ISOIMPEDANCE INHOMOGENEOUS MEDIA IN ANTENNA APPLICATIONS

A.I.KNYAZ

Abstract. Inhomogeneous medium is isoimpedance one if the equality between ratio permittivity and permeability takes place. Electrodynamics and antenna applications of these materials are considered.

INTRODUCTION

There are well known the use of dielectric rods, lens, dielectric coatings for wires in the antennas constructions. This paper is devoted to justification of the main principle - so wave device as antenna demands application of the wave material which is the inhomogeneous isoimpedance medium (IIIM). At first (p.1), the wave effects in the IIIM have been described. In p.2, the similarity and conservation theorems for immersed antennas are given. Part 3 deals with the IIIM fabrication methods. Part 4 is devoted to the results review and further perspectives.

PART 1. The IIIM is determined with the equation $\sqrt{\mu/\varepsilon} = Z_0 = \text{const}$ when

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

The using curvilinear plane-basis and sphere-basis coordinates systems are :

$$A\begin{cases} \text{PBI} & x_3 = z, x_1 + ix_2 = f(x+iy), h_3 = 1; \\ \text{SBI} & x_3 = r, x_1 + ix_2 = f[(x+iy)/(r+z)], h_3 = 1; \end{cases} \qquad (2)$$

$$B\begin{cases} \text{PBII} & \mathrm{tg}x_3 = y/x, h_3 = \rho; \\ \text{SBII} & x_3 = az/r^2; \\ \text{SBIII} & x^2 + y^2 + (z - a\ \mathrm{ctg}x_3)^2 = a^2/\sin^2 x_3; \\ \text{SBIV} & x^2 + y^2 + (z - a\ \mathrm{cth}x_3)^2 = a^2/\mathrm{sh}^2 x_3; \end{cases} \qquad (3)$$

In group B the functions (1) are linked with Lame`s coefficients :

$\alpha(x_1,x_2,x_3) = h_{3c}/h_3(x_1,x_2,x_3),\ h_{3c} = \text{const}$ and in group A

$\alpha = \alpha(x_3), \alpha = \alpha(x_1,x_2), \alpha = \alpha(x_1,x_2,x_3)$ are arbitrary functions with variants: a) partly homogeneous, b) smoothly homogeneous, c)hybrid. As example, Fig. 1 shows the IIIM characteristic $\alpha(z)$ and constancy of the IIIM impedance $Z = Z_0 = 120\pi$ Ohm.

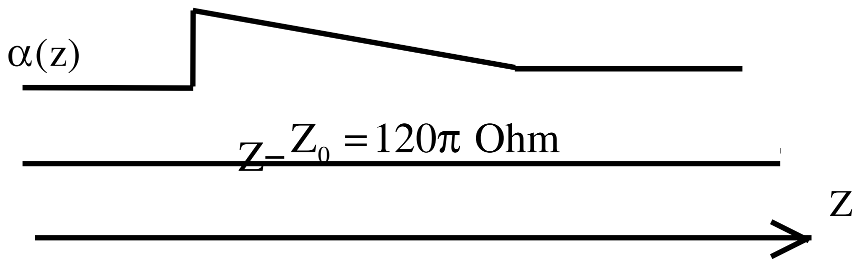

Fig . 1

Previous author's works [1-4] were devoted to the circular waves and coordinates of group B. It was shown that additionally to known T, E, H, EH-waves in the cylinder waveguides the similar ones take place in the channels waveguides with transverse intensities:

$$h\overline{E}_{\perp} = \overline{A}(x_1, x_2)e^{-jk_3h_{3c}x_3} \quad ,\left|\overline{H}_{\perp}\right| = \left|\overline{E}_{\perp}\right|/W \tag{4}$$

Simplest examples are attached with the plane-axis coordinates PBII $z, \rho, \varphi = \mathrm{arctg}(y/x)$, $\alpha = a/\rho$ where a-radius of IIIM cylinder with solution

$$E_{\perp} = E_z(\rho)e^{-jk_0a\varphi} \quad ,H_{\perp} = H_{\rho}(\rho)e^{-jk_0a\varphi} \tag{5}$$

TE circular waves (5) describe the principally new effect "refraction without reflection" (invisible cylinder , sphere) [5] when outer and inner fields are equal

$$E_z^0 = e^{-jk_0\rho\cos\varphi}, E_z = \sqrt{a/\rho}\sum_{-\infty}^{\infty}(-j)^n e^{jn\varphi} f_n(\rho), \tag{6}$$

$$f_n = J_n(\xi)\cos\eta + b_n^{-1}(0{,}5J_n + J_n')\sin\eta, \xi = k_0 a, \eta = \ln(\rho/a) \tag{7}$$

Formulae (6), (7) correspond to the situation when incident plane wave smoothly, without reflecting field, transmits through the IIIM cylinder.

In the article [6], the different variants of transmission without reflection with the cylinder and conical coordinates application have been investigated. The arbitrary longitudinal characteristics $\alpha(z)$ and normally to plane boundary z=0 incident wave are simply analyzed with the substitution

$$\exp(\pm jk_0 z) \rightarrow \exp[\pm jk_0 \int_0^z \alpha(z)dz] \tag{8}$$

It is important that any view $\alpha(z)$ doesn't disturb the boundary conditions fulfillment.

Next example is the guided wave which is going without reflection in the rectangular waveguide when space z>0 is filled with IIIM media. Appropriate solution is

$$\begin{aligned} z<0 \quad & E^0 = \sin Mx e^{-j\sqrt{k_0^2-M^2}z} \\ z>0 \quad & E = \sin Mx e^{\int_0^z \alpha\beta_i dz} e^{\int_0^z \alpha\beta_r dz} \end{aligned} \tag{9}$$

Application of the IIIM allows to create arbitrary amplitude distribution on the wave front. Sliding along x=o plane wave with arbitrary amplitude distribution in the IIIM may be represented with the formulae

$$x > 0 \quad E^0 = \exp(-jk_0 z)$$
$$x < 0 \quad E = e^{-k_0 \int_0^{k_0 x} \alpha\beta dx} e^{-jk_0 z} \tag{10}$$

$$\alpha = [\beta' + \sqrt{\beta'^2 + 4(1+\beta^2)}]/2(1+\beta^2) \tag{11}$$

The expressions (10), (11) with small changes describe [6] the wave without critical wavelength in the rectangular waveguide (Fig.2).

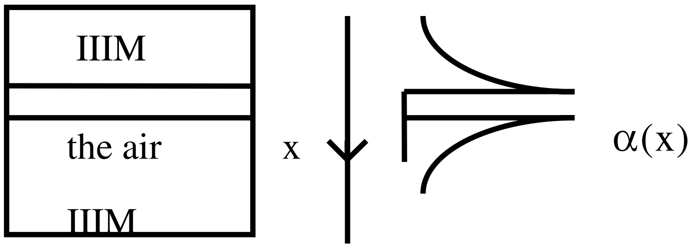

Fig.2

The IIIM synthesis methods are suggested in [7] where it is counted the influence of the IIIM characteristic on the oblique incident wave only. For example, the intensities in the problem about oblique incident plane wave and the plane boundary z=0 are

$$E^0 = E_y^0 = \exp[-jk_0(x\sin\theta_0 + z\cos\theta_0)] \tag{12}$$

$$E_y^R = R \ \exp[-jk_0(x\sin\theta_0 - z\cos\theta_0)]$$

$$E_y^T = T \ \exp[-jk(x\sin\theta_0 + \int_0^z \alpha\beta dz)] \tag{13}$$

$$\alpha^2(1-\beta^2) - jk_0^{-1}\alpha\beta_z' - \sin^2\theta_0 = 0$$

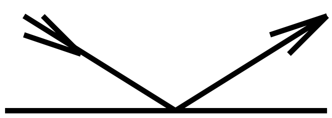

Fig.3

where (13) corresponds to reflected and transmitted waves.

The IIIM has different selectivity for different spectrum components of the normally incident wave beam:

$$E^0(x,z) = \int_{-\infty}^{\infty} F(\nu)\exp[j(\nu x - z\sqrt{k_0^2 - \nu^2})]d\nu \tag{14}$$

$$E^R(x,z) = \int_{-\infty}^{\infty} R(\nu)\exp[j(\nu x + z\sqrt{k_0^2 - \nu^2})]d\nu \tag{15}$$

$$E^T(x,z) = \int_{-\infty}^{\infty} T(\nu)\exp[j(\nu x - \sqrt{k_0^2 - \nu^2})\int_0^z \alpha(z)\beta(z,\nu)dz]d\nu \qquad (16)$$

1.5. List of the wave effects in presence of the IIIM :1)Multiplex superposition of the plane (sphere) fronts of the circular waves, 2)Refraction without reflection by special isoimpedance bodies, 3)Transmission without reflection for any IIIM characteristic $\alpha(z)$ view, 4)Independent amplitude and phase controls on the plane (sphere) wave front, 5)Angle selectivity change without influence on normal transmission, 6)Minimization of direct portion of the transmitted energy in the wave beam, 7)Formal calculating analogies for the known and new wave's types.

PART 2. Let us consider the immersion of the antennas in the IIIM. General recognition of the problem consists of combination of the Maxwell's equations and boundary equations for perfect conducting surfaces. There are considered two theorems: Proportional change (similarity) theorem and Conservation one. It is need to immerse an antenna wholly in the IIIM and then to produce the "Cut-off "procedures. In the paper, these theorems are considered with help of monopole field transformation (Fig. 4).

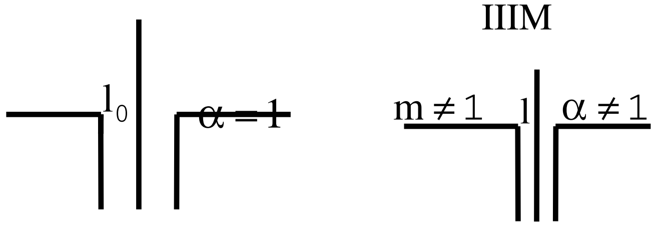

Fig.4

With using of the denotations

$$\alpha = \varepsilon_r = \mu_r \;, m = l / l_0 \qquad (17)$$

the proportional change (similarity) theorem is the following: Electrical characteristics of an antenna are changed in: a) m times if $m \neq 1, \alpha = 1$; b) α times if $m = 1, \alpha \neq 1$; c) $m\alpha$ times if $m\alpha \neq 1$.

Conservation theorem is used for $m\alpha = 1$: Electrical characteristics of an antenna are unchanged if the dimensions decrease in α times is following with the concerted increase of medium characteristic in α times.

"Cut-off" procedures are specified as the problem: To find $\alpha = \alpha(r,\theta,\varphi)$ and the perfect metal boundary configuration in order to have proportional change or constancy of the input and output electrical characteristics when the IIIM has finite sizes. In order to have the solution, one can to combine the above mentioned wave properties and the similarity-conservation theorems (finite IIIM synthesis).

On contrast to known publications we use the condition (1) obligatory that allows as theoretically so in an experiment to use not only small values of permittivity, permeability but very great ones. It is very important for practice as the possibility to create small antennas in any frequency bands. Fig. 5 shows the potential properties of real magnetic materials for antenna's sizes decrease.

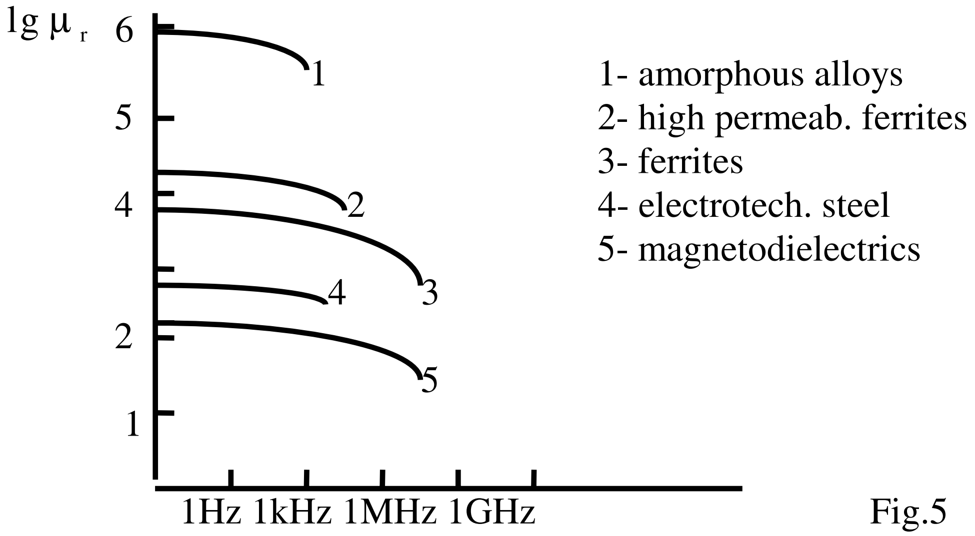

Fig.5

PART 3. The problem of the isoimpedance materials fabrication with details is considered in [5]. We can to use following methods: 1.Ferro-dielectric compositions (Particles of the magnetic and dielectric materials), 2.Ferro-aluminum compositions (Particles (rods, strips) of the magnetic material and perfect conducting metal), 3.Lumped metal-air realization (Particles of the perfect conducting metal and special turns),.4.Wave metal-air realization (Combination of the metallic plates, strips). Shown realization techniques have two variants of justification. First of them is the quasistatic method where the IIIM parameters are tested separately in the electrical and magnetic fields:

$$\varepsilon_r = 1 + P / E\varepsilon_0 \ , \mu_r = 1 + M / H\mu_0 \qquad (18)$$

According to second (wave) method it is necessary to find for travelling wave the refraction coefficient n and ratio impedance z_C :

$$\varepsilon_r = n / z_c , \mu_r = nz_c , \ \ n = c_0\beta / \omega, z_c = E_\perp / H_\perp Z_0 \qquad (19)$$

The different artificial materials are given in the 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

PART 4. The IIIM applications for the antennas optimization problem solutions have the great perspectives. Appropriate benefits are:

1. Conservation of the optimum characteristics for shorten antennas

2. Invisible lossless bodies
3. New lens ideology for beam pattern forming
4. IIIM bodies as buffers for wave (laser or acoustic) beams
5. Mobile VLF, LF, MF antennas
6. Antennas for the energy relay transmission
7. New types of the guide systems.

Of course, we have many problems. Some of them are the following:

1. Who will make the invisible body first?
2. What types of antennas are necessary to realize with IIIM application primarily?
3. How to combine the great advantages of the Microelectronics Technology with new demands of the IIIM realization?

CONCLUSION

RIGID LOGICAL CHAIN: ANTENNA IS WAVE TRANSFORMER-TRANSFORMATION TAKES PLACE IN ELECTROMAGNETIC VOLUME - THIS VOLUME MUST BE FILLED WITH WAVE MATERIAL= ISOIMPEDANCE INHOMOGENEOUS MEDIUM

REFERENCES

1. Knyaz A.I. Electrodynamical Boundary Problems. Odessa: Pub. of Odes. Electrotechn. Instit. of Svyazi (OEIS),1991.-120 p. (R)

2. Knyaz A.I. Circular Waves In Channels Waveguides / book "Devices and Methods of Applied Electrodynamics"(Proc. of second All-union science-techn. Conf.). - Od.-Moscow: Pub. of Mosc. Aviat. Inst., 1991, p. 22. (R)

3. Knyaz A.I. Circular Waves in the Channel Waveguides // Trans. of 14th Intern. Sympos. on Electromagnet. Theory, Australia, August,1992, p. 248-250.

4. Knyaz A.I. Information Systems Electrodynamics. - M.: Radio i svyaz, 1994. - 392 p.(R)

5. Knyaz A.I. Binary Materials In Radio Electronic Devices, Ukranian state Academy of Telecommunication, Odessa, 1994, 80 p.

6. Knyaz A.I. Non-reflecting Action of Inhomogeneous Isoimpedance Media, in book “Telecommunications Problems” Kiev : Tehnica ,1995 ,p.10-14

7. Knyaz A.I. Inhomogeneous Isoimpedance Media Synthesis, Proc. of Ukr. scient. radio and television institute, N 4, Odessa,1995