_c = 1/\psi$ that according to (3.5),(3.6) yield to values $\varepsilon_r = 1, \mu_r = 1/\psi^2 > 1$. Let us to note that in the book [63] the results of ridge waveguide analysis were transferred incorrectly on problem of accelerating dielectric realization. It is interesting that in case of alone impedance plane with small distance l between ridges (l<< λ) we have for decelerating coefficient $\psi = \cos(2\pi d/\lambda)$, where d- height of infinite thin ridge [64].

5,6. The decelerating isoimpedance magnetodielectric $(n > 1, z_c = 1)$ may be obtained with the help of composition of constructions which have been described for variants 1,4. Correspondingly, the accelerating isoimpedance magnetodielectric $(n < 1, z_c = 1)$ may be fabricated with using of the results from items 2,3.

7,8. Formally for creation of the magnetodielectric with small impedance $(z_c < 1)$ with constancy of wave velocity (n=1) it is necessary to make the composition of structures have been described above for variants 1,3. If we want to make the magnetodielectric with great impedance $(z_c > 1, n = 1)$, it is possible to use the variants 2,4.

3.2. Refraction without reflection

3.2.1. The isoimpedance bodies application allows to have the electromagnetic wave refraction without scattering. This declaration justification will be given in present paragraph. We start from traditional methods of reflection waves reduction. Theoretically the absence of reflection take place if plane wave is incident on plane boundary normally and if impedances of two media are equal $(Z_1 = Z_2)$. For decline wave incidence it may be only for determined incident angle-Bruster's one. It is well known in practice the method of boundary transparent method with the help of matching one/fourth wavelength layer. The great number of works is devoted to radioabsorbing coatings application [39,65,66]. Each of shown techniques has the proper limitations, for example, impossibility of practical realization of plane infinite boundary. Nowadays, besides "black" body creation idea, one develops the principles of transparent body fabrication which take participation in the electromagnetic process without effects of absorption and reflection. It was known [67,68] that it is possible to do only for selected directions due to electromagnetic traps from semitransparent screens.

At 1992 the author discovered the possibility to make scatterer as transparent body with the help of application of energy circular transfer due to circular waves which had been found earlier [6-8,69].

Let us consider normal incidence of plane wave with intensities

$$\overline{E} = \vec{z}_0 E_0 e^{-jk_o x} = \vec{z}_0 E_0 e^{-jk_o \rho\cos\varphi}, \overline{H} = -\vec{y}_0 E_0 Z_0^{-1} e^{-jk_o x} \tag{3.7}$$

on circular isoimpedance cylinder with axis $\vec{z}_0$ and radius $\rho = a$, having inside the inhomogeneous isoimpedance magnetodielectric with parameters according to (2.6). The solution of the Maxwell's equations for inner area is equal to sum of H-waves (relatively to $\zeta = \varphi$):

$$E_z = E_0 \sqrt{a/\rho} \sum_{n=-\infty}^{\infty} (-j)^n e^{jn\varphi} f_n(\rho),$$

$$H_\rho = \frac{-E_0}{\varpi\mu_0\sqrt{a\rho}}\sum_{n=-\infty}^{\infty} n(-j)^n e^{jn\varphi} f_n(\rho),$$

$$H_\varphi = E_0 Z_0^{-1}\sqrt{a/\rho}\sum_{n=-\infty}^{\infty}(-j)^{n+1} e^{jn\varphi}\psi_n(\rho). \qquad (3.8)$$

From dependence of $n^2 < N^2$ or $n^2 > N^2$, where

$$N^2 = (a^2/a_o^2 - 1)/4 > 0, a_o = \lambda/4\pi \approx 0{,}08\lambda, \qquad (3.9)$$

functions $f_n(\rho), \psi_n(\rho)$ according to formula (2.42) have the representation:

$$f_n(\rho) = J_n(k_0 a)\cos(b_n \ln\frac{\rho}{a}) + b_n^{-1}[\frac{1}{2}J_n(k_o a) +$$

$$+ k_0 a J_n'(k_0 a)]\sin(b_n \ln\frac{\rho}{a}), b_n = \sqrt{N^2 - n^2},$$

$$\psi_n(\rho) = J_n'(k_0 a)\cos(b_n \ln\frac{\rho}{a}) - b_n^{-1}[(ak_0)^{-1}(a^2 k_0^2 -$$

$$- n^2)J_n(k_0 a) + \frac{1}{2}J_n'(k_0 a)]\sin(b_n \ln\frac{\rho}{a});$$

$$f_n = \frac{1}{2}\{J_n(k_0 a)[(\frac{\rho}{a})^{\beta_n} + (\frac{a}{\rho})^{\beta_n}] + \beta_n^{-1}[\frac{1}{2}J_n(k_0 a) +$$

$$+ k_0 a J_n'(k_0 a)][(\frac{\rho}{a})^{\beta_n} - (\frac{a}{\rho})^{\beta_n}]\}, \beta_n = \sqrt{n^2 - N^2},$$

$$\psi_n = \frac{1}{2}\{J_n'(k_0 a)[(\frac{\rho}{a})^{\beta_n} + (\frac{a}{\rho})^{\beta_n}] - \qquad (3.10)$$

$$-\beta_n^{-1}[\frac{1}{ak_0}(a^2 k_0^2 - n^2)J_n(k_0 a) + \frac{1}{2}J_n'(k_0 a)][(\frac{\rho}{a})^{\beta_n} - (\frac{a}{\rho})^{\beta_n}]\}.$$

In special case of number transformation, when according to (3.9) $N = N_0$ is integer number, summonds of series (3.8) will contain the functions:

$$f_{N0} = J_{N0} + (J_{N0}/2 + k_0 a J'_{N0})\ln(\rho/a),$$

$$\psi_{N0} = J'_{N0} - [\frac{1}{k_0 a}(a^2 k_0^2 - n^2)J_{N0} + \frac{1}{2}J'_{N0}]\ln\frac{\rho}{a}. \qquad (3.11)$$

There are used ordinary denotations for Bessel's function of first kind in (3.10),(3.11).

For boundary $\rho = a$ we have according to (2.6) $\varepsilon = \varepsilon_0, \mu = \mu_0$ that provide from (3.10),(3.11) $f_n(\rho) = J_n(k_0 a), \psi_n(\rho) = J'_n(k_0 a)$,

$$E_z = E_0 \sum_{n=-\infty}^{\infty} (-j)^n e^{jn\varphi} J_n(k_0 a) = E_0 e^{-jk_0 a \cos\varphi}. \qquad (3.12)$$

In accordance with (3.12), where known expansion into Bessel's functions was used, on boundary we observe a coincidence of expression (3.12) with representation for primary field. Therefore the integration of formulas (3.8) and (3.7) takes place in the scattering field absence.

In writing formulae (3.8)-(3.12) the boundary conditions of E_z, H_φ continuation were accounted only to cylinder surface without demand of field finite values for axis **z** that is corresponded to situation with elliptic equation degradation [70]. Namely, the expressions (3.8) were obtained as solution of equation for azimuth component $\rho H_\varphi = U$:

$$\rho^2 U''_\rho + U''_\varphi + k_0^2 a^2 U = 0. \qquad (3.13)$$

The mathematician M.Keldish has shown (see [70]) that for $k_0^2 a^2 \geq 0$ it is necessary to free the degenerating at $\rho \to 0$ equation (3.13) from boundary condition on boundary $\rho = 0$ because solution and its derivation may to have infinite magnitude on line of degradation.

If to change of places in (3.7) for unit vectors $\vec{z}_0, \vec{y}_0$ nearby the intensities $\overline{E}, \overline{H}$, we come to problem with vector $\overline{H}$ which is parallel to axis **z**. With using of the known electrodynamical duality principle it is not difficult to have analogous expressions for H_z, E_ρ, E_φ, according to (3.8),(3.10). From this it follows that the possibility of cylinder transparent (without scattering field) is shown with arbitrary polarization of normally incident plane wave. The case of oblique incidence of wave also is available to analysis if to use the recommendation from [71].

Let us consider the field investigation on cylinder axis. According to (3.8) the field for $\rho \to 0$ has a singularity which is accompanied, with regard of (2.6), also by singularities of functions describing medium parameters. The situation, when in the points of some line or part of plane [44] field intensities stream to infinite, takes place due to the medium inhomogeneity.

The electromagnetic field with singularity on axis $\rho = 0$ is observed also for scattering of plane wave (3.7) by infinite thin but perfect conducting cylinder $\rho = \rho_0$. Let us, at first, do the transition $\rho \to \rho_0$ in well known (see, for example, [72]) formulae:

$$E_z = E_0 \sum_{n=-\infty}^{\infty} (-j)^n e^{jn\varphi} [J_n(k_0\rho) - H_n^{(2)}(k_0\rho) J_n(k_0\rho_0) / H_n^{(2)}(k_0\rho_0)],$$
$$H_\varphi = (E_z)'_{k_0\rho} / jZ_0, H_\rho = -(E_z)'_\varphi / j\varpi\mu_0\rho, \tag{3.14}$$

i.e. we dispose the observation point on cylinder surface. From (3.14)-(3.16) we obtain:

$$H_\varphi = 2E_0 (Z_0 \pi k_0 \rho_0)^{-1} \sum_{n=-\infty}^{\infty} (-j)^n e^{jn\varphi} / H_n^{(2)}(k_0\rho_0),$$
$$E_z(\rho_0) = 0, H_\rho(\rho_0) = 0, \tag{3.15}$$

where took into account the relationship:

$$J'_n H_n^{(2)} - H_n^{(2)'} J_n = 2j / \pi k_0 \rho_0. \tag{3.16}$$

Now in (3.15) we use for small $\xi = k_0\rho_0 << 1$ the representations:

$$H_0^{(2)}(\xi) = 1 + j\frac{2}{\pi}\ln\frac{2}{1{,}78\xi}, H_n^{(2)}(\xi) = \frac{\xi^n}{n!2^n} + j\frac{(n-1)!2^n}{\pi\xi^n},$$
$$H_{-n}^{(2)}(\xi) = H_n^{(2)}(\xi)\exp(-jn\pi) \tag{3.17}$$

and we have according (3.15)-(3.17) current density

$$J_z = H_\varphi = E_0 / j\omega\mu_0\rho_0, \tag{3.18}$$

hence, the current is $I = 2\pi E_0 / j\omega\mu_0 \neq \infty$. If in the problem about infinite thin wire according to (3.18) intensity H_φ has a singularity as $1/\rho$, for inhomogeneous isoimpedance cylinder nearby axis $\rho = 0$ we have $H_\varphi = \psi(\rho)/\sqrt{\rho}$, and $\lim_{\rho\to 0}\psi(\rho) \neq \infty$ for $n^2 < N^2$ and $\lim_{\rho\to 0}\psi(\rho) = \infty$ for $n^2 \geq N_0^2$. Given result depend of electrical size $k_0 a$ and of possibility (or impossibility) to remain the components with $n^2 < N^2$ in series (3.8).

The question about the field behavior nearby cylinder axis is close to considerations about energy losses increasing with the increasing of intensities when $\rho \to 0$. As it is noted in [44], for real inhomogeneous media due to losses presence the field intensity has a finite value instead of theoretical infinity.

3.2.2. It's possible to give the view for series (3.8) which is convenient for analysis if to consider a field nearby surface in the inner nearsurface layer of cylinder body. Assuming $\ln(\rho / a)$ as small value, we have according to (3.10):

$$f_n = J_n(k_0 a) + [J_n(k_0 a)/2 + k_0 a J'_n(k_0 a)]\ln(\rho / a), \tag{3.19}$$

$$\psi_n = J'_n(ak_0) - [\frac{a^2 k_0^2 - n^2}{k_0 a} J_n(k_0 a) + \frac{1}{2} J'_n(k_0 a)]\ln\frac{\rho}{a}. \tag{3.20}$$

Besides relation (3.12) there are justified also the equations:

$$\sum (-j)^n e^{jn\varphi} J'_n(k_0 a) = -j\cos\varphi e^{-jk_0 a\cos\varphi},$$

$$\sum (-j)^n n e^{jn\varphi} J_n(k_0 a) = k_0 a \sin\varphi e^{-jk_0 a\cos\varphi}. \tag{3.21}$$

With regard of (3.19)-(3.21) we have for electrical and magnetic fields intensities:

$$E = E_0\sqrt{a/\rho} e^{-jk_0 a\cos\varphi}(1 - jk_0 a\cos\varphi\ln\frac{\rho}{a}); \tag{3.22}$$

$$H_\rho = -\frac{E\sin\varphi}{Z_0}, \; H = -\frac{E\cos\varphi}{Z_0} -$$

$$- j\frac{E_0\sqrt{a}}{Z_0\sqrt{\rho}} e^{-jk_0 a\cos\varphi}(k_0 a\cos^2\varphi - \frac{1}{4k_0 a})\ln\rho / a, \tag{3.23}$$

where the condition of small value $\ln(\rho / a)$ was used. In so doing, the Cartesian components of magnetic field intensity vector are equal:

$$H_y = H_\rho \sin\varphi + H_\varphi \cos\varphi = -\frac{E}{Z_0} - \frac{E_0\sqrt{a}}{\sqrt{\rho} Z_0} e^{-jak_o\cos\varphi} \times$$

$$\times\cos\varphi\ln(\rho / a)(k_0 a\cos^2\varphi - 1/k_0 a), \tag{3.24}$$

$$H_x = H_\rho\cos\varphi - H_\varphi\sin\varphi = \frac{jE_0\sqrt{a}}{Z_0\sqrt{\rho}}(k_0 a\cos^2\varphi -$$

$$-1/k_0 a) e^{-jk_o a\cos\varphi}\sin\varphi\ln(\rho / a). \tag{3.25}$$

With the help of (3.22)-(3.25), we find the Cartesian components of Pointing's vector average magnitudes:

$$\Pi_x = -(E_r H_{yr} + E_i H_{yi})/2, \Pi_y = (E_r H_{xr} + E_i H_{xi})/2, \qquad (3.26)$$

where indexes r,i are corresponded to real and imaginary parts.

After substitution of (3.22), (3.24), (3.25) in (3.26) and simple transformations, we have the characteristics of longitudinal and transverse energy flows relatively to the plane wave incidence direction:

$$\Pi_x = -\frac{E_0^2 k_0^2 a^3}{\rho Z_0} \cos^2\varphi \ln^2\frac{\rho}{a}(\cos^2\varphi - \frac{1}{4k_0^2 a^2}) +$$

$$+\frac{E_0^2 a}{2Z_0\rho}(1 + k_0^2 a^2 \cos^2\varphi \ln^2\frac{\rho}{a}), \qquad (3.27)$$

$$\Pi_y = -\frac{E_0^2 k_0^2 a^3}{Z_0\rho} \sin 2\varphi \ln^2\frac{\rho}{a}(\cos^2\varphi - \frac{1}{4k_0^2 a^2}). \qquad (3.28)$$

In accordance with formulae (3.27), the input (output) through boundary $\rho = a$ energy flow is corresponded to Pointing's vector in incident plane wave $\Pi_{x\,чч} = E_0^2/2Z_0$. Essentially that continiousity on boundary takes place as for $\Pi_{x\,ч}$ so for $\Pi_y^+ = \Pi_y^- = 0$. It means that Pointing's vector lines inside cylinder start to be curvilinear only with coming away boundary that is caused by increasing of function $\Pi_y(\rho,\varphi)$ values with comparison of function $\Pi_x(\rho,\varphi)$ ones. For electrically great cylinder in nearsurface layer we have

$$\Pi_y \approx -E_0^2 k_0^2 a^3 (Z_0\rho)^{-1} \ln^2(\rho/a) \sin 2\varphi \cos^2\varphi, \qquad (3.29)$$

$$\Pi_{ч_x} \approx \frac{E_0^2 a}{2Z_0\rho}(1 + k_0^2 a^2 \cos^2 \ln^2\frac{\rho}{a}) - \frac{E_0^2 k_0^2 a^3}{\rho Z_0}\cos^4\varphi \ln^2\frac{\rho}{a}. \qquad (3.30)$$

Relations (3.29), (3.30) are in action for all φ with excluding of tangential points $\varphi = \pi/2, \varphi = 3\pi/2$. It is interesting that not only function (3.29) but and function (3.30) may have the negative values. In last case in proper points it is possible to have a motion of energy opposite to $\vec{x}_0$.

3.2.3. The practical interest exists to the problem of isoimpedance cylinder excitement with current filament. Let a primary field is created with uniphase electrical current I filament coming through points $\varphi = \varphi_0, \rho = b$. It is known that

$$\overline{E} = \vec{z}_0(-\omega\mu_0 I/4)\sum_{n=-\infty}^{\infty} e^{-jn(\varphi-\varphi_0)} J_n(k_0\rho) H_n^{(2)}(k_0 b). \tag{3.31}$$

The relationship (3.31) generalizes the representations (3.7),(3.12) for plane wave, transforming in latters with account of Hankel's function asymptotic

$$H_n^{(2)}(k_0 b) \approx \sqrt{2/\pi k_0 b}\exp[j(-k_0 b + n\pi/2 + \pi/4)], \tag{3.32}$$

which take place if $k_0 b >> 1$. Therefore, it is sufficient to withdraw a filament on electrically great distance from axis z in order to use for primary field for all $\rho < b$ the formulae (3.7),(3.12), where

$$E_0 = -\frac{I\omega\mu_0}{2\sqrt{2\pi k_0 b}} e^{-jk_0 b + j\pi/4}.$$

Therefore, during asymptotic (3.32) action the isoimpedance cylinder is also non-reflecting body for field of electrical current filament. Essentially that condition $2\pi b/\lambda >> 1$ is related only to distance between filament and cylinder axis but not between filament and cylinder surface.

3.2.4. Let us transfer obtained result about refraction without reflection also on acoustic problems. At first, we consider acoustic non-reflecting cylinder. Sound field equations in the inhomogeneous liquid or gas medium with assuming of small longitudinal vibrations are [46]:

$$p'_t + m_v c^2 \operatorname{div}\vec{v} = 0, \vec{v}'_t + m_v^{-1}\operatorname{grad}p = 0,$$

where p- sound pressure, $\vec{v}$ - sound wave velocity, m_v - medium density, c - sound velocity: $c = 1/\sqrt{m_v \kappa}$, and κ is ratio compression (κ^{-1} - medium ratio elasticity). Transition to complex amplitudes of harmonic fields gives:

$$j\omega p_m + \kappa^{-1}\operatorname{div}\overline{v}_m = 0, j\omega\overline{v}_m + m_v^{-1}\operatorname{grad}p_m = 0. \tag{3.33}$$

Similarly with (2.6) we use for the inhomogeneous cylinder parameters also inverse proportional dependencies from radius ρ:

$$\kappa = \kappa_0 a/\rho, m_v = m_0 a/\rho, \tag{3.34}$$

where κ_0, m_0 - constants corresponding to cylinder body. Substituting (3.34) in (3.33), we obtain for sound pressure the equation

$$\rho\frac{\partial}{\partial\rho}(\rho\frac{\partial p_m}{\partial\rho})+\frac{\partial^2 p_m}{\partial\varphi^2}+\rho\frac{\partial p_m}{\partial\rho}+a^2k_0^2p_m=0. \qquad (3.35)$$

The equation (3.35) has the same view that the equation for E_z in electrodynamical problem, therefore according to (3.8),(3.11) we have:

$$p_m=p_{mo}\sqrt{a/\rho}\sum_{n=-\infty}^{\infty}(-j)^n e^{jn\varphi}f_n. \qquad (3.36)$$

The incident plane wave with pressure $p_m=p_{mo}\exp(-jk_0x)$ and inner field (3.36) are satisfied bothly on boundary $\rho=a$ the continuos conditions as for pressure so for the normal component of velocity in sound wave $v_{m\rho}$. These conditions are typical for boundary of two media separation. Therefore, non-absorbing and non-reflecting cylinder realization consist of medium realization with parameters (3.34).

Let us pass to problem about non-reflecting sphere. One see an incidence of plane acoustic wave $p_m=p_{mo}\exp(-jk_0z)$ on sphere with radius r=a and ratio compression and density are according to the relations:

$$\kappa=\kappa_0a^2/r^2, m_v=m_0a^2/r^2. \qquad (3.37)$$

In spherical coordinates r,θ,φ the equations system (3.33) (for case of independence from φ) are represented by equations

$$j\omega p_m+\frac{1}{\kappa}[\frac{1}{r^2}(r^2v_{mr})'_r+\frac{1}{r\sin\theta}(\sin\theta v_{m\theta})'_\theta]=0,$$

$$j\omega v_{mr}+m_v^{-1}p'_{mr}=0, j\omega v_{m\theta}+m_v^{-1}r^{-1}p'_{m\theta}=0.$$

After substitution of (3.37) we have the second order equation:

$$(r^4p'_{mr})'_r+r^2(\sin\theta p'_{m\theta})'_\theta/\sin\theta+a^4k_0^2p_m=0. \qquad (3.38)$$

The equation (3.38) solution is

$$p_m=r^{-3/2}\sum_{n=0}^{\infty}(-j)^n(2n+1)P_n[B_nJ_\nu(\frac{k_0a^2}{r})+C_nJ_{-\nu}(\frac{k_0a^2}{r})], \qquad (3.39)$$

where $P_n(\cos\theta)$ - the Legendre's function, $J_{\pm\nu}$ - the Bessel's function,

$\nu = \sqrt{n^2 + 9/4}$. In sphere origin both Bessel's functions have finite magnitude $(J_{\pm\nu}(\infty) = 0)$. Using the primary plane wave expansion

$$p_m^{\bullet} = \sum_{n=0}^{\infty} (-j)^n (2n+1) P_n(\cos\theta) g_n(k_0 r), \qquad (3.40)$$

where $g_n(k_0 r) = \sqrt{\pi / 2k_0 r} J_{n+1/2}(k_0 r)$,

we put on (3.39),(3.40) two boundary conditions for r=a:

$$p_m = p_m^{\bullet}, (p_m)'_r = (p_m^{\bullet})'_r. \qquad (3.41)$$

It was taken into account in (3.41) that due to (3.37) on boundary $m_v = m_0$. Sphere origin, similarly to cylinder axis, must be free from boundary condition putting. Really, according (3.39) for $r \to 0$ a field has singularity of type 1/r because $J_{\pm\nu}(k_0 a^2 / r) \sim \sqrt{r}$.

The coefficients B_n, C_n will be found from relations (3.39)-(3.41). Hence, during the plane acoustic wave (3.90) incidence on the inhomogeneous isoimpedance sphere with parameters (3.37) the reflecting wave is absent, and inner field of sphere is specified by formula (3.29).

3.2.5. It is necessary to account that energy loss presence only impairs the non-scattering body properties. In book [73] the authors suggest to determine a "black" body with condition of power loss maximum that may be observed only with scattering field presence. Therefore, above considered isoimpedance bodies are correctly a non-scattering ones only if power loss is absent. But in case of small value of loss angle tangent the obtained solution are in action as an approximation.

Formally, the Maxwell's equations don't change their view if to use instead of ε_0 the complex constant $\varepsilon_0(1 - j\mathrm{tg}\delta)$. Increasing of the function $\varepsilon = \varepsilon' - j\varepsilon'' = \varepsilon_0(1 - j\mathrm{tg}\delta) a / \rho$ with a coming to axis $\rho = 0$ causes field amplitude reduction due to ε''. At boundary $\rho = a$ we have $\varepsilon \approx \varepsilon_0$ if to use an assumption $\mathrm{tg}\delta << 1$. Therefore, relations (3.8)-(3.11) take place and for non-reflecting magnetodielectric with change in argument of Bessel's function k_0a on $k_0a(1-\frac{j}{2}tg\delta)$.

Loss power absorbing by cylinder is equal to loss power, which was taken from decrement wave $E_0e^{-jk_0x}e^{-k_0xtg\delta/2}$ or appropriate cylinder area in the isoimpedance body absence. Really, the placement in decrement primary wave is accompanied with exact coincidence of media parameters on both sides from cylinder boundary.

3.3. Isoimpedance materials in antenna engineering

3.3.1. The considered unique property in the previous paragraph of the isoimpedance cylinder to make refraction without reflection is very useful for different antenna-feeder installations creation. For example, one may do a transparent coating for supports placed in the reflector antenna aperture. New possibilities will be open for lens antenna creation. The expansion of relations (2.5) to the formulae

$$\varepsilon = \varepsilon_0\chi(x,y,z), \mu = \mu_0\chi(x,y,z), \qquad (3.42)$$

where $\chi(x,y,z)$ - arbitrary continuos coordinates function, does not violate the condition (2.4). Therefore, in general case the isoimpedance inhomogeneous medium is characterized with formulae (3.42). Relation (2.18) specifies the circular wave velocity but expression $1/\sqrt{\varepsilon\mu} = \omega/\chi$ doesn't have of this physical meaning in general case. Nevertheless, for $\chi > 1$ one may to consider the medium as inhomogeneous decelerating one.

If on surface or on its part which divide the homogeneous medium with $\varepsilon_r = \mu_r = 1$ and the inhomogeneous one with $\varepsilon_r = \mu_r = \chi$, we have boundary condition $\chi_\Gamma = 1$ implement, it is continuos not only impedance but also phase velocity on boundary. In some cases there are sufficient conditions for providing of non-reflecting coming of T-wave in the isoimpedance inhomogeneous medium.

3.3.2. Let us consider relations for current and charge of wire which is immersed in the inhomogeneous medium. For curvilinear wire, disposed in homogeneous medium, the differential equations

$$-I'_{\xi}(\xi) = j\omega\tau(\xi), \tau'_{\xi}(\xi) = -j\omega\varepsilon_0\mu_0 I(\xi) + f(\xi) \qquad (3.43)$$

have been analyzed [7,74], where

$$I = a\int_0^{2\pi} H_{\varphi}(\xi,\varphi)d\varphi, \tau = a\varepsilon_0\int_0^{2\pi} E_{\rho}(\xi,\varphi)d\varphi,$$

$$f(\xi) = a\varepsilon_0\int_0^{2\pi}(E_{\xi})'_{\rho}d\varphi = 2a\pi\varepsilon_0(E_{\xi m})'_{\rho}. \qquad (3.44)$$

Disposition of wire in the inhomogeneous medium is accompanied by preservation in (3.44) the formula for current, but it is need to modify the linear charge definition:

$$\tau = a\int_0^{2\pi}\varepsilon E_{\rho}d\varphi \approx 2\pi a\varepsilon(\xi)E_{\rho m}(\xi). \qquad (3.45)$$

According to (3.45) we suppose that in points of wire section contour due to small value of radius a one may to consider the permittivity of environment medium is constant and is equal to function $\varepsilon = \varepsilon(\rho = 0, \xi)$ in points of wire axis line. Together with (3.45) it is generalized the formula for nearsurface field characteristic:

$$f(\xi) = 2a\pi\varepsilon(\xi)(E_{\xi m})'_{\rho}. \qquad (3.46)$$

The generalized equations for I, τ derivation is similar to relations (3.43) fabrication [7,74]. The Maxwell's equations intengrated along the wire contour ($E_{\varphi} = 0, H_z = H_{\rho} = 0, \xi = z$) give:

$$-\frac{\partial H_m}{\partial z} = j\omega\varepsilon E_{\rho m}, \frac{\partial E_{\rho m}}{\partial z} - \frac{\partial E_{zm}}{\partial\rho} = -j\omega\mu H_m,$$

$$\frac{1}{\rho}\frac{\partial}{\partial\rho}(\rho H_m) = j\omega\varepsilon E_{zm}. \qquad (3.47)$$

Hereto, the view of first from the equations (3.43) is unchanged but second equation will be more complicate:

$$\tau'_\xi(\xi) - (\ln \varepsilon)'_\xi \tau(\xi) = -j\omega\varepsilon(\xi)\mu(\xi)I(\xi) + f(\xi). \tag{3.48}$$

The substitution of first relation from (3.43) in (3.48) leads to ordinary differential equation

$$I''_\xi - (\ln \chi)'_\xi I'_\xi + k_0^2\chi^2(\xi)I = -j\omega f(\xi), \tag{3.49}$$

which is wrote for further to be analyzed the isoimpedance medium variant, characterizing with relations (3.42).

The equation

$$I''_\xi + k_0^2 I = -j\omega f(\xi) \tag{3.50}$$

has operated [7,74] in the homogeneous medium instead of (3.49). It is interesting to note that the homogeneous variants of equations (3.49),(3.50) have analogical solutions. Namely, if free part of wire current, when medium is homogeneous one, according to (3.50) is

$$I_0(\xi) = C_1 e^{-jk_o\xi} + C_2 e^{jk_o\xi}, \tag{3.51}$$

in a problem with the inhomogeneous medium analogical solution has a view

$$I_0(\xi) = C_1 e^{-jk_o\zeta} + C_2 e^{jk_o\zeta}, \text{where} \zeta(\xi) = \int \chi d\xi. \tag{3.52}$$

3.3.3. Let us research the two-wire line electromagnetic field when the line is placed in partly inhomogeneous medium. Wires of the line are going normally to plane z=0, and half space z<0 is occupied with an air and half space z>o is filled with the inhomogeneous isoimpedance material. In each of media a field has T-wave structure that allow to consider due to f(z)=0 the functions (3.51),(3.52) as full currents in wires. Coming from half space z<0 current wave $I_0^- = C_1 \exp(-jk_0 z)$ transforms in current wave $I_0^+ = C_1 \exp(-jk_0\zeta)$ for z>0, where $\zeta = \int_0^z \chi(x_0, y_0, z)dz$, and x_0, y_0 - are wire cross section center coordinates. Because for any view of function $\chi(x, y, z)$ on boundary z=0 we have also $\zeta = 0$, one observes the current continuity for z=0. For charge continuity it is necessary to put $\chi(x, y, 0) = 1$, that with account of (3.42) causes boundary parameters continuity. Coming over without reflection in half space z>0 electromagnetic T-wave safe a structure of two-line field but has a decelerating in accordance with formula for phase velocity $v = c_0 / \chi < c_0$ when $\chi > 1$.

Let us consider a problem about field of two-wire line laying on plane boundary between homogeneous and inhomogeneous impedance media. Now each of wires has partial boundaries as with air so with magnetodielectric. As it is shown for strip lines in [57] it is expedient to diverse two currents: current with an air surround I^a and current with magnetodielectrical surround I^{md}. These currents are described with help of formula (3.44) but with integration only on appropriate parts of circle $\rho = a$. In each of half spaces now only quasi T-wave is coming, and only longitudinal component of electrical field intensity is present. Due to $f(\xi) \neq 0$ the currents I^a, I^{md} consist of summons (3.51),(3.52) and ones depending on right parts of inhomogeneous equations (3.50),(3.49), because additional energy motion takes place in planes z=C. Hence, the inhomogeneity of space where two-wire line is disposed causes an appearance of transverse radiation energy.

3.3.4. Let us now consider a spiral antenna disposition, at least partly, in magnetodielectric cylinder with parameters according (2.6). One folds two-wire feeder so that its wires create the hyperbolic parallel spirals

$$\rho = a / \varphi, z = \pm h (0 < \varphi < \infty). \tag{3.53}$$

All points of spiral wire, corresponding to z=h, $\varphi > 1$, are inside the cylinder. Length of spiral plane curve is found [75] according formula

$$\xi = a[-\sqrt{1+\varphi^2} / \varphi + \ln(\varphi + \sqrt{1+\varphi^2})]\Big|_{\varphi_0}^{\varphi}, \tag{3.54}$$

where for wire part in air $0 < \varphi_0 < \varphi \leq 1$ and for wire part inside cylinder $1 = \varphi_0 < \varphi < \infty$. At first part the equation (3.50) is valid and at second part-equation (3.49). For coefficients $(\ln \varepsilon)'_\xi = (\ln \chi)'_\xi$ and $\chi^2(\xi) = a^2 / \rho^2(\xi)$ finding it is necessary from (3.53),(3.54) to have the dependence $\rho(\xi)$. It is need to have representation of inverse function $\varphi(\xi)$ that is difficult to obtain due to transcendental character of function $\xi(\varphi)$. But on the turn $2m\pi < \varphi < 2(m+1)\pi$, very close to a circle, one may to give the approximate linear relation:

$$\xi = \xi_s - \frac{2ma}{2m+1} + \frac{a\varphi}{(2m+1)\pi} = C_1 + C_2\varphi,$$

$$\xi_s = \sqrt{2}a - \sqrt{a^2 + \rho_s^2} + a\ln[(a + \sqrt{a^2 + \rho_s^2})/\rho_s(1+\sqrt{2})]. \qquad (3.55)$$

It is simply to find with help of (3.55) the functions

$$\chi(\xi) = (\xi - C_1)/C_2, \zeta(\xi) = \int_{\xi_s}^{\xi} \chi d\xi = C_2^{-1}(\xi^2/2 - C_1\xi)\Big|_{\xi_s}^{\xi}$$

which are in formulae (3.49),(3.52).

Due to the isoimpedance cylinder the plane T-wave of straight-line feeder is converted in circular T-wave of folded feeder. The similar effect is not observed if the feeder is fold in an air.

Because of the folded feeder is placed in the inhomogeneous medium, there are present the longitudinal components of electrical and magnetic fields $\acute{\Gamma}_\varphi, H_\varphi$ relatively to wires currents. Their addition to circular T-wave intensities makes inside cylinder a field in view of conditionally quasi T-wave which is convoyed with normal energy flows (due to $E_\varphi H_z, H_\varphi E_z$) and axis energy flows (due to $E_\varphi H_\rho, H_\varphi E_\rho$). Two opposite directing along axis z flows create the great mutual compensation. But for radially convergenting energy the nearaxis area $\rho \to 0$ performs a role of perfect screen, and the radial coming away energy flow of radiation must to increase. The additional contribution in transformation of circular T-wave in quasi T-wave is given by effect of infinite medium change on its part as the isoimpedance body.

Therefore, in suggested spiral antenna we have a smooth transformation of feeder T-wave in cylindrical radially divergenting wave with intermediate "agent" - circular quasi T-wave. During practical realization of antenna with circular wave it is necessary to produce MD cylinder with finite height. Particularly, spiral wires may be placed on the cylinder's tops.

It is interesting to consider a slot spiral antenna with circular wave. The antenna may be made in view of the narrow spiral slot in metal disc of radius **a**, and disc is placed between two MD half cylinders. The circular quasi T- wave has E_ρ, H_z and radiates due to $\Pi_z = E_\rho H_\varphi$ and $\Pi_\rho = E_\varphi H_z$.

3.3.5. Let us pass to consideration of screw antenna construction with circular wave. Two-wire feeder is connected to two screw wires which have axis lines with equations

$$x = \rho_1 \cos\varphi, y = \rho_1 \sin\varphi, z = h\varphi / 2\pi;$$
$$x = \rho_2 \cos\varphi, y = \rho_2 \sin\varphi, z = h\varphi / 2\pi,$$

where h- step of winding. Screw line of small radius ρ_1 is placed completely inside MD cylinder. The screw line of great radius $\rho_2 > \rho_1$ may be placed as inside cylinder so on its surface. For longitudinal coordinates ξ_1, ξ_2 along each of wires we have

$$\xi_{1,2} = \varphi\sqrt{\rho_{1,2}^2 + h^2 / 4\pi^2}. \qquad (3.56)$$

The motion along screw line is accompanied according to (2.6) with independence ε, μ from z that allows to put nearby inner (outer) wire $\chi_1 = a/\rho_1 (\chi_2 = a/\rho_2)$. The equation (3.50) becomes simpler:

$$I''_{1,2}(\xi_{1,2}) + k_0^2\chi_{1,2}^2 I_{1,2} = -j\omega f_{1,2}(\xi_{1,2}). \qquad (3.57)$$

The homogeneous equations (3.57) have the solutions:

$$I_0^{1,2} = C_1^{1,2} e^{-jk_0\chi_{1,2}\xi_{1,2}} + C_2^{1,2} e^{jk_0\chi_{1,2}\xi_{1,2}}.$$

Due to (3.56) the phases of running waves of two wires currents are not coincide in general case. But for small step $h << 2\pi\rho_{1,2}$ it is absent that corresponds to circular quasi T-wave between two screw windings

$$(|E_\rho| >> |E_z|, |H_z| >> |H_\rho|, E_\varphi^0 \approx 0, H_\varphi^0 \approx 0).$$

Curvilinearity of wires and the inhomogeneity of magnetodielectric cause for (3.57) $f_{1,2} \neq 0$, i.e. existence of currents creating a radiation into direction ρ and z due to $E_\varphi \neq 0, H_\varphi \neq 0$. Flows of power, characterizing with values $E_z H_\varphi, E_\varphi H_\rho$, are not great that it is impossible to say about $\Pi_\rho = E_\varphi H_z, \Pi_z = E_\rho H_\varphi$. The control of relation $|\Pi_\rho| / |\Pi_z|$ allows to create a radiation previously in radial or axis directions.

3.3.6. Let us now consider on the radiation patterns calculation for the shown antennas. The presence of the isoimpedance inhomogeneous body in antenna construction makes the radiation field calculation more complex. If the electrical (magnetic) current $\bar{j}^{e,m}$ is placed in the homogeneous medium, in far zone of radiation field the intensities components are equal to

$$E_\theta = -j2\pi(Z_0 A_\theta^e + A_\varphi^m)/\lambda, H_\varphi = E_\theta / Z_0, H_\theta = -E_\varphi / Z_0,$$
$$E_\varphi = -j2\pi(Z_0 A_\varphi^e - A_\theta^m)/\lambda, E_r = 0, H_r = 0, \quad (3.58)$$
$$A_\theta = A_x \cos\theta\cos\varphi + A_y \cos\theta\sin\varphi - A_z \sin\theta,$$
$$A_\varphi = -A_x \sin\varphi + A_y \cos\varphi,$$
$$A_{x,y,z}^{e,m} = \frac{e^{-jkr}}{4\pi r}\int j_{x,y,z}^{e,m} e^{jk(x'\sin\theta\cos\varphi + y'\sin\theta\sin\varphi + z'\cos\theta)} dx'dy'dz'. \quad (3.59)$$

As is well known that the filling of volume **v** with the inhomogeneous MD may be taken into account by means of adding to formula (3.59) the equivalent currents

$$\bar{j}^e = (\varepsilon - \varepsilon_0) j\omega\bar{E}, \bar{j}^m = -(\mu - \mu_0) j\omega\bar{H}, \quad (3.60)$$

where $\bar{E}, \bar{H}$ - field intensities in volume v. Really, the Maxwell's equations easily may be transformed:

$$\mathrm{rot}\bar{H} = j\omega\varepsilon_0\bar{E} + j\omega(\varepsilon - \varepsilon_0)\bar{E} = j\omega\varepsilon_0\bar{E} + \bar{j}^e,$$
$$\mathrm{rot}\bar{E} = -j\omega\mu_0\bar{H} - j\omega(\mu - \mu_0)\bar{H} = -j\omega\mu_0\bar{H} + \bar{j}^m.$$

Hence, for wire antenna radiation field finding the formulae (3.58)-(3.60) are used, where volume integral $\int_v ...dv = \int_{-h}^{+h} dz \int_0^{2\pi} d\varphi \int_0^a ...\rho d\rho$ is used, and also it is necessary to use a linear integral for current satisfying to equation (3.49). Hereto, it is justify the traditional assumption about possibility of non-full wire current application but only its harmonic part according to (3.52). Similarly instead of full field in (3.60) one may to account only known part in view of circular wave.

3.4. Radio circuits components miniaturization

3.4.1. The problem of radio circuits wave-elements miniaturization attracts the attention of the specialists for many years. The classification of elements with the linear dimension **l** as lumped one ($l << \lambda$) or distributed one ($l \sim \lambda$) has some non-rigorousity. For example, thin coaxial cable part with $l \sim \lambda$ may be fold into a spiral with diameter $d << \lambda$, "disturbing" a principle of elements dividing on lumped and distributed ones. In contrast to UHF circuits the MF, HF circuits elements don't usually contain the long lines due to great sizes. Meanwhile, the functional abilities of the wave elements with multi-conductor lines [76,77] are very various because it is may be realized the impedances transformers, the broad-band matching devices, couplers, filters, multiplexers, symmetrical installations and so on.

The electromagnetic field inside wave multi-ports devices are described with quasi T-waves composition. The ideal T-wave, being non-varying electromagnetic structure in the infinite frequency band, provides in real conditions the broad band characteristic representation of wave multiports circuits.

The multi-cylinder coaxial construction of the line [76] is not convenient for production, it is hard to make a ring from one. During folding of non-screening multiconductor line the electromagnetic field is not a quasi T-waves variety because the essential azimutial (longitudinal) components of field vectors E_φ, H_φ appear that create the radiation energy losses. Due to shown cases one can't to do the multiconductor lines miniaturization for MF, HF, VHF excluding partial miniaturization for spiral elements of filters. At present time this consideration may be revised because one may to add to known miniaturization techniques [76-79] the principally new possibilities if to use the circular T-waves.

3.4.2. The generalizing the problem, has been considered in p.3.3.3., we dispose the multiconductor line in the isoimpedance medium. Let a half space z>0 is filled with the inhomogeneous medium with $\varepsilon_r = \mu_r = \chi(z)$ having the same impedance which is for homogeneous half space (z<0) with $Z_0 = \sqrt{\mu_0 / \varepsilon_0}$. If **m** wires are placed normally to planes z=C a field in the inhomogeneous medium is two T-waves with summary intensity

$$\overline{E}_\perp = \overline{E}^0_\perp(x, y)(C_1 e^{-jk_o\zeta} + C_2 e^{jk_o\zeta}), \qquad (3.61)$$

where $\zeta = \int_0^z \chi(z)dz$. For wires currents and their linear charges the representations $I_v(z) = C'_v e^{-jk_o\zeta} + C''_v e^{jk_o\zeta}, \nu = 1,2,...m$,

$\tau_v(z) = \chi(z)\sqrt{\varepsilon_0\mu_0}(C'_v e^{-jk_o\zeta} - C''_v e^{jk_o\zeta})$ are justified. The phase velocity of T-wave, running along axis z, is equal to $v = c_0 / \chi(z)$.

For example, if medium characteristic is

$$\chi(z) = 1 + tg(\pi z / 2l), \qquad (3.63)$$

we have $v \to 0$ for distance z=l, i.e. the total decelerating of T-wave. Hence, according to (3.61), (3.62), the plane T-wave in the inhomogeneous medium is one with varying velocity depending from characteristic $\chi(z)$. Standard determination of wavelength $\lambda(z) = v / f = \lambda_0 / \chi(z)$ shows that for $\chi > 1$ the shorting of wavelength takes place when λ is smaller than λ_0 as wavelength in free space. Hence, the application of multiconductor line, immersed in the inhomogeneous magnetodielectric, allows to produce an equivalent homogeneous line with middle wavelength

$$\lambda_m = \lambda_0 l^{-1} \int_0^l dz / \chi(z). \qquad (3.64)$$

For example, substitution (3.63) in (3.64) gives $\lambda_m = \lambda_0 / 2$, but it is possible to do and more shorting.

3.4.3. Let us now consider the peculiarities of wave elements calculation if the T-wave approximation is used. The UHF wave elements, containing wires segments, are couplers, filters, impedance transformers and so on [76-80]. The problem of adequacy of description of the electromagnetic fields of these devices with the help of the telegraphy equations, i.e. in approximation of T-waves, has not [78] of quantity estimations. The schemetechnique specialists are forced to be satisfied with necessity of experimental testing of theoretical results. The electrodynamical analysis of such constructions is very complex as on stage of boundary problem recognition so and during solution reception. We now consider the electrodynamical justification of schemetechnical models of multiconductor wave elements with utilization of non-homogeneous differential equations for currents and charges of wires [7,74].

In exact meaning the plane T-wave may be observed only in line with infinite length and parallel placement of wires. The real curvilinearity and finite sizes of wires lead to necessity of estimation of the difference between real quasi T-wave and ideal T-wave. A quasi T-wave modeling may be made relatively simply if to take as basic the differential equations for current and linear charge (3.43). The convenient view of results is obey to refusal from field intensities analysis. For output parameters multiports matrix it is sufficient to analyze only corrections to wires currents

$$I(\xi) = C_1 e^{-jk_o\xi} + C_2 e^{jk_o\xi}, \tag{3.65}$$

corresponding to ideal T-waves. Current of each wire has, besides expression (3.65), also non-homogeneous equation (3.50) solution as integral

$$I_n(\xi) = -j\omega k^{-1}\int_0^{\xi} f(\xi')\sin k(\xi-\xi')d\xi'. \tag{3.66}$$

The charge linear density is finding with the help of substitution of (3.65), (3.66) in the first of equations (3.43), whence we have for each wire

$$\tau(\xi) = k(C_1 e^{-jk\xi} - C_2 e^{jk\xi})/\omega + \int_0^{\xi} f(\xi')\cos k(\xi-\xi')d\xi'. \tag{3.67}$$

As example, for four terminal networks (two port) we shall show the matrix **[a]** procedure, taking into account the difference between two-ports field and T-wave with the help of the additional summons of current (3.66). Two wires with arbitrary axis geometry are subjected to condition of voltages determinations in regular areas: the beginning of wires form an input pair of terminals and the ends- output pair of terminals. As for input so for output the conditions are fulfilled for charges: $\tau_1 = -\tau_{1'}, \tau_2 = -\tau_{2'}$ and for currents $I_1 = -I_{1'}, I_2 = -I_{2'}$. Wire 12 has a length l and wire $1'2'$ - length l'. Formulae (3.65)-(3.67), considering for wire beginning 12 ($\xi = 0$) and for end ($\xi = l$), give the equations ($\theta = kl$):

$$I_2 = I_1 \cos\theta - jc_0\tau_1 \sin\theta - jc_0 \int_0^l f(\xi')\sin k(l-\xi')d\xi', \tag{3.68}$$

$$\tau_2 = -jI_1 c_0^{-1} \sin\theta + \tau_1 \cos\theta + \int_0^l f(\xi')\cos k(l-\xi')d\xi'. \tag{3.69}$$

Input and output of two-port circuit are created by regular feeder segments, hence their capacities per length unit C_1 are the proportional coefficients between charges and voltages. Participating in (3.68),(3.69) near-surface field characteristic is equal to zero only in approximation of T-wave. In considering general case for it the linear relation

$$f_{12}(\xi) = \tau_2 F_\tau(\xi) + I_2 F_I(\xi) \tag{3.70}$$

is justified where functions F_τ, F_I according to(3.70) correspond to fields in open circuit and short circuit tests for two-port output:

$$F_\tau = f_{12} / \tau_2 \quad \text{for} I_2 = 0, \quad F_I = f_{12} / I_2 \quad \text{for} \tau_2 = 0. \tag{3.71}$$

The substitution of (3.70) in (3.68),(3.69) leads after simple transformation to matrix [a] of equation system

$$\begin{bmatrix} U_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} U_2 \\ I_2 \end{bmatrix},$$

namely:

$$a_{11} = \cos\theta + B_\tau \cos\theta + jc_0^{-1} A_\tau \sin\theta,$$

$$a_{12} = jZ_{e1} \sin\theta + (jc_0^{-1} A_I \sin\theta + B_I \cos\theta) / C_{\bullet},$$

$$a_{21} = jZ_{e2}^{-1} \sin\theta + C_{\bullet}(jc_0 B_\tau \sin\theta + A_\tau \cos\theta),$$

$$a_{22} = \cos\theta + A_I \cos\theta + jc_0 B_I \sin\theta, \text{ where} \tag{3.72}$$

$$A_{\tau,I} = jc_0 \int_0^l F_{\tau,I}(\xi)\sin k(l-\xi)d\xi, B_{\tau,I} = -\int_0^l F_{\tau,I} \cos k(l-\xi)d\xi. \tag{3.73}$$

In idealized variant of parallel placement of wires 12 and $1'2'$ and with neglecting of end fields we have $F_\tau = 0, F_I = 0$ and the known formulae

$$a_{11}^0 = a_{22}^0 = \cos\theta, a_{12}^0 = jZ_e \sin\theta, a_{21}^0 = jZ_e^{-1} \sin\theta. \tag{3.74}$$

Two-port inversion condition demands after substitution in it of formula (3.72) for numbers $A_{\tau,I}, B_{\tau,I}$ of fulfillment of relation

$$A_I + B_\tau + B_\tau A_I - B_I A_\tau = 0. \qquad (3.75)$$

Therefore, functions $F_{\tau,I}$ arbitration is limited by equation (3.75) implement demand. We may introduce the models [74] of small deflection of the electrical field force line nearby wire. It will give a possibility to estimate according to (3.71)-(3.73) a contribution of quasi T-wave in comparison with field of ideal T-wave by means of comparison of parameters (3.72) with values (3.74).

3.5. Circular waves action on electron and plasma beams

3.5.1. The electron or plasma beams perform an active role in varies devices of modern engineering: particles accelerators, electron-optical devices, electron devices for amplifying and generating of vibrators, electron microscopes, plasma guns and so on. The beams parameters control is usually making with the help of the electromagnetic fields of proper structure 81]. Evidently, that for these purposes We may use the electrical and magnetic fields of the circular waves in the inhomogeneous isoimpedance media. In creating of the appropriate devices, it is useful to account the proper peculiarities of suggested fields structures.

In the electromagnetic wave a charged particle is forced as from electrical so from magnetic fields. Therefore it is possible to have differential combinations of action and control of electron beams.

For T-wave and, mainly for E,H-waves, ones may to observe force lines structure maintenance at frequency band. This property of guided waves represents an interest for problem solution of stable electron and plasma beams.

The circular waves have the additional peculiarities else. The circular character of energy motion with repentance and superposition of plane (sphere) fronts one on other potentially promotes to creation of the high intensity fields. The wave performs in role of electromagnetic screw-view coating for electron or plasma beams. For creation of effective exchange of energy between beam and wave it is important that using isoimpedance material provides wave decelerating with doing of any desirable velocity value. The screw-view character of electromagnetic energy motion creates conditions for increasing of time of interaction between wave and particles beams. At last, isoimpedance media and circular waves have additional possibilities of unusual beam and field interaction due to authophasing condition in view of relationships (2.29),(2.45).

Let us discuss how the circular waves may be used in plasma electromagnetic holding installations. Despite on the great number of theoretical and experimental works [82] at magnetic holding of high temperature plasma, this problem hasn't desirable solution at present time. Besides others, one principal contradiction opposes to the solution. Usually for plasma thermoisolation one tries to use a magnetic field with non-varying structure of force lines in the time and space. But an appearance of plasma non-stability almost is accompanied with alternating electromagnetic fields that isn't coordinated with external static fields.

It is interesting to consider the next argument: for holding of such dynamic object as plasma it is necessary to use electrodynamical methods which allows to have electromagnetic waves with stable structure of Poiting's energy vector lines. Otherwise speaking, initially a problem of holding must be recognized in electrodynamics frameworks but with solution searching in classes of waves with stable force lines of the electrical and magnetic fields.

As is well known, that in the homogeneous media such waves are plane and sphere T-waves only, having parallel or divergent unlimited straight-lines as energy lines. Therefore, to hold a plasma in finite volume with the help of plane (sphere) T-waves only is impossible. It is suggested to use for thermoisolation the circular T-waves in the isoimpedance inhomogeneous media. From four possible classes the most interest is application of the coordinates of PBII class (plane-axis) and SBIII class (sphere-axis).

During T-wave application problem consideration we use for plasma the usual assumptions [82]: a) about high electroconductibility which take place for great temperature, b) about possibility of observation of forces on plasma surface only as for gas-view perfect conducting body.

One traditional idea consist of doing of plasma beam selfsqeezing due to the longitudinal surface currents, i.e. to circular lines of magnetic field intensities. Second traditional idea is the following: in order to stabilize the plasma beam form it is necessary to use longitudinal lines of magnetic field, i.e. current circular lines. Generally, it is need to create on plasma beam surface the screw lines of current.

We may make the circular T-wave to participate in plasma beam holding if it will be one of two conductors forming the channel waveguide.

This is the simplest construction of hot plasma holding installation shown on Fig.3.2. The vessel **1** with gas is located inside the isoimpedance inhomogeneous magnetodielectric **2** having ratio permittivity and permeability variation along radius in accordance with law (2.6).

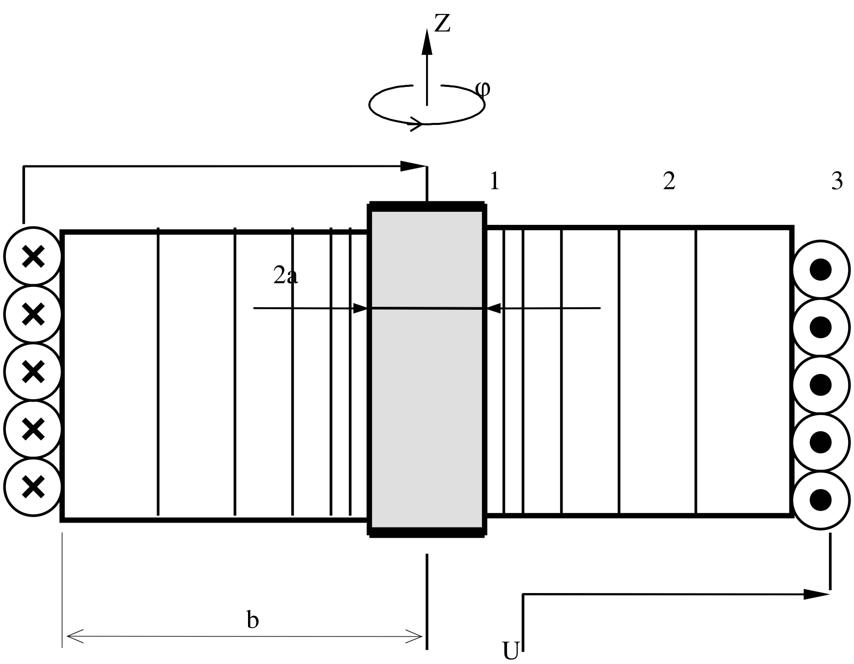


Fig. 3.2

Along wire of winding 3 the current wave runs with velocity c_0 because for $\rho = b$ we have $\varepsilon_r = \mu_r = 1$. After conversion of gas in plasma a conductor **1** performs in role of inner winding with screw current, and in nearsurface layer for $\rho = a$ one observe the decelerating motion of electromagnetic energy with velocity $v = c_0 / \varepsilon_r = c_0 a / b$. The simplest circular T-wave has circular (along φ) energy flows with fields intensities according (2.24):

$$E = E_\rho = \frac{U}{b-a} e^{-jk_0 b\varphi} = Z_0 H = -Z_0 H_z, \tag{3.76}$$

where U is electrical voltage for running wave. Two quasi T-waves (direct and reflect) will be observed in construction shown on Fig.3.2. with intensities closed to relations (3.76). Evidently that for great intensity H production it is necessary in accordance with (3.76) to do a difference b-a small value. But, if to recognize a problem of near plasma wave velocity decreasing, it is necessary to choose appropriately the ratio a/b.

Let us now consider also thoroidal construction with circular T-wave. For mathematical description the coordinates (2.34) from class SBIII are used. For existence of T-wave with intensities (2.35) the isoimpedance medium must have ratio parameters according to (2.8). The expressions (2.8),(2.35) are more complex than (2.6),(3.76) that is accompanied a transition from straight-line beam (Fig.3.2) to circular plasma beam with radius $\rho = a$. The magnetic field intensity H_η is tangential to beam surface and is a stabilizing cause for it. Second guiding conductor is a winding which is placed on the thoroidal isoimpedance magnetodielectric surface.

3.6. About utmost parameters realization

3.6.1. The interest to the dielectric and ferromagnetic with utmost magnitudes of parameters $\varepsilon \to \infty, \mu \to \infty$ exists during all period of the electrodynamics development. The natural dielectric material with $\varepsilon \to \infty$ is absent. If it will create this material artificially, that its behavior on boundary will be equivalent to perfect conductor presence. Hence, formally in the electromagnetic installations we may use instead of conductors the utmost dielectrics if only frequency $\omega > 0$. The various applications will be find and for utmost ferromagnetic with $\mu \to \infty$. Let us consider the principal possibilities of artificial realization of the utmost dielectric and ferromagnetic with metal-air production methods application (p.3.1). It is known [12,38] that ratio permittivity of dielectric, has been made from metal particles, may be found according to formula

$$\varepsilon_r = (1+2v)/(1-v), \qquad (3.77)$$

where v is ratio volume occupied by a metal. That less place is taken in material for an air than due to $v \to 1$ a permittivity ε_r is close to infinity. The similar result may be obtained with the help of the device shown at Fig.3.1,a, if the space between capacitor's plates will be filled with metal rods, sizes of which must be more and more smaller. The ferromagnetic material creation is produced according p.3.1.2. with the help of small turns L loaded by capacities C. For frequencies $\omega < \omega_0 = 1/\sqrt{LC}$ the additional impedance, which have been brought from the turn to primary winding L_0, has the inductance character so that equivalent inductance of the winding is equal to $L_э = L_0\left[\omega_0^2 + \omega^2(k^2 - 1)\right]/(\omega_0^2 - \omega^2)$, where k is coupling coefficient. The presence of great number of the turns demands of the relation obtaining of the view likes (3.77) but the principal possibility of the approach $\mu \to \infty$ already is evident. For that is it necessary to diminish sizes of turns with simultaneous increasing of their number.

3.6.2. The variants of utmost dielectric and ferromagnetic application are useful to consider with regard of formal analogy- Maxwell's equations duality principle for fields creating by dielectric and ferromagnetic filaments. The electromagnetic field of two-filament dielectric transmission line for $\omega > 0$ has the same electric and magnetic force lines that the field of usual line from two metal wires. According to formal analogy between two Maxwell's equations two-filament ferromagnetic transmission line has the electrical force lines embracing filaments and the magnetic force lines coming from one filament to another one.

If it will be created utmost ferromagnetic filament, it will give a possibility to realize the capacity transformer [83,84]. For that it is need to embrace two closely placed capacitors with a winding from the ferromagnetic filament with $\mu \to \infty$. To one capacitor the alternating electrical voltage source is connected, second capacitor is loaded. The electrical induction vector flow of first capacitor creates an alternating magnetic field where along the force line we shall dispose the ferromagnetic filament. The magnetic winding with alternating by time magnetizing embraces the second capacitor plates inducing in latter the electrical induction alternating flow. Therefore, in the load the electrical current will appear with value depending on mutual capacity magnitude. The electrical induction flow in each capacities will be consist of the algebraic sum of two flows: proper one, which are created by electrical voltage between own plates, and mutual one, caused by magnetic field intensity curl, i.e. depending on electrical voltage on another capacitor. The capacity transformer equations are the following:

$I_1 = j\omega C_1 U_1 \pm j\omega T U_2, I_2 = \pm j\omega T U_1 + jC_2 U_2$, where I_1, I_2 are currents of capacitors, U_1, U_2 - its voltages and T is mutual capacity between capacitors. On the contrary to inductance transformer for the capacity one the optimal regime is deals with small load impedance. This property may be useful for matching of high impedance of source with small load impedance.

CONCLUSION

The dielectric and magnetic properties of material are usually investigated with separate action of electric and magnetic fields. This ideology owes, at first, to historical way of electrodynamics establishment by means of combination and generalization of electric and magnetic phenomena theories. Besides others, in natural matters the macroscopic processes of polarization and magnetizing are presented simultaneously very rarely, therefore usually materials are divided on dielectrics and magnetics.

At present time the conditions are suitable for "wave" view establishment: wave process in medium demands the equivalent and interrelated participation of the dielectric and magnetic properties. Besides, the technical possibilities of artificial media realization are very broad now. The realization of the functional characteristics of devices with the help of appropriate parameters synthesis of the inhomogeneous media - it is progressive technology of our days. It is sufficient to remind the great achievements of integral microelectronics, integral optics.

This work spreads the exploration and application of media with the interrelated dielectric and magnetic properties - binary materials. It is shown great number of variants of the inhomogeneous isoimpedance media and circular (globally plane, sphere) waves in this media. There are more generalized media with factorizied permeability/permittivity ratio and generalized T,E,H-waves.

It is possible to forecast the further research directions. At first, the binary material creation methods will develop, so as dielectric and magnetic particles unification and their compositional creation in metal-air constructions. At second, it is need to broad the theory of waves in binary media. There are perspective the further investigations of anisotropic isoimpedace media, on controlled isoimpedance materials which may be useful for electrical control lens antennas [85]. The circular waves in the isoimpedance media due to variety and uniqueness of some properties will find application in radio electronic, electroengineering equipments that is shown in this work only partly.

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