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COMPARATIVE ANALYSIS OF THE WAVE CHARACTERISTICS OF CIRCULAR AND RECTANGULAR WAVEGUIDES WITH GYROTROPIC FILLING

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A comparative analysis of the propagation constants of the structurally similar H_{01}-mode of a circular waveguide and the H_{10}-mode of a rectangular waveguide with transversely magnetized ferrite fillings is presented, based on a rigorous electrodynamic calculation.

Circular and rectangular waveguides supporting the H_{01} and H_{10} modes, respectively, are electromagnetic analogs, and hence, when they are filled with different material media they can serve as a basis for a comparative analysis of the wave processes that occur in them. We choose as such a filling a ferrite layer lying in the E-plane and, to fix our ideas, we assumed the layer to be close to the side of an ideally conducting wall of the waveguide (Fig. 1).

A ferrite plate and a concentric layer in the waveguides are magnetized transverse to the direction of propagation by a magnetic field along the lines of force of the high-frequency electric field. In the circular waveguide this ferrite layer is magnetized in the azimuthal direction.

The geometrical dimensions of the fillings are chosen so as to achieve the same type of interaction between the electromagnetic field and the material without departing from the assumed relations between the dimensions of the waveguides and the wavelength. The filling factor of the waveguides with ferrite was taken to be 5.6% and $r/\lambda_0 = 0.719$, where λ_0 is the wavelength in the empty waveguide and r is the radius of the circular waveguide.

Both the linear and azimuthal transversely magnetized ferrite medium is characterized by a magnetic permeability tensor of the form

$$\bar{\mu} = \begin{vmatrix} \mu & 0 & i\mu_\alpha \\ 0 & \mu & 0 \\ -i\mu_\alpha & 0 & \mu_{\parallel} \end{vmatrix}.$$

We used the Landau–Lifeshite model [1] to calculate the components of the magnetic permeability tensor

$$\mu_\alpha = p/(\sigma^2(1+\alpha^2) - 1 + 2i\alpha\sigma), \quad \mu = 1 + \mu_\alpha(\sigma(1+\alpha^2) + i\alpha),$$

where $p = 4\pi M|\gamma|/\omega$ is the relative magnetization of the ferrite $\sigma = H_0|\gamma|/\omega$ is the absolute value of the state magnetizing field, $|\gamma|$ is the absolute value of the gyromagnetic ratio, α is the dimensionless attenuation parameter, and $i = \sqrt{-1}$. For a ferrite medium magnetized to saturation, the diagonal component $\mu_{\parallel} = 1$. The permittivity of the ferrite was chosen to be $\varepsilon = 11$.

The relative magnetization of the ferrite fillings in the mathematical modeling was varied from $p = 0.2$ to $p = 1.0$. The relative value of the magnetizing field was varied over a wide range $\sigma = 0$-2, included the subresonance, resonance, and beyond-resonance values. The attenuation parameter $\alpha = 0.07$.

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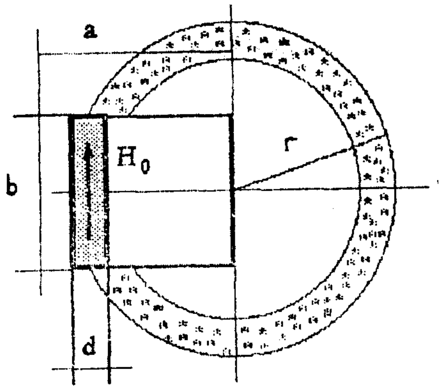

Fig. 1. Transverse cross-section of the wave-guiding structures considered, showing the geometrical dimensions and the direction of the magnetizing field.

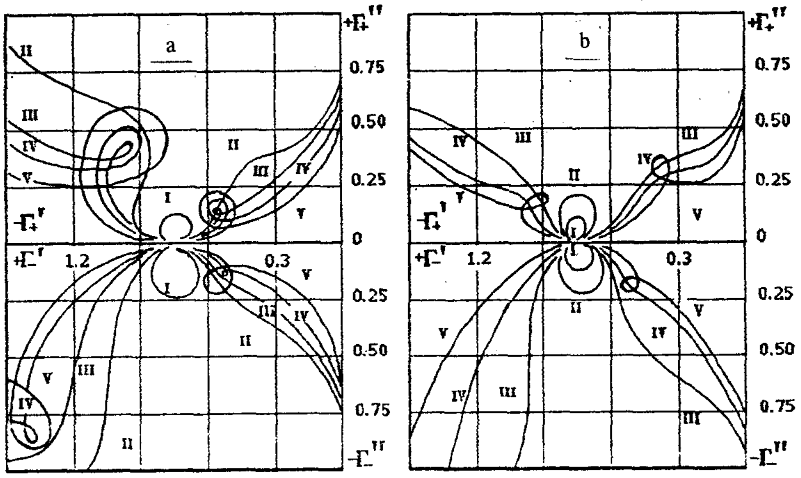

Fig. 2. Complex propagation constant Γ as a function of the relative parameters of the saturation magnetization p and the magnetizing field σ for a circular waveguide (a) and for a rectangular waveguide (b).

To obtain numerical values of the complex propagation constants $\Gamma_{\pm} = \Gamma_{\pm} + i\Gamma_{\pm}$ of the forward wave (subscript +) and the backward wave (subscript −) as a function of σ and p we used algorithms and methods developed in [2-4], and also numerical integration of the eigenvalue problem for the system of generalized wave equation.

In Fig. 2 we show, in parametric form, in the complex plane Γ, bounded by an absolute value of the attenuation of unity, the results of calculations of the propagation constants for a continuous change in the magnetizing field σ for a number of discrete values of the relative magnetization p (0.2, 0.4, 0.6, 0.8, and 1.0 – curves I-V). In the figures the same values of σ are represented by the same arbitrary numbers. The question of the evolution of higher and other modes, present in the waveguide structures considered, is outside the scope of this paper.

It can be seen from Fig. 2, that for small values of p closed curves, close in form to circles, touch the real axis of $\Gamma_{\pm}$. These curves correspond to the propagating quasi-H_{10} mode of a rectangular waveguide and the quasi-H_{01} mode of a circular waveguide. The backward wave in a rectangular waveguide suffers greater attenuation than the forward wave, while in a circular waveguide the isolation ratio $\Gamma_{-}\Gamma_{+}$ is close to unity. The situation changes as p increases, and this ratio increases more rapidly for a circular waveguide than for a rectangular waveguide. One other feature of a circular waveguide compared with a rectangular waveguide is the fact that the absolute value of the loss is twice as great for the forward and backward waves. This is obviously due to the absence in the rectangular waveguide of a ferrite plate on the right-hand wall. It follows from a consideration of the ratios of the slowing factors of the forward and backward waves that they are considerably higher in the rectangular waveguide than in the circular waveguide.

A further increase in p leads to a break in the closed curves and the appearance of two branches on the left and right sides of the figures. Each of the branches represents the conversion of the modes considered into higher modes (the right branch) and vice versa (the left branch). A break in the closed curve for the rectangular waveguide occurs for larger values of the magnetization than for the circular waveguide. The behavior of the propagation constants depends very much on the value of p. When $p > 0.5$, in the region of the ferromagnetic resonance the $\Gamma(\sigma)$ curve has a complex form. A loop occurs on the curve, which can be interpreted as competition between higher modes, into one of which the mode considered is converted. If we consider the right branch (conversion into higher modes), then for larger values of p we can obtain a reduction in the loss for the forward wave. In the rectangular waveguide this leads to an increase in the phase shift for an isolation ratio close to unity. The circular waveguide in this region behaves as a reciprocal device both with respect to phase and with respect to losses. The situation changes considerably when we consider the transition from higher modes to the dominant mode (the left branch). For this branch there is both a high isolation ratio and a large phase shift for both waveguides.

An analysis of the field structure of the waveguides shows that the break in the closed curves leads to a considerable readjustment of the field pattern and can be classified from the point of view of the qualitative theory of the solutions of differential equations as a bifurcation phenomenon.

The results of the above analysis can be used to construct physical models of microwave ferrite devices and to optimize their characteristics.

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