Isoimpedance Inhomogeneous Media

Arkadi Knyaz

Abstract. Technical devices are usually immersed in the air as isoimpedance medium with the intrinsic impedance $Z_0 = \sqrt{\mu_0 / \varepsilon_0} = 377$ Ohms. This value is also observed in any point of the inhomogeneous isoimpedance magnetodielectric (IIMD) if the numerical equation for relative permittivity and permeability $\varepsilon_r(x,y,z) = \mu_r(x,y,z) = \alpha(x,y,z)$ takes place. This paper is devoted to theoretical and practical results dealing with IIMD applications: 1) ultimate small antennas immersed in IIMD, 2) lossless reflectionless refractors («invisible hats»), 3) electromagnetic wave pressure engine (for «flying plates»).

Introduction. Inhomogeneous isoimpedance magnetodielectrics (IIMD) are determined with help of equation

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

when $\sqrt{\mu / \varepsilon} = Z_0 = \text{const}$. Besides well-known (after Fresnel) trivial impedance matched case when $\alpha(\mathbf{z}) = \mathbf{const}$ is step-constant value and the traveling wave has the plane-parallel fronts z=C, numbers variants of the waves in IIMD with functions

$$\alpha(x_1, x_2, x_3) = h_{3C}(x_{10}, x_{20}, x_{30}) / h_3(x_1, x_2, x_3) \qquad (2)$$

are investigated [1-3]. Formula (2) is given in the special plane-basis (2 classes) and the sphere-basis (4 classes) curvilinear coordinates with Lame`s coefficients $h_1 = h_2 = h,\ h_3$.

Waves with the parallel fronts. Plane-parallel waves in IIMD with arbitrary function $\alpha = \alpha(z)$ are investigated [3] where the synthesis method for characteristic $\alpha = \alpha(z)$ reconstruction is also suggested. Sphere-parallel waves in IIMD with radial inhomogeneous function $\alpha = \alpha(r)$ are most important for utmost small size immersed antennas. It is principally mandatory [2] to regard the presence of the longitudinal (radial) intensity vector components in order to refine well-known impedance relation between intensities transverse components. Appropriate similarity theorems are given in [3].

Waves with the non-parallel fronts. Besides above considered plane-parallel and sphere-parallel waves when $\mathbf{x}_3 = \mathbf{z}$ or $\mathbf{x}_3 = \mathbf{r}$ one could to introduce else four curvilinear coordinates systems [1] with

$$\begin{array}{ll} \mathrm{tg}x_3 = y/x, & x_3 = az/r^2, \\ x^2 + y^2 + (z - a\ \mathrm{ctg}x_3)^2 = a^2/\sin^2 x_3, & x^2 + y^2 + (z - a\ \mathrm{cth}x_3)^2 = a^2/\mathrm{sh}^2 x_3 \end{array} \qquad (3)$$

As new so traditionally determined (TEM, E, H, EH) waves have the fields intensities

$$h\overline{E}_{\perp} = \overline{A}(x_1, x_2)e^{-jk_0 h_{3C} x_C}, \quad |\overline{H}_{\perp}| = |\overline{E}_{\perp}| / Z_0 \qquad (4)$$

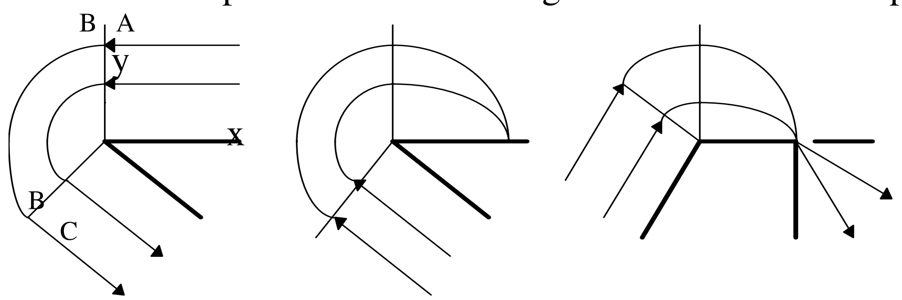
According to (3) new waves are ones with non-parallel phase fronts and they are called as : 1) plane-axis, 2) sphere-point, 3) sphere-axis, 4) bi-spherical waves. Isoimpedance media for these waves have according to (2) the following representations

$$\alpha = a/\sqrt{x^2+y^2} = a/\rho, \qquad \alpha == a^2/(x^2+y^2+z^2) = a^2/r^2,$$
$$\alpha = b^2/\sqrt{(r^2+a^2)^2 - 4\rho^2 a^2}, \qquad \alpha = b^2/\sqrt{(r^2+a^2)^2 - 4z^2a^2} \qquad (5)$$

Generalization of the expressions (4) for waves in the anisotropic isoimpedance magnetodielectrics are given in [2].

About isoimpedance media realization. At least, four methods of the IIMD realization may be suggested: 1) as composite material from dielectric and magnetic particles when equation (1) takes place, 2) as combination of the metallic particles and small loops with capacity [3], 3) multi-layer construction from ready dielectric and magnetic plates, 4) self-matched decelerating conducting chain structures [3,chapter 3]. More details will be represented in the lecture.

Composed full-transparent media and waves. One could to combine different inhomogeneous media with characteristics (5) and to have smooth reflectionless transition for composed wave consisting of the ones with non-parallel fronts.



a b c

Fig.1

For example [3], Fig.1 shows the energy flow lines for three composed waves: a) plane-parallel $\Rightarrow$ plane-axis $\Rightarrow$ plane-parallel, b) plane-parallel $\Rightarrow$ plane-axis $\Rightarrow$ bi-spherical, c) plane-parallel $\Rightarrow$ plane-axis $\Rightarrow$ bi-spherical $\Rightarrow$ sphere -parallel ones. Appropriate formulae for the wave type a) are the following:

$$\text{(A)}\ \overline{E} = \overline{y}_0 E_0 e^{jk_0 x}, \ \text{(B)}\ \overline{E} = (\overline{x}_0 \cos\varphi + \overline{y}_0 \sin\varphi)E_0 e^{-jk_0 a(\varphi - \pi/2)},$$

$$\text{(C)}\ \overline{E} = (\overline{x}_0 \sin\varphi_0 - \overline{y}_0 \cos\varphi_0)E_0 e^{-jk_0(x\cos\varphi_0 + y\sin\varphi_0) - jk_0 a(\varphi - \pi)}$$

Reflectionless losless refraction is the basis for the invisible (full-transparent) bodies and coatings creations. Additional possibilities occur for combinations of the lossless IIMD refractors and traditional («black») absorbers.

Electromagnetic wave pressure engine. More one hundred years ago J.C.Maxwell theoretically and P.N.Lebedev experimentally studied the light wave pressure. Our proposals [3] are to give the electromagnetic energy from IIMD (but not from the air) on the absorbing (or perfect conducting) wall. It allows to intensify this effect in the five (six) orders because electromagnetic energy density in IIMD is higher in α times in comparison with one in the air.

With help of Fig.2 one could to estimate necessary voltage U(kV) and current I(A) in order to push with force F (Newton) the electromagnetic pusher consisting of the IIMD and metallic spacers. The straight lines 0,1,...6,7 are corresponded to the media characteristics $\alpha = 1,\ 10^1,...10^6,10^7$. Results are given for coaxial construction of the electromagnetic wave pressure engine - half wave length resonator.

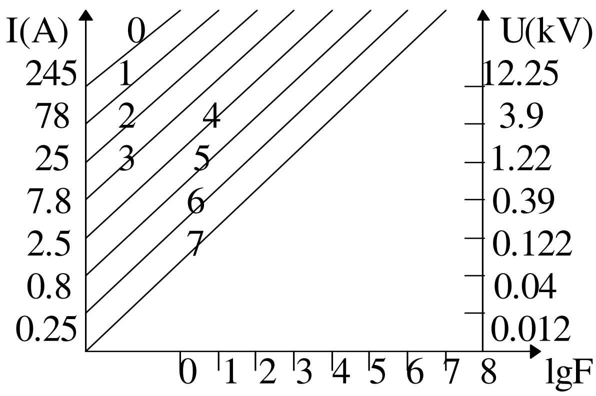


Fig.2

Very interesting parameter is a ratio of the demanding power to desired force

$$\eta = \frac{P}{F} = \frac{\omega_0 W_m^m}{QF} = \frac{4\pi c_0}{\alpha Q} \approx \frac{4\cdot 10^9}{\alpha Q} \tag{6}$$

The Fig.3 is given according to the formula (6). Working compromise between source power **P**, media parameter α, quality factor Q is corresponded to shown triangle.

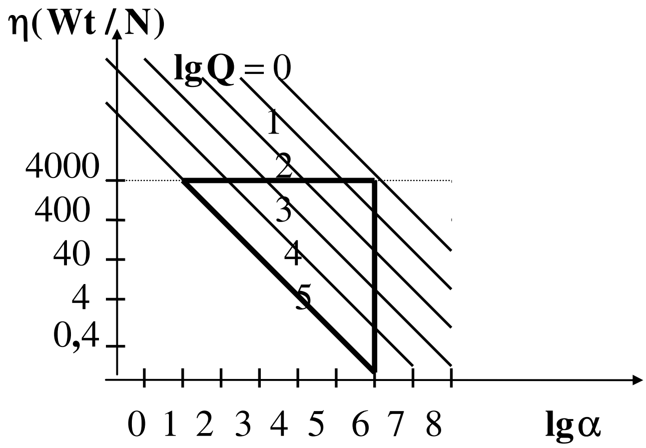


Fig.3

Conclusion. Wave materials - isoimpedance (full-transparent) media must be created artificially. Traditional positive properties of the impedance matched wave regime are reproduced in a number variants of the inhomogeneous isoimpedance media with new types of plane and spherical waves. At least, three great areas for practical applications have been shown: 1) utmost small antennas, 2) reflectionless lossless refractors, 3) electromagnetic wave pressure engines.

References

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