Analysis of low loss magneto-dielectric antenna for the mobile communication (Invited Paper)

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***Abstract* – A theoretical analysis of a cylindrical ferrite resonator antenna with steady magnetization utilizing the boundary conditions of a magnetic wall is presented. We theoretically derived exact eigenvalue equations for the mode-splitting phenomenon of hybrid mode. The presented theory is used to measure the permeability tensor and analysis the antenna performance.**

***Index Terms* — Antennas, ferrite loaded resonators, permeability tensor.**

1. Introduction

With the development of wireless communications, antennas that have functions of multiband, wideband, and tunable operation have been required to support various services. A ferrite-loaded antenna is a good candidate for this requirement. Among the ferrite antennas, the cylindrical ferrite resonator antenna(FRA) is very attractive due to polarization selectivity which is an additional feature. In addition, the FRA shares all the advantages with the dielectric resonator antenna(DRA).

In this study, three structures of a resonator have been studied: a cylindrical resonator that consists of an annular ring ferrite and a cylindrical dielectric located between parallel metal plates, a cylindrical ferrite above a metal plate, and the same ferrite containing a cylindrical dielectric material above the same metal plate. A theoretical analysis of the cylindrical resonators of three structures is conducted. It is derived from transcendental equations after calculating fields of the inside and outside the resonators.

A Li-ferrite with the permittivity ε_r = 16.5 and a saturation magnetization $4\pi M_s$ = 1960 Gauss is considered in this paper. Based on the theoretical analysis, we derived a relative permittivity and permeability from the first structure at the demagnetized state. Also, at the magnetized state, we propose a novel method to measure the value of magnetization and permeability tensor in great precision. With the second and third structures, we developed a DRA antenna utilizing ferrites and investigated its performance. The presented theory is shown to correlate well with measured results. It is found that the antenna can be used as frequency, bandwidth, and polarization tunable antenna.

2. Theoretical Analysis

The geometries of the resonators are shown in Fig. 1. There structures have been popular for a theoretical analysis. Corresponding formulas for the electromagnetic fields in a ferrite layers and in dielectric cylindrical layers can be found

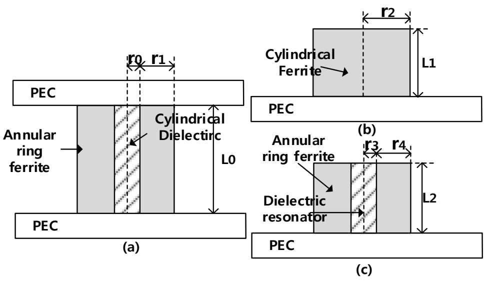

Fig. 1. Theoretical model of the cylindrical resonators. (a) the 1st structure (the measurement structure of ferrite properties) (b) the 2nd structure (FRA) (c) the 3rd structure (FRA)

in several papers and textbooks[1]-[2] and they will not be reproduced here. At the boundaries between particular regions the electromagnetic fields must satisfy well-known boundary conditions, which create a system of linear equations with respect to the constant coefficients appearing in the field expressions. In order to obtain the non-trivial solution of the system F, the determinant of system of linear equations should be zero,

$$Det(F(M))=0 \quad (1)$$

where, M is magnetization. To calculate the magnetization and the permeability tensor of the ferrite using the first structure, we used the statistic equation of the permeability. In the partially magnetized state, the tensor component, μ, κ, and μ_z can be estimated by [3]-[4]

$$\mu = \mu_d + (1-\mu_d)\left(\frac{M}{M_s}\right)^{\frac{3}{2}}$$
$$\kappa = \gamma 4\pi M / \omega \quad (2)$$
$$\mu_z = \mu_d^{\left(1-(M/M_s)^{\frac{5}{2}}\right)}$$

where, M_s is saturation magnetization, μ_d is the relative permeability, γ(=2.8MHz/Gauss) is the gyromagnetic ratio and ω is an angular frequency. The magnetization is calculated by substituting (2) into (1). Finally, the permeability tensor components are predicted by substituting calculated magnetization value into (2).

The resonant frequencies for the splitting modes of 2nd and 3rd structures are identified by the vanishing of the determinant of matrix F. In addition, in a tensor medium, the splitting two mode are orthogonal. Therefore, circular polarized radiation of the FRA can be obtained when having two adjacent resonances with a proper dc magnetic bias.

3. Experimental Results

The radius of the dielectric resonator(r_0) and annual ring ferrite(r_1) in 1st structure are 1 mm and 3.83 mm, respectively,

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and the height are both 7.5 mm. The calculated results of the first two modes are illustrated in Fig. 2. The HE_{111} mode (the first mode) and TE_{011} mode (the second mode) in the demagnetized state are observed at 8.81 GHz and 9.97 GHz, respectively. However, when a static magnetic bias is applied, the HE_{111} mode is split into two resonant modes whereas the variation of the TE_{011} mode is small. It is found that the HE_{111} mode is split into the HE_{+111} and HE_{-111} modes.

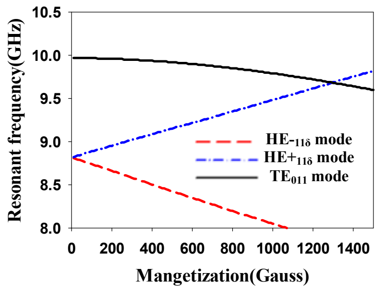
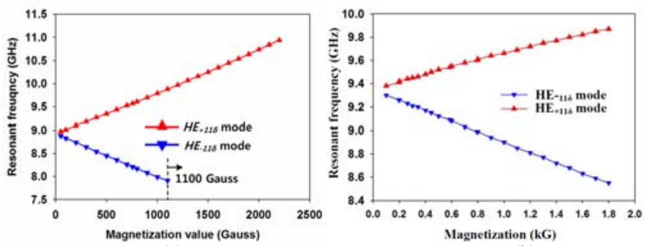


Fig. 2. Calculated resonant frequencies versus the magnetization value of structure (a) of Fig. 1.

Based on the calculated magnetization values, the permeability tensor of the ferrite is estimated with the consideration of frequency dependent characteristics. For instance, if the resonant frequencies of the HE_{-111} mode is observed at 8.58 GHz, the magnetization value M is 300 Gauss. These parameters can be used for calculating the permeability tensor (using eq. (2)). The result is then

$$[\mu]=\begin{bmatrix} 0.8456 & j0.1006 & 0 \\ -j0.1006 & 0.8456 & 0 \\ 0 & 0 & 0.8372 \end{bmatrix}$$

Based on the calculated permeability tensor using 1^{st} structure, we estimated the resonance frequencies of the FRA of the 2^{nd} and 3^{rd} structures. The radius (r_2) and height (L_1) of the FRA of 2^{nd} structure is 3.83 and 3.5mm, respectively. The radius of the dielectric resonator(r_3) and annual ring ferrite(r_4) in 3^{rd} structure are 2 mm and 3.83 mm, respectively, and the height are both 3.5 mm. the results are shown in Fig. 3. The resonance frequencies at demagnetized state are observed at 8.9GHz and 9.3GHz, respectively. After applying a static magnetic bias, they get split into two resonant modes.

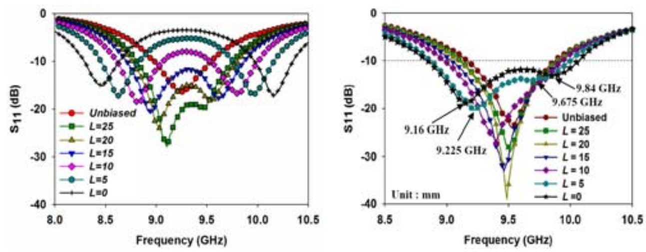


(a) (b)

Fig. 3. Resonanct frequency as a function of the magnetization of (a) 2^{nd} strcuture and (b) 3^{rd} strcuture.

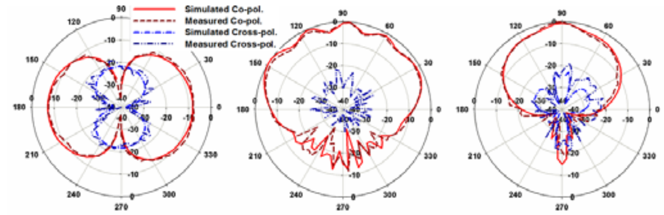
When the distance(L) between antenna and permanent magnet is changed, the measured reflection coefficients of the FRAs are illustrated in Fig.4. The measured results are a good agreement with the theoretical analysis.

The simulated and measured radiation patterns of the unbiased antenna at the resonant frequency are shown in Fig. 5. The cross polarization level is less than -20dB at boresight (+z-axis), which indicates linearly polarized radiation. There is good agreement with the simulated and measured results. Under the bias condition, two resonances of the FRA are closely adjacent and mutually orthogonal. It is well-known that such resonances enable the antenna to obtain circularly polarized radiation.



(a) (b)

Fig. 4. Measured resonant frequencies versus the magnetization value of (a) 1^{st} structure and (b) 2^{nd} structure.



(a) (b) (c)

Fig. 5. Simulated and measured radiation patterns of the unbiased 3^{rd} structure antenna at 9.525 GHz in the (a) xy-plane, (b) xz-plane, (c) yz-plane.

4. Conclusion

A cylindrical hybrid ferrite resonator and its theoretical model in the case of steady magnetization along the longitudinal direction(z-axis) are investigated in this work. Using the example of a Li ferrite resonator, we estimate the permeability tensor and calculate the resonant frequencies. The operating frequency of the resonator with the proposed scheme can be readily controlled by the size and the permittivity of the dielectric as well as applying a dc magnetic field.

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