Steerable Electromagnetic Transmission of Metal Strips on a Magnetized Ferrite Slab

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This paper presents a rigorous analysis of electromagnetic scattering and transmission of a metal-strip grating on a magnetized ferrite slab. The Fourier transform is used to represent the electric and magnetic fields in the spectral domain and the boundary conditions are enforced to obtain two simultaneous equations using the mode-matching technique. Numerical results show that the metal-strip grating exhibits a steerable electromagnetic transmission property due to the magnetized ferrite slab.

***Index Terms*—Electromagnetic shielding, Fourier transform, magnetized ferrite, metal-strip grating, mode-matching technique.**

I. Introduction

A metal-strip grating on a magnetized ferrite substrate has been widely used in the design of non-reciprocal antenna radomes, quasi-optical isolators, and circulators. The reason is that the microwave ferrite materials have a permeability tensor whose elements can be easily controlled by a dc magnetic bias field [1], [2]. So far, the previous studies have been focused on the electromagnetic scattering and diffraction phenomena of an infinite number of metal strips with a negligible thickness on a magnetized ferrite substrate [1]-[3]. However, few researches have discussed how magnetized ferrite materials as shielding materials affect the electromagnetic transmission properties of the metal-strip grating. The understanding of electromagnetic transmission into the metal strips with finite thickness is important in the evaluation and control of seam or aperture leakage often encountered in electromagnetic shielding problems.

In this paper, an analytical formulation is proposed to investigate the electromagnetic transmission into a metal-strip grating on a magnetized ferrite slab. We deal with a finite number of metal strips with finite thickness on a magnetized ferrite slab, which is a more practical structure than the infinite number of metal strips. The main point in our formulation is the determination of a complete set of mode functions for the grating layer. The Fourier transform and series are used to represent the electric and magnetic fields in the spectral domain. Mode-matching technique based on the boundary conditions is utilized to obtain simultaneous equations for the modal coefficients of each slit region. Numerical results show that the metal-strip grating exhibits a steerable electromagnetic transmission property due to the magnetized ferrite slab.

II. Analytical Formulation

Fig. 1 shows geometry of metal strips on a magnetized ferrite slab. The incident, reflected, and scattered electric fields in region (I) ($-\infty < x < \infty$, $y > d$) with the $e^{-i\omega t}$ time convention are

$$E_z^i(x,y) = -Z_0 e^{ik_x x - ik_y(y-d)} \tag{1}$$

$$E_z^r(x,y) = Z_0 e^{ik_x x + ik_y(y-d)} \tag{2}$$

$$E_z^s(x,y) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \tilde{E}_z^s(\zeta) e^{-i\zeta x + i\kappa_0(y-d)} d\zeta \tag{3}$$

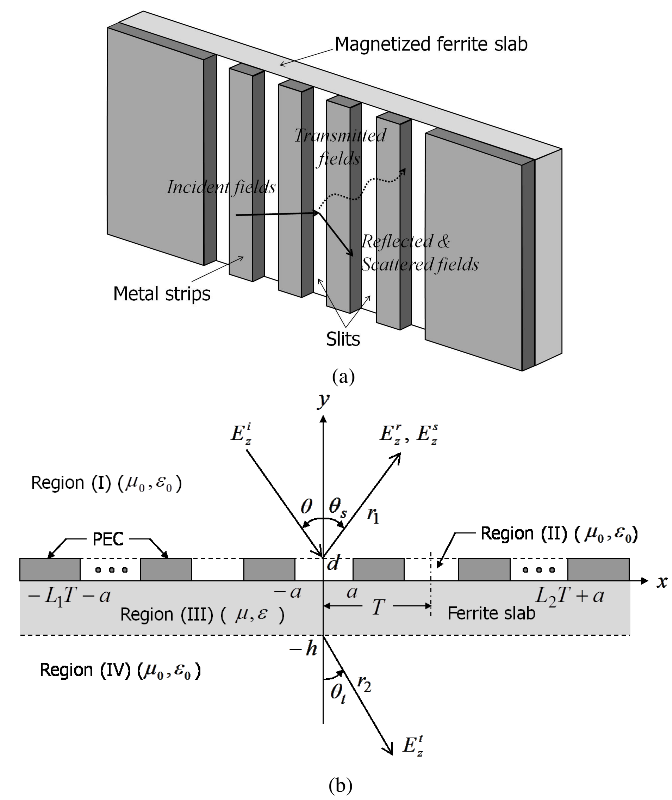

Fig. 1. Geometry of metal strips on a ferrite slab: (a) Perspective view; (b) Cross-sectional view.

where $k_x = k_0 \sin\theta$, $k_y = k_0 \cos\theta$, $k_0 = \omega\sqrt{\mu_0\varepsilon_0}$, $Z_0 = \sqrt{\mu_0/\varepsilon_0}$, $\kappa_0 = \sqrt{k_0^2 - \zeta^2}$, and $\tilde{E}_z^s = \int_{-\infty}^{\infty} E_z^s(x,d) e^{i\zeta x} dx$.

In region (II) ($lT - a < x < lT + a$, $0 < y < d$), the electric field is

$$E_z^l(x,y) = \sum_{m=1}^{\infty} \left[b_m^l \cos(\xi_m y) + c_m^l \sin(\xi_m y) \right] \times \sin a_m(x - lT + a) \tag{4}$$

where $a_m = m\pi/(2a)$, $\xi_m = \sqrt{k_0^2 - a_m^2}$, and $l = -L_1, \cdots, -1, 0, 1, \cdots, L_2$. Thus, the total number of slits between metal strips is $N = L_1 + L_2 + 1$.

In region (III) ($-\infty < x < \infty$, $-h < y < 0$), the electric field within the ferrite slab is

$$E_z^f(x,y) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\left[\tilde{E}_z^+(\zeta)e^{i\kappa y} + \tilde{E}_z^-(\zeta)e^{-i\kappa y}\right]e^{-i\zeta x}d\zeta \quad (5)$$

where $\kappa = \sqrt{k^2-\zeta^2}$, $k = \omega\sqrt{\mu_0\mu_{eff}\varepsilon_0\varepsilon_f}$, and $\mu_{eff} = (\mu^2 - K^2)/\mu$.

The direction of the applied dc magnetic field is parallel to the z-axis and the permeability tensor is given by

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

where

$$\mu = 1 + \frac{\omega_m(\omega_0 - i\alpha\omega)}{(\omega_0 - i\alpha\omega)^2 - \omega^2} \quad (6)$$

$$K = \frac{\omega_m \omega}{(\omega_0 - i\alpha\omega)^2 - \omega^2}, \quad (7)$$

$\omega_0 = \gamma H_{in}$, $\omega_m = \gamma 4\pi M_s$, and α is the damping factor. γ is the gyromagnetic ratio of ferrite, H_{in} is the dc internal magnetic field within ferrite, and $4\pi M_s$ is the saturation magnetization of ferrite.

In region (IV) ($-\infty < x < \infty$, $y < -h$), the transmitted electric field is

$$E_z^t(x,y) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\tilde{E}_z^t(\zeta)e^{-i\zeta x - i\kappa_0(y+h)}d\zeta. \quad (8)$$

Using Maxwell curl equation $\nabla\times\mathbf{E} = i\omega\bar{\bar{\mu}}\mathbf{H}$, the tangential component of magnetic field H_x can be formulated as follows

$$H_x = \frac{1}{i\omega\mu_0(\mu^2-K^2)}\left[\mu\frac{\partial E_z}{\partial y} + iK\frac{\partial E_z}{\partial x}\right] = \frac{1}{i\omega\mu_0\mu_{eff}}\left[\frac{\partial E_z}{\partial y} + i\frac{K}{\mu}\frac{\partial E_z}{\partial x}\right]. \quad (9)$$

From the boundary conditions of E_z- and H_x-continuity at $y = d, 0, -h$, we can obtain two simultaneous equations using the mode-matching technique based on the Fourier transform [4]. A detailed derivation of our analytical formulation will be presented in a full paper.

The far-zone scattered and transmitted fields at distances r_1 and r_2, respectively, in Fig. 1(b) can be evaluated by using the stationary phase approximation.

$$E_z^s(r_1,\theta_s) = e^{i(k_0r_1-\pi/4)}\sqrt{\frac{k_0}{2\pi r_1}}\cos\theta_s\tilde{E}_z^s(k_0\sin\theta_s) \quad (10)$$

$$E_z^t(r_2,\theta_t) = e^{i(k_0r_2-\pi/4)}\sqrt{\frac{k_0}{2\pi r_2}}\cos\theta_t\tilde{E}_z^t(k_0\sin\theta_t) \quad (11)$$

where $r_1 = \sqrt{x^2+(y-d)^2}$, $r_2 = \sqrt{x^2+(y+h)^2}$, $\theta_s = \sin^{-1}(x/r_1)$, and $\theta_t = \sin^{-1}(x/r_2)$.

III. Numerical Results

Fig. 2 shows the simulated geometry and material parameters. Fig. 3 shows the scattered and transmitted fields of eight metal strips on a magnetized ferrite slab at 7.5 GHz. The scattered field is slightly reduced and has symmetrical pattern along the angle. However, the transmitted field has more attenuation at the angles from -30^o to -90^o than at the angles

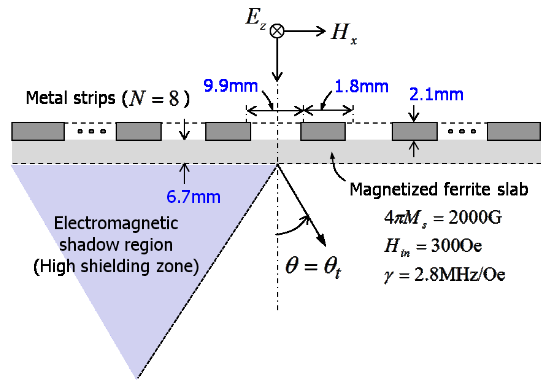

Fig. 2. Simulation geometry of metal strips on a ferrite slab.

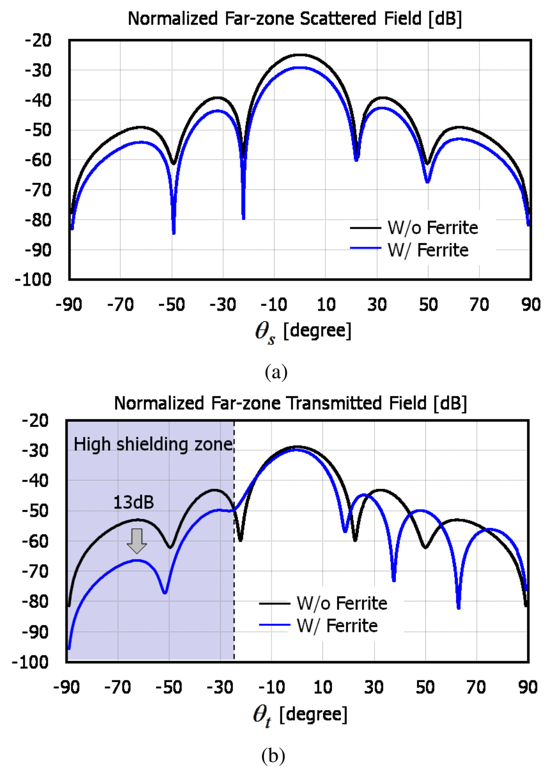

Fig. 3. Far-zone fields at 7.5 GHz. (a) Scattered field. (b) Transmitted field.

from 30^o to 90^o. Therefore, it can be observed that the metal-strip grating exhibits a steerable electromagnetic transmission property due to the magnetized ferrite slab. More simulation results and their validation by a commercial electromagnetic simulator will be presented in a full paper.

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