RADIATION FROM SLITS ON FERRITE-FILLED PARALLEL PLATES WITH A SUPERSTRATE

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1. INTRODUCTION

A dielectric superstrate has been widely used to improve the low efficiency and low gain of antennas. For instance, research works for microstrip antennas covered by a superstrate have been reported [1-3]. The experiments for a single microstrip patch antenna with a dielectric superstrate have been performed [4]. The resonance condition for high gain enhancement can be achieved by adjusting the distance between a radiating element and superstrate. Extremely high gain enhancement using multilayered superstrates has been reported in [5]. The purpose of the present paper is to investigate the effect of a supersrtate on the radiation performance of aperture array antenna. This paper presents an analysis of radiation from multiple slits on a ferrite-filled parallel plates with a superstrate. Our analysis is based on the Fourier transform and mode matching [6], which yields a fast convergent series solution. To demonstrate the validity of our theoretical approach, the computational results are compared with the simulation data of Microwave Studio of CST.

2. FIELD ANALYSIS

Figure 1 shows a leaky wave antenna consisting of a ferrite-filled parallel plates with a superstrate. Similar leaky wave antennas without a superstrate have been investigated in [6, 7] using the Fourier transform and mode matching. No field variation is assumed in the y-direction, thereby making the antenna geometry two-dimensional. The $\exp(-i\omega t)$ time convention is suppressed throughout the analysis. Assume that an incident TE_s mode propagates along the x-direction in the ferrite-filled parallel plates. For theoretical convenience, some of the field representations in [7] are used here. The permittivity and tensor permeability of ferrite-loaded medium are ε_f and $\bar{\mu}$, respectively. The direction of the applied DC magnetic field is parallel to the y-axis and the permeability tensor is given by

$$\bar{\mu} = \mu_0 \begin{bmatrix} \mu & 0 & iK \\ 0 & 1 & 0 \\ -iK & 0 & \mu \end{bmatrix} \tag{1}$$

where $\mu = 1 + \dfrac{\omega_m(\omega_o - i\alpha\omega)}{(\omega_o - i\alpha\omega)^2 - \omega^2}$, $K = \dfrac{\omega_m \omega}{(\omega_o - i\alpha\omega)^2 - \omega^2}$, $\omega_o = \gamma H_{in}$, $\omega_m = \gamma 4\pi M_S$, α is the damping factor, γ is the gyromagnetic ratio of ferrite, H_{in} is the internal DC magnetic field within ferrite, and $4\pi M_S$ is the saturation magnetization of ferrite. The effect of ferrite linewidth is included in terms of α.

The incident and scattered electric fields in region (I) $(-b < z < 0)$ are

$$E_{yi}^I(x,z) = \sin k_{zs}(z+b) e^{ik_{xs}(x+x_i)} \tag{2}$$

$$E_{ys}^I(x,z) = \frac{i}{\pi} \int_{-\infty}^{\infty} \tilde{E}_y^I(\zeta) \sin(\kappa_1 z) e^{-i\zeta x} d\zeta \tag{3}$$

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where $k_{zs} = \frac{s\pi}{b}$, $k_{xs} = \sqrt{k_1^{\,2} - k_{zs}^{\,2}}$, $\kappa_1 = \sqrt{k_1^{\,2} - \zeta^2}$, $\mu_f = \frac{\mu^2 - K^2}{\mu}$, and $k_1 = \omega\sqrt{\mu_0 \mu_f \varepsilon_0 \varepsilon_f}$. Note that the x_i is the half length of a ferrite slab. In region (II) $(-b-d < z < -b)$, the scattered electric field is

$$E_{ys}^{II}(x,z) = \sum_{m=1}^{\infty} \sin a_m (x + a - lT)\left[b_m^l \cos \xi_m (z+b) + c_m^l \sin \xi_m (z+b)\right] \tag{4}$$

where $a_m = \frac{m\pi}{2a}$, $\xi_m = \sqrt{k_2^{\,2} - a_m^{\,2}}$, and $k_2 = \omega\sqrt{\mu_0 \mu_2 \varepsilon_0 \varepsilon_2}$. In regions (III), (IV) and (V), the scattered electric fields are represented as, respectively,

$$E_{ys}^{III}(x,z) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\left[\tilde{E}_{III}^{+}(\zeta)e^{i\kappa_3(z+h_1)} + \tilde{E}_{III}^{-}(\zeta)e^{-i\kappa_3(z+h_1)}\right]e^{-i\zeta x}d\zeta \tag{5}$$

$$E_{ys}^{IV}(x,z) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\left[\tilde{E}_{IV}^{+}(\zeta)e^{i\kappa_4(z+h_2)} + \tilde{E}_{IV}^{-}(\zeta)e^{-i\kappa_4(z+h_2)}\right]e^{-i\zeta x}d\zeta \tag{6}$$

$$E_{ys}^{V}(x,z) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{E}_{y}^{V}(\zeta)e^{-i\kappa_5(z+h_2)}\,e^{-i\zeta x}d\zeta \tag{7}$$

where $\kappa_q = \sqrt{k_q^{\,2} - \zeta^2}$, $k_q = \omega\sqrt{\mu_0 \mu_q \varepsilon_0 \varepsilon_q}$, and $q = 3,4,5.$

To determine the unknown modal coefficients b_m^l and c_m^l, the boundary conditions of E_y and H_x continuities must be enforced at each boundary. Enforcing the boundary conditions in conjunction with the mode matching and Fourier transform [6, 7] results in a set of simultaneous equations for the discrete modal coefficients b_m^l and c_m^l. The radiated far-zone power density in region (V) is given in terms of b_m^l and c_m^l as

$$p_s(r,\theta_s) = \frac{k_5}{4\pi r \eta_0}\cos^2\theta_s \left|K(\theta_s)\right|^2 \tag{8}$$

where

$$K(\theta_s) = \sum_{l=-L_1}^{L_2}\sum_{m=1}^{\infty} a_m\left[b_m^l \cos \xi_m d - c_m^l \sin \xi_m d\right]e^{ik_5 \sin\theta_s lT} \cdot \frac{\kappa_4 F_m(\zeta)}{\kappa_4 \cos(\kappa_4 c) - i\kappa_5 \sin(\kappa_4 c)} \frac{A(\zeta) + B(\zeta)}{A(\zeta)e^{i\kappa_3 h} + B(\zeta)e^{-i\kappa_3 h}}\Bigg|_{\zeta = k_5 \sin\theta_s}, \tag{9}$$

$$A(\zeta) = \kappa_4(\kappa_3 - \kappa_5) - i\kappa_3\kappa_5 \tan(\kappa_4 c) + i\kappa_4^{\,2}\tan(\kappa_4 c), \tag{10}$$

$$B(\zeta) = \kappa_4(\kappa_3 + \kappa_5) - i\kappa_3\kappa_5 \tan(\kappa_4 c) - i\kappa_4^{\,2}\tan(\kappa_4 c), \tag{11}$$

and

$$F_m(v) = \frac{e^{iva}(-1)^m - e^{-iva}}{v^2 - a_m^{\ 2}}. \tag{12}$$

Equation (8) represents a fast convergent series for radiation from a ferrite-filled leaky wave antenna with a superstrate.

3. NUMERICAL RESULTS

Figure 2 illustrates the radiation efficiency for N (the number of slots)=1 when a =4.95 mm, b =6.7 mm, c =2.54 mm, d =2.1 mm, x_i =70 mm, $4\pi M_S$ =1300 G, ΔH =0 oe, H_{in} = 0 oe, ε_f =11.8, ε_4 =10.8, and $\varepsilon_2 = \varepsilon_3 = \varepsilon_5$ =1. Without a superstrate, the radiation efficiency increases monotonously from 8.5 GHz to 11.5 GHz. When the distance between slots and a superstrate h is 16.5 mm and 14.5 mm, the other peaks are observed at 9 GHz and 10 GHz, respectively, due to the presence of a superstrate. Note that the distance h satisfies the resonance condition $(h = 0.5\lambda_0)$ to achieve gain enhancement [3, 4].

Figures 3 and 4 show the normalized H-plane radiation patterns for multiple slots (N =9). The operating frequency is 10.05 GHz, slot period T =11.7 mm, and the rest of antenna dimensions are the same as those in Fig. 1. The ferrite used in our computation is commercially available one (TT1-109, Trans-Tech). As H_{in} increases from o to 1033 oe, the radiated main beam scans about 17° ($-11^\circ \sim 6^\circ$). To demonstrate the validity of our theoretical approach, our radiation patterns are compared with the simulation data of Microwave Studio of CST. Figures 3 and 4 show a favorable agreement between our results and the simulation data.

Figure 5 shows the main beam intensity versus the distance h at 10.05 GHz. The antenna dimensions and the applied DC magnetic field are the same as those in Fig. 3. The main beam intensity of the antenna without a superstrate is shown as a reference. When the distance h =13 mm, the maximum of main beam intensity is observed, where the intensity is 4.5 dB higher than that without a superstrate.

4. CONCLUSION

Radiation from multiple slits on ferrite-filled parallel plates with a superstrate is investigated using the Fourier transform and mode matching techniques. Our computational results favorably compare with other simulation data. Use of a superstrate layer has an advantages of gain enhancement when the distance between slots and a superstrate satisfies the resonance condition.

REFERENCES

[1] D. R. Jackson and N. G. Alexopoulos, "Gain enhancement methods for printed circuit antennas," *IEEE Trans. Antennas Propagat.*, vol. 33, no. 9, pp. 976-987, Sept. 1985.

[2] G. V. Eleftheriades and M. Simcoe, "Gain and efficiency of linear slot arrays on thick substrates for millimeter-wave wireless applications," *IEEE Int. Symp. Antennas Propagat.*, vol. 4, pp. 2428-2431, July 1999.

[3] W. Choi, C. Pyo, Y. H. Cho, J. Choi, and J. Chae, "High gain and broadband microstrip patch antenna using a superstrate layer," *IEEE Int. Symp. Antennas Propagat.*, vol. 2, pp. 292-295, June 2003.

[4] X. H. Shen, P. Delmotte, and G. A. E. Vandenbosch, "Effect of superstrate on radiated field of probe fed microstrip patch antenna," *IEE Proc. Microw. Antennas Propagat., vol*. 148, no. 3, pp. 141-146, June 2001.

[5] H. Y. Yang and N. G. Alexopoulos, "Gain enhancement methods for printed circuit antennas through multiple superstrates," *IEEE Trans. Antennas Propagat.*, vol. 35, no. 7, pp. 860-863, July 1987.

[6] J. H. Lee, H. J. Eom, and J. W. Lee, "Scattering and radiation from finite thick slits in parallel-plate waveguide," *IEEE Trans. Antennas Propagat.*, vol. 40, no. 2, pp. 212-216, Feb. 1996.

[7] K. C. Hwang and H. J. Eom, "Radiation from a ferrite-filled rectangular waveguide with multiple slits," *IEEE Microwave Wireless Compon. Lett.*, accepted for publication, 2004.

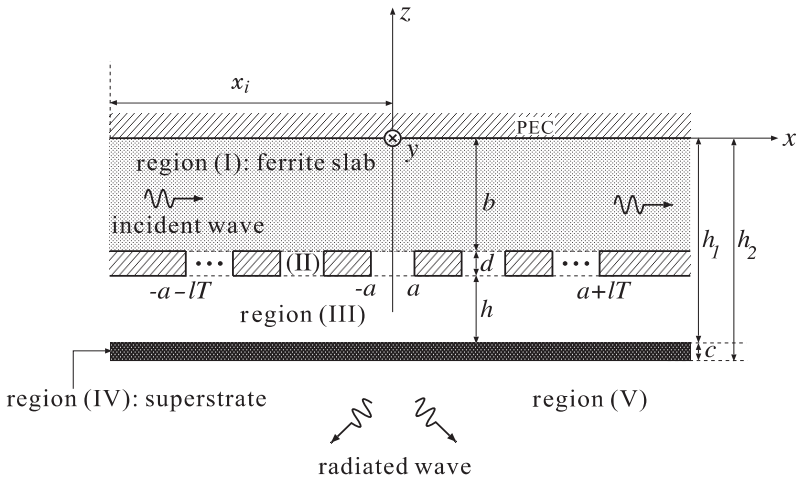

Figure 1. Problem geometry

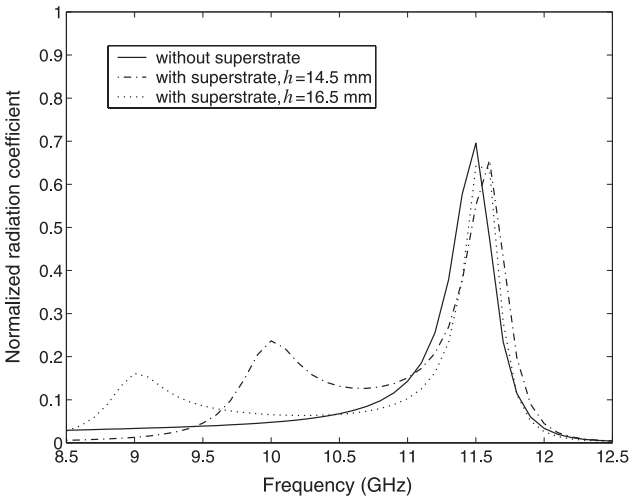

Figure 2. Radiation efficiency

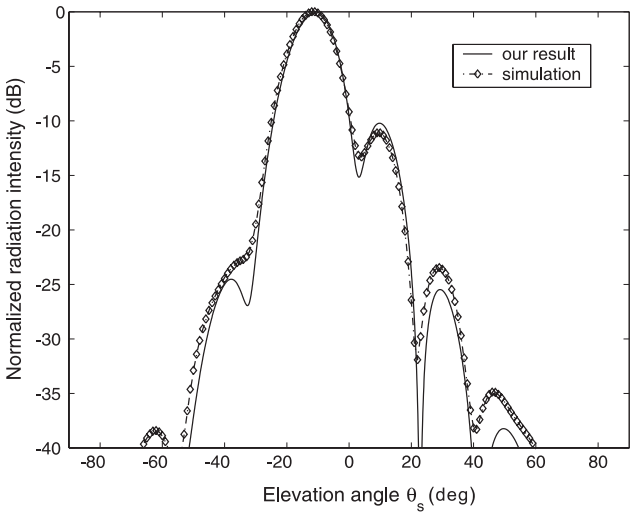

Figure 3. Normalized H-plane radiation pattern, h =13.0 mm, H_{in} = 0 oe

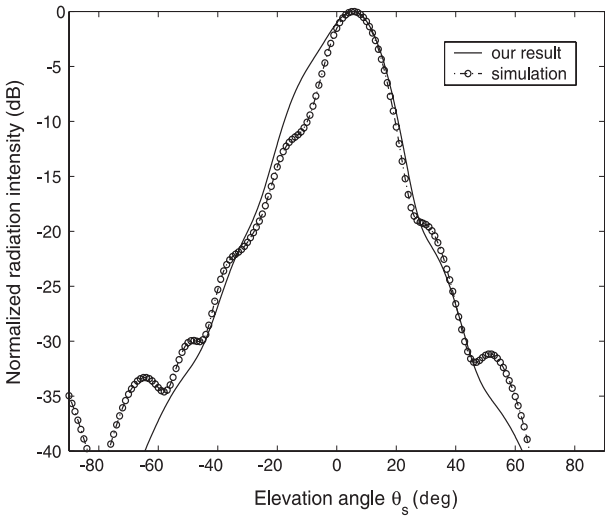

Figure 4. Normalized H-plane radiation pattern, h =13.0 mm, H_{in} = 1033 oe

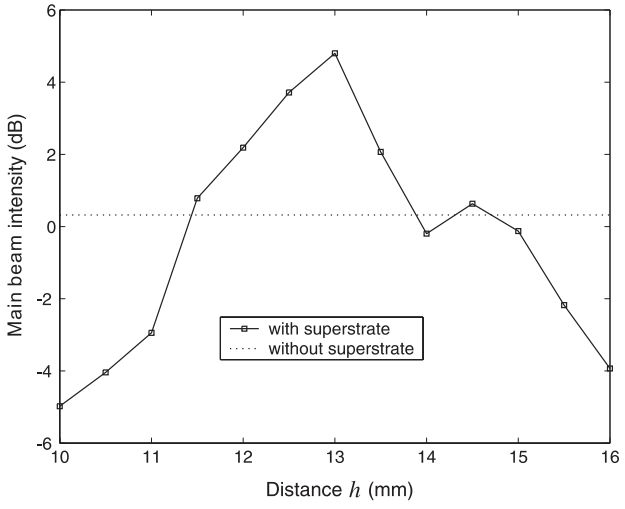

Figure 4. Maximum radiation intensity versus the distance h