Effect of damping coefficient of precession on the transmission of electromagnetic waves through a structure containing ferromagnetic material waveguide

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Abstract

The electromagnetic wave propagation through a structure consisting of left-handed material (LHM) and dielectric slabs embedded in vacuum is analysed theoretically and numerically. The LHM is composed of magnetized ferrites to provide a negative permeability and a wire array to provide a negative permittivity. Maxwell's equations are used to determine the electric and magnetic fields of the incident waves at each layer. Snell's law is applied and the boundary conditions are imposed at each layer interface to calculate the reflected, transmitted and loss powers of the structure. Numerical results are illustrated to show the effect of frequency, LHM thickness, applied magnetic fields and ferrite permittivity on the transmitted power of the structure as the damping coefficient of precession of ferrite changes. The obtained results are in agreement with the law of conservation of energy.

1. Introduction

Metamaterials (sometimes termed left-handed materials (LHMs)) are materials whose permittivity e and permeability m are both negative and consequently have negative index of refraction. These materials are artificial and theoretically discussed first by Veselago [1] over 40 years ago. The first realization of such materials, consisting of split-ring resonators (SRRs) and continuous wires, was first introduced by Pendry [2, 3].

Magnetized ferrite is an additional alternative to SRR to provide negative permeability. This ferrite has tuneable properties by varying the applied bias magnetic fields, and exhibits negative permeability at a certain frequency band. Consequently, a tuneable LHM can be constructed by inserting periodic continuous wires into the magnetized ferrite waveguide [4-7]. Y. He et al [8] have studied the role of ferrites in negative index metamaterials. M. Augustine et al [9] have formulated a theoretical analysis of ferrite-superconductor layered structures. H. Zhao et al [10] have studied a magnetotunable left-handed material consisting of yttrium iron garnet slab and metallic wires.

In this paper, we consider a waveguide structure consisting of LHM and dielectric slabs inserted between two half free spaces. A plane polarized wave is obliquely incident on it. The LHM is composed of magnetized ferrites to provide a negative permeability and a wire array to provide a negative permittivity. The effect of damping coefficient of ferrite material on the wave propagation through the structure is investigated in detail, analytically and numerically. Maxwell's equations are used to determine the electric and magnetic fields of the incident waves at each layer. The boundary conditions for

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the fields are matched at each layer interface. Then, Snell's law is applied to obtain a number of equations with unknown parameters. The equations are solved for the unknown parameters to calculate the reflection and transmission coefficients of the structure. These coefficients are used to determine the reflected, transmitted and loss powers. The effect of many parameters like frequency, applied magnetic fields etc. on the transmitted power is studied in detail by changing the damping coefficient of the ferrite material. The obtained numerical results are in agreement with the law of conservation of energy given by [11, 12]. It is also noticed that the numerical results of Figure 4 is similar to Figure 12 obtained by [12], this is another evidence for validity of the performed computations.

2. Numerical Results and Discussion

In this section the transmitted power of the structure are calculated numerically as a function of frequency, LHM thickness, applied magnetic fields and relative permittivity of ferrite. In our method we have used the parameters as in [5, 7]: B = 4 × 10^4 A/m, M = 3.5 × 10^5, g = 3.518 × 10^{-5} GHz/(A/m), h = 3.14 × 10^{-3} m, r_1 = 2 × 10^{-5} m, r_2 = 4.8 × 10^{-4}, ε_r = 4 and the angle of incidence θ is considered to be zero for all examples. Three values of the damping coefficient α are selected to be α = 1 × 10^{-3} , α = 5 × 10^{-3}, and α = 10 × 10^{-3} . The central frequency is selected to be 8 GHz. This frequency is chosen such that ε_f and μ_f are both simultaneously negative for all values of the damping coefficients. The slab thickness is assumed to be one half-wavelength long at the central frequency.
The transmitted power as a function of frequency is calculated in Fig. 1. The frequency is changed between 5.8 GHz and 11 GHz, because the simultaneously negative values of Re (μ_f) and Re (ε_f) under the three values of α can be realized in this range.
Fig. 2 presents the transmitted power versus the ferrite thickness for three values of the damping coefficient. The slab thickness is changed from zero mm to 3λ/4 (28 mm). It can be observed that the transmitted show oscillatory behaviour with the increasing of the thickness for all values of the damping coefficients.

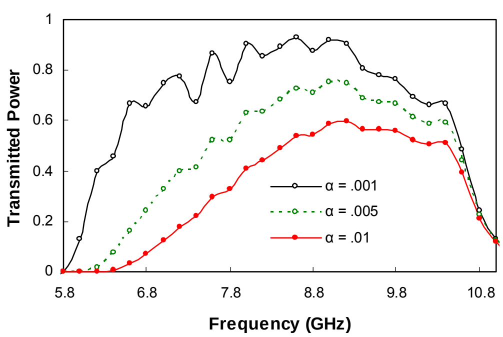

Fig. 1: Transmitted power as a function of frequency for three values of the damping coefficient.

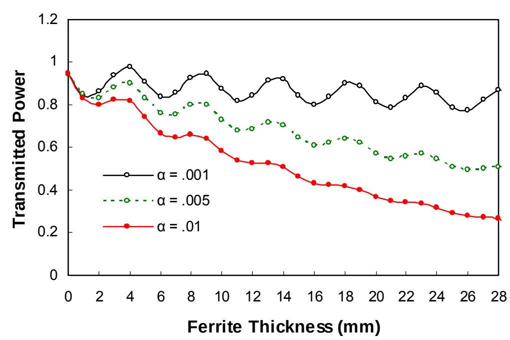

Fig. 2: Transmitted powers versus the ferrite thickness under three values of the damping coefficient.

Fig. 3 illustrates variations of the transmitted power as the relative permittivity of ferrite ε_r changes under the three values of the damping coefficients. The relative permittivity of ferrite ε_r is allowed to change from 1 to 16. From the figure, at ε_r values from 1 to 9 the transmission is high (while the reflection is low). At these value of ε_r the real parts of ε_f and μ_f are similar in signs and hence the real part of the complex refractive of the LHM is much greater than the imaginary part of it. At ε_r values from 10 to 16 the transmission is low while the reflection is high. This means that the real parts of ε_f and μ_f are different in signs and hence the real part of the refractive index of the LHM is very small as compared to its imaginary part.
The transmitted power is also computed to show the effect of the applied magnetic fields B. The computed results are presented in Fig. 4. The value of B changes from 20 × 10^3 A/m up to 60 × 10^3 A/m. At these values of B both of ε_f and μ_f are simultaneously negative in sign. As confirmed from the figure, the transmitted power shows oscillatory behaviour with the increasing of the applied magnetic

fields for all values of the damping coefficients. Note that this behaviour decreases with applied magnetic fields.

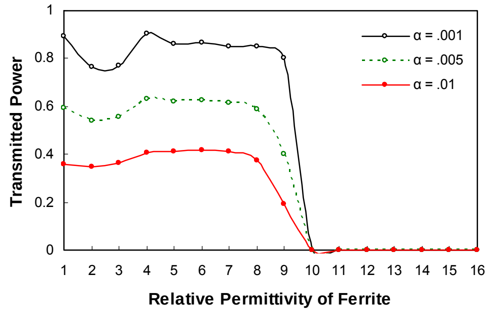

Fig. 3: Transmitted power against the relative permittivity of ferrite for three values of the damping coefficient

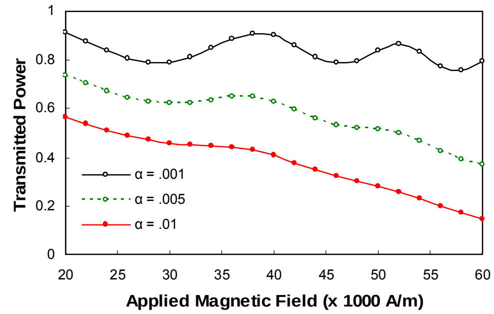

Fig. 4: Transmitted power as a function of the applied magnetic fields when the damping coefficient changes.

3. Conclusions

The transmission properties of a waveguide structure consisting of a pair of LHM and dielectric slabs inserted between two half free spaces is investigated theoretically with the emphasis on the damping coefficient of the LHM. The transmitted power is studied numerically as a function of frequency, the LHM thickness etc. to observe the effect of the damping coefficient on it. It is noticed that, if the damping coefficient changes, the characteristic of the powers will be affected from this change. The amount of this change depends on the value of the damping coefficient which affects the value of the imaginary part of the refractive index of the LHM. Thus we can say that the damping coefficient which changes the behaviour of the powers plays an important role in the variation of the transmission of the waves through the structure.

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