Propagation through chiro-ferrite slab waveguides

N. Iqbal and P.K. Choudhury*
Institute of Microengineering and Nanoelectronics (IMEN) Universiti Kebangsaan Malaysia 43600 UKM Bangi, Selangor, Malaysia
*E-mail: pankaj@ukm.edu.my

I. Introduction

Propagation and scattering problems dealing with different geometries along with various forms of mediums have been studied [1,2]. With the advent of modern optical technologies, metamaterials have become vital in tailoring wave propagation as desired. Particularly chiral and chiral nihility mediums got enough attention in the context of fabricating negative refractive index (RI) materials [3,4]. The design of a dispersion compensator [5] based on these mediums has great importance in optics. Chiro-ferrite material is another form of composite medium [6] having both chiral and ferrite properties, and find fabulous applications in numerous nonreciprocal devices such as phase shifters, isolators and circulators. In this short report, the dispersive characteristics of chiro-ferrite slab waveguide are investigated. Effective indices are evaluated corresponding to various values of material parameters for low-order modes.

II. Theory and Discussion

We consider a chiro-ferrite slab waveguide, wherein the core section has such material of width $2h$ along the x-axis, and infinitely extended along the z-axis. The clad section is free-space, and infinitely extended along the x- and the z-axes. The axial time t-harmonic field components in the guide are

$$E_{z1} = A_{1+}\cos(s_+x) + A_{1-}\cos(s_-x) \qquad |x| < h \qquad (1)$$

$$E_{z2} = A_{2+}e^{-\tau_+(|x|-h)} + A_{2-}e^{-\tau_-(|x|-h)} \qquad |x| > h \qquad (2)$$

Here $A_{1\pm}$ and $A_{2\pm}$ are unknown constants, the values of which can be determined by using the boundary conditions. Also, the quantities $s_\pm$ and $\tau_\pm$ are wavenumbers in the core and the clad sections, respectively, which can be evaluate by solving the coupled wave equations, as deduced upon using the constitutive relations (of chiro-ferrite medium) into Maxwell's equations.

Considering the dispersion characteristics of chiro-ferrite slab waveguide, similar to chiral mediums, chiro-ferrites also support hybrid modes only. The dispersion relation can be obtained upon implementing the boundary conditions which, in turn, would yield the cutoff frequency. We consider three low-order hybrid modes ($m = 0, 1$ and 2), and evaluate the dependence of respective effective RIs against the normalized frequency. The parameters present in permeability tensor $\bar{\bar{\mu}}$ of chiro-ferrite material [6] are; μ, μ_z and k, which for the case of non-magnetic chiral material assume the form as $\mu = \mu_z = \mu_0$ along with $k = 0$. We assume the admittance of such chiral medium as $\xi = 0.002$S.

The dispersion plots in terms of the effective RIs against the normalized V-parameter are shown in fig. 1. We observe that, for the $m = 0$ mode, n_{eff} increases with the increase in frequency, and then it starts decreasing after a certain value of V. For the other modes ($m = 1$ and $m = 2$), however, the value of n_{eff} increases slowly with increasing V.

For the case of chiro-ferrite material, the parameters of permeability tensor $\bar{\bar{\mu}}$ would assume the values as $\mu = 0.5\mu_0$, $k = 0.4\mu_0$, $\mu_z = \mu_0$ along with the same admittance value (μ_0 being the free-space permeability); the respective dispersion plots are shown in fig. 2. We observe in this case that n_{eff} remains almost constant for the entire frequency range corresponding to $m = 0$ mode, whereas for the other modes, it decreases with V. We find that the cutoff frequencies for this case are higher than the non-magnetic chiral material having the same admittance value of modes.

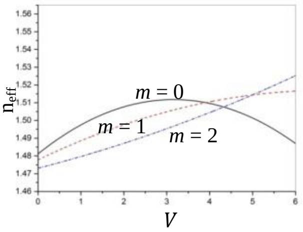

Fig. 1: n_{eff} vs. V in chiral case.

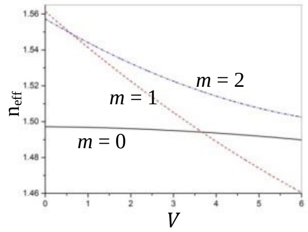

Fig. 2: n_{eff} vs. V for $\xi = 0.002S$.

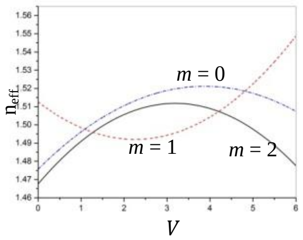

Fig. 3: n_{eff} vs. V for $\xi = 0.0022S$.

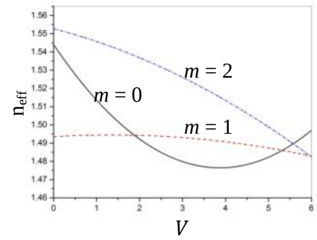

Fig. 4: n_{eff} vs. V for $\xi = 0.0025S$.

Upon increasing chirality parameter as $\xi = 0.0022$S and $\xi = 0.0025$S, the respective dispersion plots are illustrated in figs. 3 and 4. We notice that the dispersion features are greatly altered, and the cutoff frequency for chiro-ferrite material based guides decreases with the increase in admittance value.

III. Conclusion

Effective RIs are analyzed against the normalized frequency for different values of material parameters taking into account a few low-order modes sustained in the chiro-ferrite guide. The cutoff frequency for chiro-ferrite guide is found to be higher than that of the chiral counter-part (of the guide). Effects on the propagation characteristics are investigated under varying features of the magnetic medium.

References

[1] N. Iqbal and P.K. Choudhury, "Scattering from silver metal cylinder due to L-nihility coated with conducting sheath helix embedded dielectric medium," J. Mod. Opt., In Press.

[2] N. Iqbal and P.K. Choudhury, "Dispersion features of conducting sheath helix embedded elliptical and circular fibers with chiral nihility core," J. Nanomat. 2015; 2015: Article ID 912569.

[3] A. Lakhtakia, "An electromagnetic trinity from 'negative permittivity' and 'negative permeability'," Int. J. Infrared and Millimeter Waves 23, pp. 813–818, 2002.

[4] S. Tretyakov, I. Nefedov, A. Sihvola, S. Maslovski, and C. Simovski, "Waves and energy in chiral nihility," J. Electromagn. Waves and Appl. 17, pp.695–706, 2003.

[5] N. Iqbal and P.K. Choudhury, "Tailoring of group velocity dispersion in dual-core chiral nihility waveguide," J. Electromagn. Waves and Appl., In Press.

[6] N. Engheta, D.L. Jaggard, and M.W. Kowarz, "Electromagnetic waves in Faraday chiral media," IEEE Trans. Antenna and Propagat. 40, pp. 367–374, 1992.