Analysis of Mode Splitting Behavior for Cylindrical Ferrite Resonator Antenna

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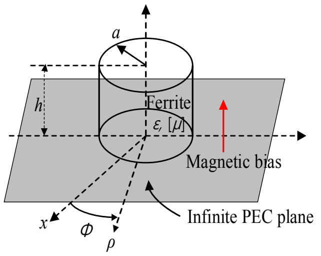
***Abstract*— A theoretical analysis of a cylindrical ferrite resonator antenna with steady magnetization that don't use the magnetic wall assumption is presented. The resonance frequency and radiation pattern of the antenna are calculated and verified. It is shown that the frequency, bandwidth, and polarization of the antenna are tunable.**

Keywords—ferrite ;resonator antenna; theoretical model; mode splitting phenomenon.

I. INTRODUCTION

Recently, wideband, tunable operation, high efficiency, and multi-functional antennas have been developed to provide various wireless communication services. Antennas using ferrite materials are good candidates for future wireless communication. It is well-known that the electromagnetic properties of the ferrites can be varied by applying a static magnetic field. This feature can be utilized to develop multifunctional antennas. Experiment results for the Ferrite resonator antenna(FRA) were introduced in [1]. Unfortunately, explaining the tuning mechanism with such a bias direction is very difficult theoretically. In this paper, to calculate the resonance frequency and radiation pattern, accurately, we present a theoretical analysis of a biased Cylindrical FRA that is applied to the all-boundary conditions. Then, three tuning performances (frequency, bandwidth, and polarization) of the antenna will be discussed.



(a)

Fig. 1. Theoretical model of the cylindrical FRA

II. THEORETICAL DERIVATIONS

To analyze the dielectric resonator model, the magnetic wall assumption is widely used because it is simple and instructive and leads to reasonable results when the ferrite is of high permittivity[2]. Two type of model exist which are based on the magnetic wall assumption(first-order model and second-order model). The geometry of the first-order model of the CFRA is that surface of the CFRA is modeled with the perfect magnetic conductor (PMC) walls. However, the accuracy of this model is quite low because the energy outside the FRA is not considered. An improvement in the first-order model is the second-order model described by [4]. Although the accuracy of the second-order model improved compared to the first-order model, the second-order model has a large error due to the magnetic wall assumption. Therefore, an improved model, which is shown in Fig. 1, is proposed to obtain the accurate results. This model applies the all-boundary condition without the magnetic wall assumption. Corresponding formula for the electromagnetic fields in a ferrite layers and in dielectric cylindrical layers can be found in several papers and textbooks[2]-[3] 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,

$$Det(F(M))=0 \tag{1}$$

where, M is magnetization inside ferrites.

The resonant frequencies for the splitting modes of the structure are identified by the vanishing of the determinant of matrix F. In addition, according to Huygen's principle[2], the radiation patterns of a FRA can be calculated using the electromagnetic fields of ferrites. 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.

III. ANALYSIS AND DISCUSSION

Li-ferrite with saturation magnetization($4\pi M_s$) of 1960 Gauss was used for the ferrite resonator. The diameter(a) and the height(h) of the resonator are 7.66 mm and 3.5 mm, respectively. The measured results depending on the magnetization is shown in Fig. 2. The bandwidth can be extended from 5.9 % to 10.2 %. The calculation results of $HE_{11\delta}$ mode for the first-order model, the second-order model, and the all open boundary model and the measurement results of the resonance frequencies of the FRA are shown in Fig. 3. When a magnetic bias is applied, the $HE_{\pm11\delta}$ mode of the FRA is split into two $HE_{\pm11\delta}$ modes in all models. As the magnetization increases, the discrepancy between the resonant frequencies of the two $HE_{\pm11\delta}$ modes increase. The discrepancy between the all open boundary model and measured results is only from 0.4 % to 3 %. As a result, the all open boundary model fits the measured results best because the proposed model considers more the field energy than the other models.

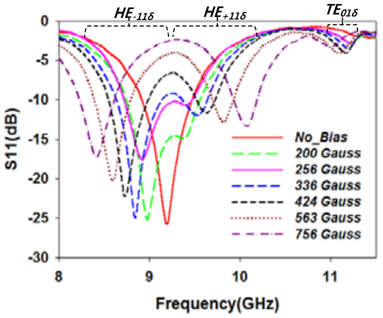


Fig. 2. Measured resonant frequencies versus the magnetization value

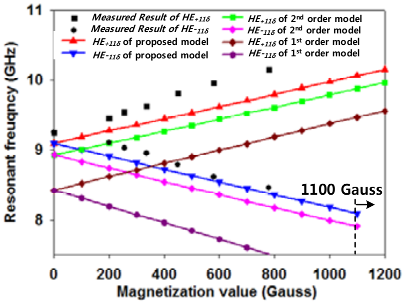


Fig. 3. Measured and calculated results of the $HE_{11\delta}$ modes as function of the magnetization

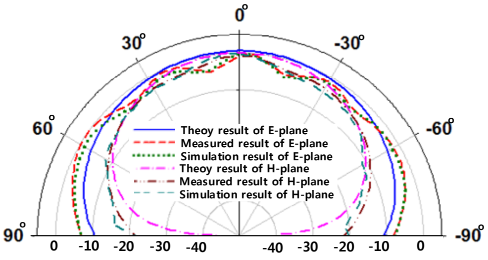


Fig. 4. Theoretical, simulated and measured radiation patterns of the biased FRA with magnetization of 336 Gauss

The theoretical radiation patterns can be obtained, based on the material parameters and the physical dimensions of the proposed CFRA. The simulated, measured, and theoretical results of the biased FRA with the magnetization of 336 Gauss are shown in Fig. 4. There is a close agreement between the theoretical results, simulated results, and measured results. Fig. 5 shows the measured axial ratio with the magnetization of 336 Gauss. The linear polarization is radiated at no bias condition. At magnetized states, the circular polarization is radiated because two resonances of the FRA are closely adjacent to each other and mutually orthogonal. Fig. 5 presents the realized gain in the broadside direction throughout the frequency band. The realized gain at No bias and magnetized condition are 6.53 dBi and 7.01 dBi, respectively. Basically, the magnetic loss of ferrites is reduced by applying the magnetic bias. Therefore, the improvement of gain is due to the loss reduction of magnetized ferrites.

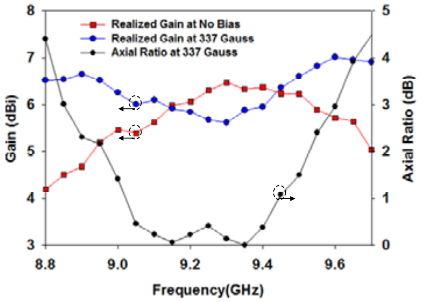


Fig. 5. Measured realized gain and axial ratio at boresight

IV. CONCLUSION

Theoretical model of the ferrite resonator antenna that is applied all boundary condition without the magnetic wall assumption is introduced are found to be efficient to explain the $HE_{11\delta}$ mode splitting behavior. In addition, this unique feature provides various functions: frequency and bandwidth tuning, and polarization switching performances. This indicates that the proposed antennas are suitable for multifunctional antennas.

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