Resonance characteristics of patch antenna using in-plane and weakly biased ferrite substrate

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1 Introduction

Many kinds of tunable devices using magnetized ferrite has been reported by many researchers. In such devices, we can control the wavelength by changing the strength of applied dc magnetic field $\mu_0 H_0$. This characteristics can usually be explained by the tensor permeability which is a function of $\mu_0 H_0$, where all magnetization vectors have been assumed to be saturated. The wavelength in the ferrite becomes shorter as the $\mu_0 H_0$ becomes stronger.

The authors also have reported on an ferrite patch antennas biased in-plane[1][2]. In this antenna, we utilized the characteristics of the ferrite under the magnetically unsaturated state so that we can control the axial ratio of the polarization[1] and switch the polarization between left-handed circular polarization (LHCP) and right-handed circular polarization (RHCP)[2]. In this paper, the author reports on the resonance characteristics of the ferrite patch antenna with an yttrium iron garnet(YIG) polycrystalline substrate under the magnetic unsaturation state. This resonance characteristics are calculated using the FDTD mothod with consideration of the behavior of magnetic domains. Finally, the theoretical results are compared with the experimental results.

2 Numerical analysis of the resonance characteristics

Fig.1 shows the patch antenna geometry of the problem. This antenna has a YIG polycrystalline substrate which is magnetized to y or z direction. The typical dependence of the resonance frequency fy and fz on the magnetic bias $\mu_0 H_0$ for the case of magnetization to y and z respectively has been shown in fig.2. In the result, the fy becomes higher as the magnetic bias field becomes higher, conversely the fz becomes lower at once and then becomes higher. This difference may be due to the behavior of magnetizing process under unstaturated state of the ferrite[3]. Although an empirical effective permeability was proposed in [4], few papers have taken notice of the behavior in unsaturated state in detail.

To understand the effect of this behavior, the authors used a simple model of the magnetization process for the FDTD method and then simulated qualitatively. To express the charac-

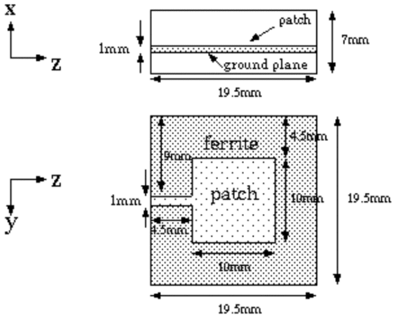

Figure 1: Antenna geometry of the problem.

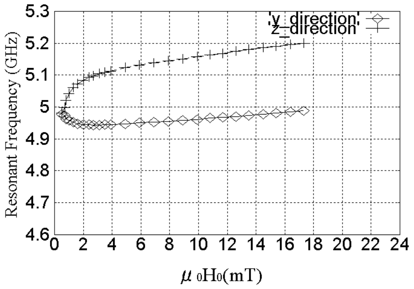

Figure 2: Experimental result of the resonance frequency.

teristics of microwave ferrite, we used the following motion equation of electrons in magnetized ferrite;

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma(\mathbf{M} \times \mathbf{B}) + \frac{\alpha}{|\mathbf{M}|}\mathbf{M} \times \frac{\partial \mathbf{M}}{\partial t}, \tag{1}$$

where $\mathbf{M}$ is the magnetization, α means the magnetic loss, γ is magnetic rotating ratio$(1.76 \times 10^{11}(rad/sec))$, and $\mathbf{B} = \mu_0(\mathbf{M} + \mathbf{H})$.

In the FDTD analysis for x direction, (1) is described as the following differential form;

$$\begin{aligned} & \frac{M_x^{n+\frac{1}{2}} - M_x^{n-\frac{1}{2}}}{\Delta t} \\ = & -\frac{\gamma}{2}\left(M_y^{n+\frac{1}{2}} B_z^n - M_z^{n+\frac{1}{2}} B_y^n \right. \\ & \qquad \left. + M_y^{n-\frac{1}{2}} B_z^n - M_z^{n-\frac{1}{2}} B_y^n \right) \\ & -\frac{\alpha}{M_s \Delta t}\left(M_y^{n+\frac{1}{2}} M_z^{n-\frac{1}{2}} - M_z^{n+\frac{1}{2}} M_y^{n-\frac{1}{2}}\right) \end{aligned} \tag{2}$$

where n means the nth time step and $\mathbf{M_x}, \mathbf{M_y}$, and $\mathbf{M_z}$ are located at the center of Yee's cell, and then the all components of $\mathbf{B}$ are located at the same positions as those of $\mathbf{H}$[5]. Using this equation, we can calculate the magnetic field from the relationship of $\mathbf{H} = \mathbf{B}/\mu_0 - \mathbf{M}$. The $\mathbf{B}$ and $\mathbf{E}$ can be calculated from the conventional Yee's algorithm.

In the magnetization process, both the magnetic flux density and magnetization depend on the magnetic field as shown in fig.3 and the magnetic walls are moved like the figure described in the lower part of the fig.3. For the microstrip antenna shown in fig.1, the FDTD method was carried out with the cell sizes of 0.5mm × 0.5mm × 0.5mm, 0.5ps time step, and 2^{15} points FFT.

Fig.4 shows the model of the domain behavior in the FDTD analysis, where the each arrow means the magnetization vector and the each area means the magnetic domains. In this model, each square domain is made of 10 cells × 10 cells. At first, when the $\mu_0 H_0$ is 0, all the vectors are directed in random like the step 1 in fig.4. In this model, the $\mu_0 H_0$ to y direction was increased in propotion to the difference between the number of domains directed to same and opposite directions as the magnetic bias.

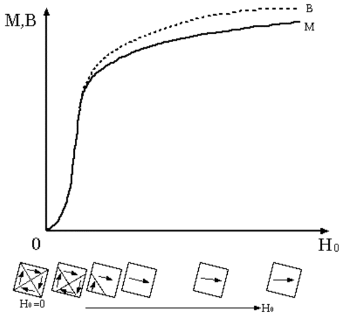

Figure 3: Magnetizing process and domain behavior.

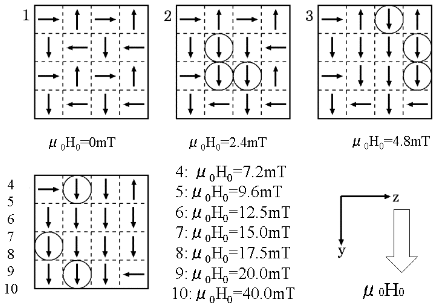

Figure 4: Dependence of the magnetic domain model on the magnetic bias.

As the $\mu_0 H_0$ is increased, the area of domains which are occupied by the vectors directed to the magnetic bias becomes larger, conversely the area of the domains which are occupied by the vectors not directed to the bias field becomes smaller. The circled vectors in fig.4 mean the ones whose directions are different from the previous step. When the bias field is 7.2mT, we set the domain situation as shown at the step 4 in the fig.4. Although the $\mu_0 H_0$ is increased up to 40mT, the vector situation is not changed in this calculation because we assumed the saturation magnetization is still larger (80mT).

Fig.5 shows the calculated results of the resonance frequency for applying the bias field to y and z. The resonance frequency was derived from the frequency where the imaginary part of input impedance is 0. Throughout the process when the magnetic bias is applied to z, the fz by the current which is parallel to the bias field moves to higher frequency. Conversely, the fy by the current which is perpendicular to the bias field becomes lower at once and then becomes higher. This result also shows the same tendency as the experimental results as shown in fig.2. As a result, we could give a model to explain the unsaturated behavior and confirmed the validity of the model.

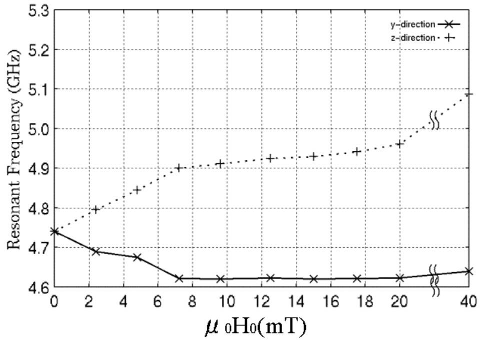

Figure 5: Numerical result of the resonance frequency.

3 Conclusion

The authors reported about a square patch antenna using in-plane biased yttrium iron garnet (YIG) polycrystalline substrate. An FDTD method for unsaturated ferrite was carried out to simulate the resonance frequencies considering the behavior of the Weiss's domain stucture. The characteristics of the resonance frequencies showed same tendencies as the experiments.

References

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