THE FERRITE_DIELECTRIC INTERFACE AND ITS APPLICATIONS

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ABSTRACT

A single ferrite/dielectric interface (incidence from ferrite side), with the bias direction transverse to the direction of propagation is analysed. Reflection and transmission coefficient expressions are obtained and plotted with respect to frequency and angle of incidence.

INTRODUCTION

Waveguides with ferrite and dielectric loading are frequently used to build isolators. For many years various structures have been developed to obtain better isolation with wider bandwidths at higher frequencies. A key aspect of the behaviour of any configuration is reflection and refraction of waves at a single ferrite_dielectric interface. Therefore the interface problem is worthy of further study.

Figure 1 shows four of the 16 possible situations that can be met in the general case of oblique incidence on a single ferrite/dielectric interface. These 16 apparently different situations arise by changing the direction of bias and the incident side of the interface: 8 for incidence from dielectric side and 8 for incidence from ferrite side. However, each set of 8 contains 2 sets of identical solutions and therefore for any given set of parameters there is only two problems to be solved. The problem of a wave incident from the dielectric side [Figs 1(a)(c)] has been discussed in [1] and references therein. So this paper is concerned with the second problem, that is the waves incident from the ferrite side, Figs 1(b)(d). This case is of particular interest for explaining fundamental structures such as ferrite loaded waveguides or grounded ferrite slabs. The TE modes are chosen here because this mode provides the best use of precessional motion of ferrite dipoles in nonreciprocal ferrite image guide structures. It is also well known that TE modes in grounded ferrite slabs biased in the plane in a direction transverse to the direction of propagation exhibit nonreciprocal behaviour. [2] But the physical insight to this problem had never been studied in the literature before. Fig. 2 (equivalent to Fig. 1(b)) shows a TE wave travelling in the x-z plane incident from the ferrite side obliquely incident on an interface at z=0. The permeability tensor of a ferrite biased in +y direction is given by;

$$[\mu]=\begin{bmatrix} \mu & 0 & -j\kappa \\ 0 & \mu_0 & 0 \\ j\kappa & 0 & \mu \end{bmatrix} \qquad (1)$$

where μ and κ are as defined in [3]. Using Maxwell's equations and boundary conditions, a modified version of Snell's Law (including the frequency dependence of $[\mu]$) and the reflection and transmission coefficients can be found by (2-4).

$$\beta_e \sin\theta_i = \beta_1 \sin\theta_t \qquad (2)$$

where

$$\beta_e = \omega\sqrt{\mu_{eff}\varepsilon_2} \ \text{ and } \ \beta_1 = \omega\sqrt{\mu_1\varepsilon_1} \qquad (3)$$

and β_e and β_1 are propagation constants in ferrite and dielectric regions respectively.

$$\Gamma = \frac{\dfrac{\cos\theta_i}{\eta_2} + \dfrac{j\kappa\sin\theta_i}{\eta_2\mu} - \dfrac{\cos\theta_t}{\eta_1}}{\dfrac{\cos\theta_i}{\eta_2} - \dfrac{j\kappa\sin\theta_i}{\eta_2\mu} + \dfrac{\cos\theta_t}{\eta_1}} \qquad \mathrm{T} = \frac{\dfrac{2\cos\theta_i}{\eta_2}}{\dfrac{\cos\theta_i}{\eta_2} - \dfrac{j\kappa\sin\theta_i}{\eta_2\mu} + \dfrac{\cos\theta_t}{\eta_1}} \qquad (4)$$

where $\eta_1=(\mu_1 / \varepsilon_1)^{1/2}$ and $\eta_2=(\mu_{eff} / \varepsilon_2)^{1/2}$ are the intrinsic impedances of the dielectric and ferrite regions respectively. The solution to Fig.1 (d) can be found by using negative values of θ_i or by reversing the bias, which can be taken into account by using $-\kappa$ instead of $+\kappa$. Magnitude of reflection coefficient $|\Gamma|$, corresponding to Fig. 1(b), is shown in Fig 3, as a function of frequency and angle of incidence. The following data were used: $\varepsilon_1=1$, $\varepsilon_2=12.7$, $\mu_1=\mu_0$, $H_o=500$ Oe, $4\pi M_s=2150$ G. When the case in which the bias in Fig 1b is reversed is examined, (or as in Fig 1(d) or Fig1(b) with negative going wave) it can be seen that although the magnitude of the reflection coefficient does not change, the phase does change and this results in a different transmission coefficient graph. A careful examination of these graphs will explain the nonreciprocal behaviour of ferrite in various isolator designs.

The analysis and 3D plots of reflection and transmission coefficients at a ferrite/dielectric interface are potentially confusing. The excessive amount of information in these graphs makes it possible to lose simple but important points. However the key features of the behaviour, can neatly be summarised, in a way not found in textbooks, by plotting the complex reflection coefficients on the complex plane. In order to discuss this it is helpful to note the three regions of the μ_{eff} characteristics shown in Fig 4. In Region I, $1<\mu_{eff}<\infty$; In Region II, $-\infty<\mu_{eff}<0$; In Region III, $0<\mu_{eff}<1$. If the wave is normally incident, $\theta=0$, the variation of complex Γ vs f is shown in Fig 6. The impedance of two medium at f=0, are 377Ω(air) and 243.54Ω (ferrite), giving a reflection coefficient of 0.215. As the frequency increases, wave sees a matched second medium when the locus of Γ passes from origin. This is where the numerical value of μ_{eff} is equal to that of ε_2. Then $|\Gamma|$ becomes 1 with a phase of 180° and the second medium behaves inductive until μ_{eff} curve reaches Region III. If the wave is obliquely incident on the ferrite/dielectric interface, the nonreciprocal behaviour of Γ (discussed in association with Eqn(4)) is shown for a frequency of 15 GHz in region III in Fig 7. Realise that the phase of the reflection coefficient is different for positive and negative bias cases. (Negative bias case sees an open circuit but positive bias case does not)

The ferrite/dielectric interface problem is associated with the guidance of waves by ferrite slabs, occurs due to multiple reflections at the interfaces. A TE wave travelling in a single transversely magnetised slab in a homogeneous dielectric medium exhibits reciprocal propagation coefficients, but the two F/D interfaces are nonreciprocal. The propagation is reciprocal because the interfaces are symmetrically exchanged when the propagation is reversed. When the two media external to the slab are different, the slab exhibits nonreciprocal propagation coefficients. Based on this concept, a ferrite image guide isolator has been designed [8].

CONCLUSION

It has been shown that a single ferrite/dielectric interface has different reflection and transmission coefficients that depend upon the direction of propagation or the direction of bias (bias being transverse to the direction of propagation). Physical insights to this problem have assisted the understanding of the non-reciprocal behaviour of various ferrite structures and have suggested the possibility of new novel isolator structures working at millimetre wavelengths.

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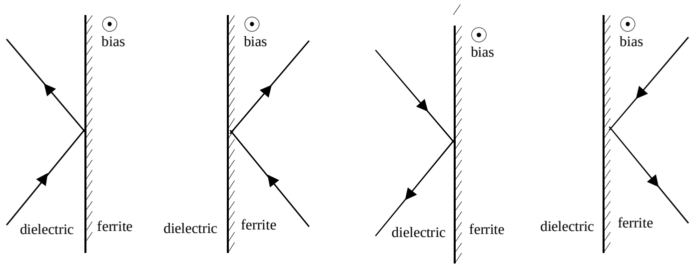


(a) (b) (c) (d)

Fig 1 Schematic representation of 4 cases of reflection at a single ferrite-dielectric interface

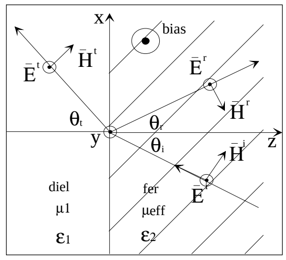


Fig. 2 A ferrite-dielectric interface

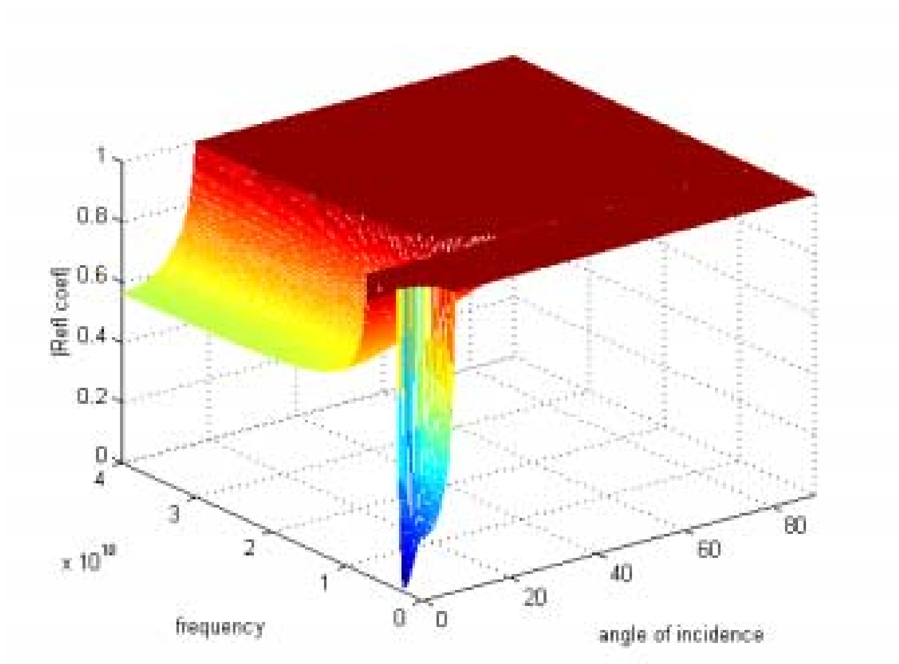


Fig. 3 Variation of the magnitude of reflection coefficient at a ferrite-dielectric (air) interface, with both frequency and angle of incidence. ε_1=1, ε_2=12.7, $\mu_1=\mu_0$, H_o=500 Oe, $4\pi M_s$=2150 G.

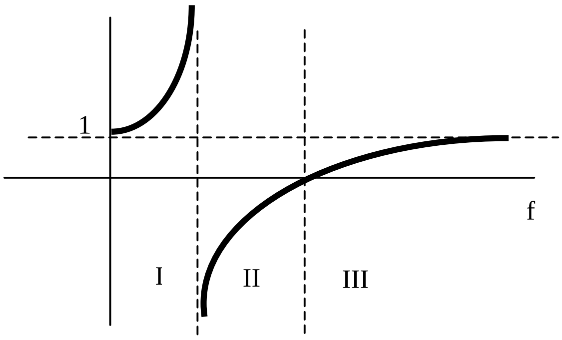


Fig 4 Schematic representation of μ_{eff} vs f

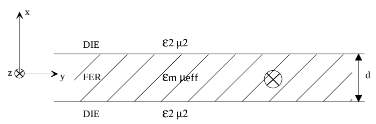


Fig 5. Transversely biased ferrite slab of thickness d in a homogeneous dielectric region

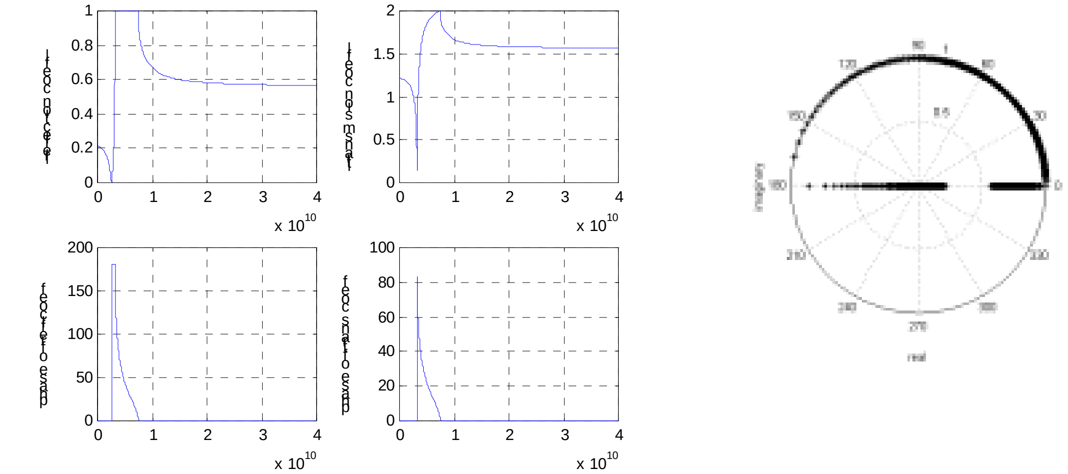
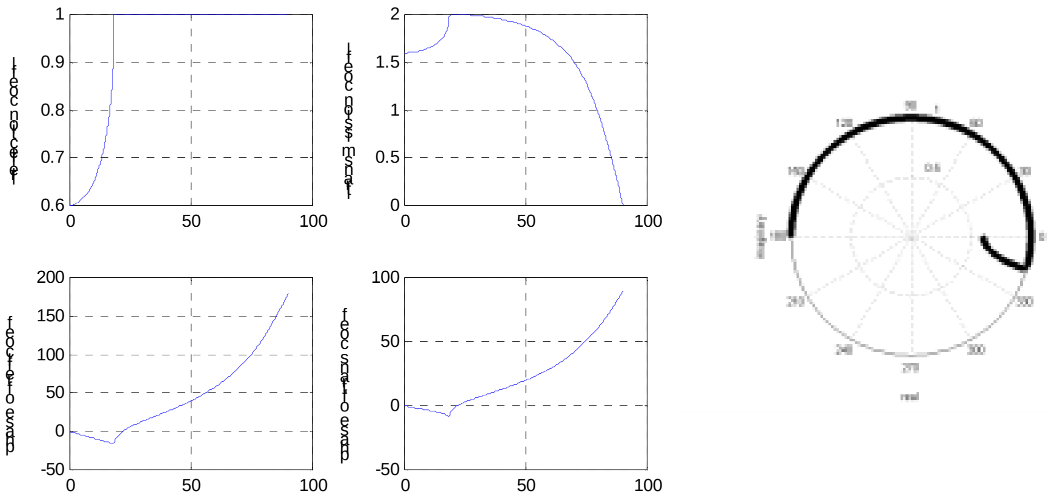
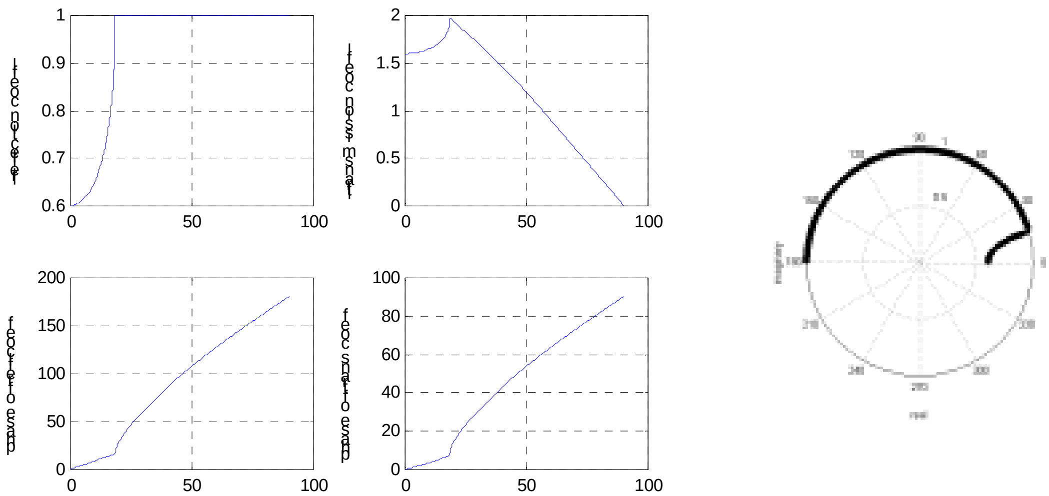


Fig 6 The variation of complex Γ vs f. ε_1=1, ε_2=12.7, μ_1=μ_0, H_o=500 Oe, 4πM_s=2150 G.



positive bias



negative bias

Fig 7 The variation of complex Γ vs angle of incidence for positive and negative bias cases at f=15 GHz