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# Splitting Axially Heterogeneous Modes in Microwave Gyromagnetic and Gyroelectric Resonators

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**Abstract**—Theory of calculating eigenmodes spectrum for gyrotropic resonators when using scalar potentials formalism is developed. Equations for calculating splitting of resonant frequencies of gyromagnetic and gyroelectric cylinder resonators in magnetic field are derived. Theoretical results are compared to the experimentally obtained figures for microwave gyromagnetic resonators made of barium hexaferrite. Example of a resonator made of indium antimonide demonstrates the possibility of using magnetized semiconductor resonators cooled to liquid nitrogen temperature to achieve the same characteristics offered by resonators made of magnetically firm hexaferrites when designing unidirectional microwave devices.

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## INTRODUCTION

Microwave band is of great interest to applications connected with wireless communications systems, auto radars, radioastronomy and satellite communications systems [1]. Circulators based on gyrotropic resonators are an essential part of transceiving equipment. A number of designs uses the phenomenon of splitting resonant frequencies of azimuth-heterogeneous modes in gyrotropic resonator which possesses cylinder symmetry.

Extension of the operating frequency range for waveguide H-circulators is accomplished by using gyrotropic resonators that partially fill the waveguide's height. In a resonant system consisting of such devices, in contrast to microstrip Y-circulators, axial (along the junction axis) resonances are observed providing an additional degree of freedom (sample's height) and expanding the control of resonator's eigenmodes spectrum.

To calculate ferrite resonators partially filling the waveguide's height both analytical (eigen oscillations method [2]) and numerical (FDTD [3], FEM [4]) methods are used. However the available literature seems to have left unconsidered splitting of eigenmodes in gyrotropic resonators with axially heterogeneous resonances accounting for the resonator's open side wall.

Decreasing the mass and dimensions of magnetic system of unidirectional microwave devices is achieved by using gyrotropic resonators made of magnetically firm hexaferrites with strong uniaxial anisotropy fields. In a number of cases this allows fully eliminating the magnetic system [5].

Another alternative of designing unidirectional microwave devices expects using a sample of lightly doped semiconductor with high charge carrier mobility, for example, InSb, cooled to liquid nitrogen temperature as a resonator. When placing such a resonator in constant magnetic field it reveals gyroelectric properties, hence splitting the resonator's eigenmodes and favoring circulation. Such mode splitting in disc and ring gyroelectric semiconductor resonators is considered in [6]. In this case a special case of a resonator with a boundary electric wall on the side wall without electromagnetic field variations along the magnetization direction was analyzed.

Meanwhile when designing waveguide H-circulators consideration of spectrum of axially heterogeneous oscillations in magnetized cylinder semiconductor resonator partially filling the rectangular waveguide's height as well as estimation of resonator's eigenmodes splitting in magnetic field is of significant practical interest.

This paper aims to develop analytical theory of calculating splitting of resonant axially heterogeneous eigenmodes in gyromagnetic and gyroelectric cylinder resonators.