16a-D4-3

Propagation Modes through Circular DB waveguide Loaded with Uniaxial Chiral Metamaterial

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1. Introduction

Metamaterials are artificially designed structures that owe unusual features [1, 2]. These gain exotic properties due to their structures rather than the composition. Metamaterials are used in many spectacular applications, e.g. cloaking, perfect lensing and power confinements [1–4]. In the present work, we investigate the propagation pattern of energy flux density through circular waveguide made of uniaxial chiral metamaterial, bounded by the DB medium. DB boundary conditions are relatively new wherein the normal components of electric/ magnetic fields become zero at its interface. These are defined as

$$\hat{n}\cdot\vec{B} = 0 \text{ and } \hat{n}\cdot\vec{D} = 0 \qquad (1)$$

2. Theory and Discussion

We consider a circular waveguide having its radius r, and infinitely extended along the z-axis The core section is composed of uniaxial chiral metamaterial while the outer surface has DB boundary. We consider a time t-harmonic and axis z-harmonic waves to propagate through the guide along the +z-direction. Now, the constitutive relations for uniaxial chiral metamaterials are prescribed as [6]

$$\vec{D} = \left[\varepsilon_t \bar{\bar{I}}_t + \varepsilon_z \hat{u}_z\hat{u}_z\right]\cdot\vec{E} - j\kappa\sqrt{\varepsilon_0\mu_0}\hat{u}_z\hat{u}_z\cdot\vec{H} \qquad (2a)$$

$$\vec{B} = \left[\mu_t \bar{\bar{I}}_t + \mu_z \hat{u}_z\hat{u}_z\right]\cdot\vec{H} - j\kappa\sqrt{\varepsilon_0\mu_0}\hat{u}_z\hat{u}_z\cdot\vec{E} \qquad (2b)$$

Where ε_t and μ_t are, respectively, the permittivity and the permeability of medium, in the transverse direction, while ε_z and μ_z are those along the axial direction. Further, κ defines the chirality parameter and the unit transverse dyadic is given as

$$\bar{\bar{I}}_t = \hat{u}_x\hat{u}_x + \hat{u}_y\hat{u}_y \qquad (3)$$

Investigations have been made of the energy flux density patterns through the core section of the guide corresponding to the allowed values of propagation constant β (m^{-1}), as deduced by implementing suitable boundary conditions at the DB interface. The continuity conditions require vanishing normal components of electric/magnetic fields at the DB interface [3]. The values of unknown coefficients and the expression for flux density through the guide are deduced by adopting the procedure used in refs. [3, 4].

Figures 1 and 2 demonstrate the behavior of energy flux densities through the core region of the guide, corresponding to Type I and Type II mediums, respectively, as defined through the captions of the respective figures. Also, in both the figures, (a) and (b), respectively, correspond to the situations when the radii values are considered to be 20 μm and 60 μm. It is noteworthy that chiral mediums can sustain only hybrid modes, and therefore, studies have been made for the two low-order propagating modes H_{-11} and H_{11}, and the corresponding natures are represented by dashed and solid lines, respectively, in figs. 1 and 2. The obtained β-values for the respective modes are stated in the inset of figures, which demonstrate that the energy flux density is maximally confined in the central region of the guide. Moreover, the flux density patterns are altered by changing the material type as well as the radial dimension of the guide. The noticeable feature remains that both forward as well as backward waves are sustained by the guide.

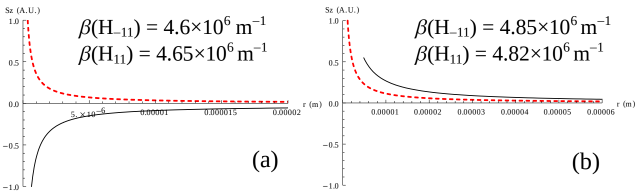

Fig. 1: Plots of energy flux density vs. r (Type I medium with $\mu_t = \mu_z = \mu_0$, $\varepsilon_t = 2\times\varepsilon_0$, $\varepsilon_z = \varepsilon_0$ and $\kappa = 2$).

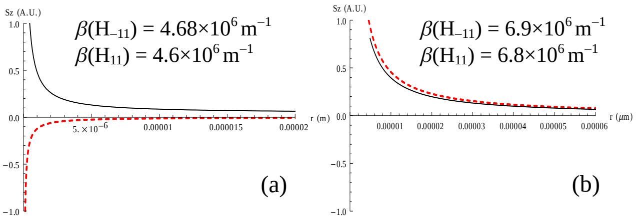

Fig. 2: Plots of energy flux density vs. r (Type II medium with $\mu_t = \mu_z = \mu_0$, $\varepsilon_t = \varepsilon_0$, $\varepsilon_z = -2\times\varepsilon_0$ and $\kappa = 2$).

2. Conclusion

Energy flux density patterns through uniaxial anisotropic chiral medium bounded with DB interface are analyzed. It has been found that the trends of flux density can be altered by introducing changes in constitutive parameters as well as dimensions that would lead to even backward waves in the guide.

References

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