Patch Antenna with Electrically Tunable Ferrite-ferroelectric Bilayer

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Abstract— A coaxial-fed patch antenna with a ferrite-ferroelectric bilayer above a regular alumina substrate has been designed and analyzed. The ferrite-ferroelectric bilayer, multiferroic heterostructure, consists of a near-single-crystal ferrite yttrium iron garnet (YIG) film layer and a ferroelectric ceramic barium strontium titanate (BST) film layer with thicknesses of 1 μm and 0.5 μm, respectively. When the electric field applied across the BST layer changes from 2.5 V/um to 15 V/um, its permittivity will be tuned, thus the operating frequency of the antenna will shift as well. We also analyze the influence of the static magnetic field variation to the operating frequency of the antenna.

1. INTRODUCTION

Planar patch antennas are widely used because of their low cost, easy design, and suitability for integration with other printed circuits. In order to lower the operating frequency or miniaturize the overall size of the antenna, metamaterials with embedded metallic periodic structures have been used as antenna substrate for achieving relative permeability larger than unit [1], but it is so complicated to design and fabricate. Recently, the electric-field-tunable ferrite-ferroelectric bilayer structures [2, 3] with high permittivity and permeability but low loss have been demonstrated. In this paper, we apply this multiferroic heterostructure bilayer YIG and BST into the patch antenna to make the operating frequency electrically tunable. The interactions among the parameters of YIG and BST are also explored and analyzed.

2. FERRITE-FERROELECTRIC MATERIAL ANALYSIS

For the ferrite media, the permeability tensor of a gyromagnetic ferrite substrate, depending on the excitation frequency and applied DC bias magnetic field, has the following Hermitian form [4]:

$$\bar{\bar{\mu}} = \begin{bmatrix} \mu & -j\kappa & 0 \\ j\kappa & \mu & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{1}$$

where μ and κ are given by [4]

$$\mu = \mu_+ + \mu_- \tag{2}$$

$$\kappa = \mu_+ - \mu_- \tag{3}$$

$$\mu_\pm = \mu'_\pm - j\mu''_\pm \tag{4}$$

$$\mu_0(1-\mu'_\pm) = \frac{\gamma Ms(\omega_0 \pm \omega)T^2}{1+(\omega_0 \pm \omega)^2 T^2} \tag{5}$$

$$\mu_0\mu''_\pm = \frac{\gamma Ms T^2}{1+(\omega_0 \pm \omega)^2 T^2} \tag{6}$$

The definition of parameters in above equations can be found in Table 1, where $\omega_0 = \gamma H_0$, $T = 2/(\gamma\Delta H)$. All the above parameters are in cgs unit. The relative permeability can be expressed by $\mu_r = (\mu^2 - \kappa^2)/\mu$. Here we use the ferrite layer with $\gamma = 2.8\,\text{MHz/Oe}$, $Ms = 3000\,\text{G}$, $\Delta H = 350\,\text{Oe}$, and $H_0 = 2800\,\text{Oe}$, and the variation of relative permeability μ_r has been illustrated in Fig. 1. The relative permeability is constant with the value of 2 except the range from around 1.1 to 1.4 GHz.

For the ferroelectric layer, the tunable electric field applied across the BST layer can change its permittivity [3]. In reality, in some range of the static magnetic field operated on the ferrite media YIG, there are interactions between the permittivity of BST and permeability of YIG. For instance, the gyromagnetic ratio of YIG is taken $\gamma = 6.15\,\text{MHz/Oe}$ while the other parameters Ms, ΔH and H_0 are the same as the aforementioned values. When electric field value $E = 2.5\,\text{V/um}$,

Table 1.

γ	Gyromagnetic ratio	T	Relaxation time period	Ms	Saturation magnetization
H_0	Bias magnetic field	ΔH	Magnetic line width	ω	Angular excitation frequency

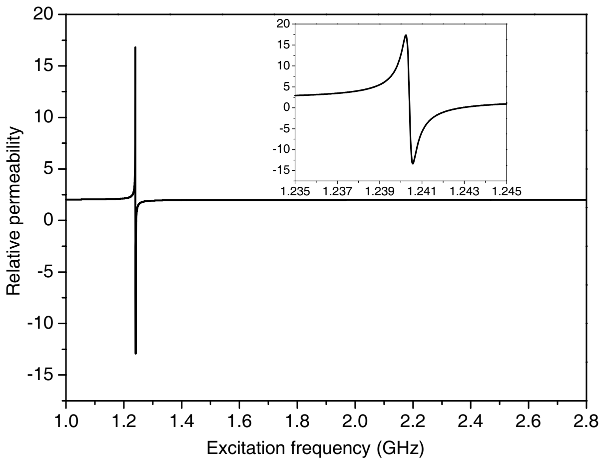


Figure 1. Variation of relative permeability at different excitation frequencies. The inset is the zoomed plot from 1.235 to 1.245 GHz.

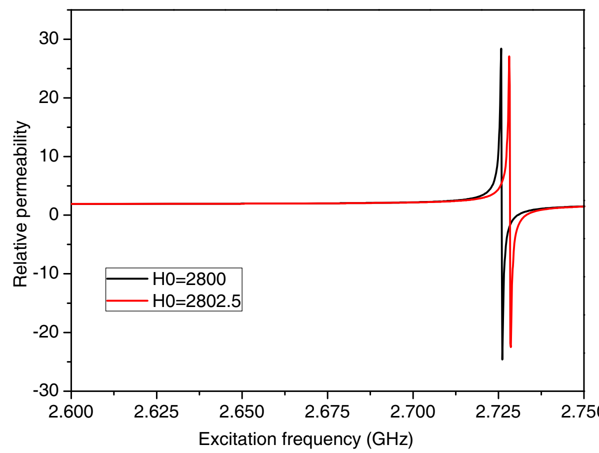


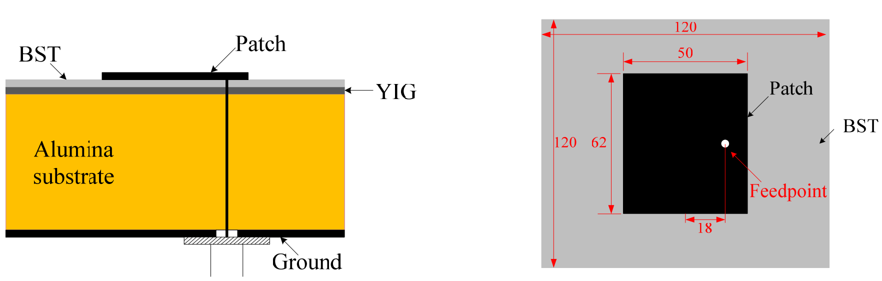
Figure 2. Variation of relative permeability at different bias magnetic field.

where the corresponding relative permittivity of BST is about 850 obtained from [3], is tuned to $E = 15.0\,\mathrm{V/um}$, i.e., $\varepsilon_r = 570$, the static field H_0 will be increased by around 2.5 Oe. Fig. 2 illustrates the variation of relative permeability at two different bias magnetic fields. At frequency 2716 MHz, the relative permeability will reduce from 15 to 3 as H_0 shifts from 2800 to 2802.5 Oe.

3. ANTENNA CONFIGURATION AND RESULTS

The proposed coaxial-fed patch antenna is comprised of a regular alumina substrate (relative permittivity $\varepsilon_r = 9.9$, thickness $h = 2\,\mathrm{mm}$), a ferrite-ferroelectric bilayer, a copper patch and a ground plane, which can be seen in Fig. 3. The ferrite-ferroelectric bilayer consists of a near-single-crystal ferrite yttrium iron garnet (YIG) film layer and a ferroelectric ceramic barium strontium titanate (BST) film layer with thicknesses of 1 µm and 0.5 µm, respectively. The two thin electrodes deposited on both surfaces of the BST and electromagnet for biasing the YIG can be neglected in the simulation model of the antenna. When we use the ferrite YIG layer with $\gamma = 2.8\,\mathrm{MHz/Oe}$, $Ms = 3000\,\mathrm{G}$ and $\Delta H = 350\,\mathrm{Oe}$, and apply bias magnetic field $H_0 = 2800\,\mathrm{Oe}$, the parameters (i.e., $\varepsilon_r = 14.78$ and $\mu_r = 2$) of the ferrite YIG layer can be almost unchanged if the operating frequency is not at $1.235 \sim 1.245\,\mathrm{GHz}$. Thus, when the electric field applied across the BST layer changes from 2.5 V/um to 15 V/um, the operating frequency of the antenna will be shifted from 2615 MHz up to 2716 MHz as shown in Fig. 4.

However, if we use the ferrite YIG layer with $\gamma = 5.92\,\mathrm{MHz/Oe}$, $Ms = 3000\,\mathrm{G}$ and $\Delta H = 350\,\mathrm{Oe}$, and still apply bias magnetic field $H_0 = 2800\,\mathrm{Oe}$, the relative permeability at 2.5 V/um (i.e., 2615 MHz) will not vary as shown in Fig. 2, while the relative permeability at 15 V/um will be



(a) (b)

Figure 3. The proposed patch antenna. (a) Side view, and (b) top view (units: mm).

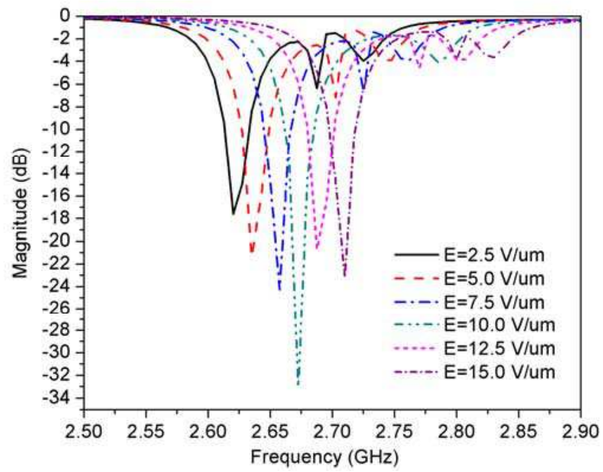


Figure 4. S_{11} of the antenna with tunable E-field across the BST layer.

reduced from 15 to 3, which makes the resonant frequency increase from 2716 MHz to 2760 MHz through the simulation. Using this method, the operating frequency tunability can be larger (the width range from 101 to 145 MHz) under the confined tunable electrical field.

4. CONCLUSION

A coaxial-fed patch antenna with electrically tunable ferrite-ferroelectric bilayer has been designed. The interactions between the electrical field applied in the BST and relative permeability of the YIG have been explored and analyzed, which enable the future work to further improve the tunability of the operating frequency range of the antenna.

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