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Frequency Splitting Effect of Degenerate Modes in Ferrite Resonators

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Abstract—The splitting of magneto-dielectric modes frequency in disk ferrite resonators in a magnetic field is considered. A simplified formula is obtained for estimation of the splitting magnitude. Theoretical and experimental results of the frequency splitting effect in magneto-dielectric modes in the millimeter wave range are compared. The use of the splitting of the magneto-dielectric modes frequencies as an alternative to ferromagnetic resonance in devices with magnetic frequency tuning is suggested, with values of the magnetization fields being an order of magnitude lower than for ferromagnetic resonance. The features of the splitting modes effect in different ferrite classes are investigated and it is shown that it occurs in both microwave and optical ranges. The estimated magnitude of the mode frequency splitting in the iron-yttrium garnet (YIG) transparency window can reach 9 GHz, which is comparable to the 5 GHz splitting in the millimeter range. The frequency ranges where frequency splitting effect is of practical interest are discussed. In particular, the effect in barium hexaferrite can be used both in post-resonance and pre-resonance regions, which is almost impossible for ferrogarnets and ferrospinels.

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INTRODUCTION

The frequency degeneracy of eigen waves and oscillations is quite common. In electrodynamic systems with axial symmetry, azimuthally inhomogeneous modes are at least doubly degenerate [1], since there is a so-called polarization degeneracy. The latter is understood as a fact that modes with different polarization of electromagnetic fields have the same frequency.

The formal sign of degeneracy is the quadratic dependence of mode frequencies on azimuthal index. In relation to a homogeneous isotropic infinite medium, it can be regarded as axially symmetric with respect to the propagation direction of electromagnetic waves. Therefore, the eigen waves are doubly degenerate and both eigen waves have the same dispersion characteristics independent of the field polarization, which can be either linear or circular [2].

Axially inhomogeneous modes H_{mn} and E_{mn}, EH_{mn} and HE_{mn}, in circular hollow metallic waveguides and open dielectric waveguides respectively, are at least doubly degenerate, since $m \neq 0$ [2, 3]. Since resonator is often a waveguide section, the eigenmodes of axially symmetric resonators, for example, of the most common cylindrical and disk resonators [1, 4], are degenerate for $m \neq 0$.

Degeneration of axially inhomogeneous modes is discarded if an axial symmetry of the electrodynamic system is lost [5], if losses in metal walls and associated loss of eigenmodes orthogonality are taken into account [6] or if at least partial filling of the electrodynamic system with gyrotropic media takes place [7].

The splitting of frequencies of degenerate modes with different polarizations in axially symmetric ferrite resonators arises from their magneto-gyrotropic properties. Thus, the effect of frequency splitting in magneto-dielectric modes of ferrite resonators means the removal of the frequency degeneracy of the azimuthally inhomogeneous modes in the presence of a magnetizing field or self-magnetization, and the magnetic frequency tuning that arises in this case. This effect is fundamental for circulators [8].

Such peculiarity of the effect as frequency tuning by a magnetic field is of particular practical interest, considering that the problem of frequency tuning of resonators in the centimeter and millimeter ranges remains relevant at the present time for filters [9–13], circulators [14], phase shifters [15, 16] and antennas [17]. The studies of the gyrotropic materials behavior deserve separate attention [18–21].

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