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EM Penetration into Narrow Circumferential Slots on a Conducting Circular Cylinder

Min G. Kang [1] and # Hyo J. Eom [2]
[1] Digital Media Lab., LG Electronics Inc.
16 Woomyeon-dong, Seocho-gu, Seoul, 137-724, Korea
Email: mkkang79@lge.com
[2] Division of Electrical Engineering, Korea Advanced Institute of Science and Technology
373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Korea
Tel: +82-42-869-3436, Fax: +82-42-869-8036, Email: hjeom@ee.kaist.ac.kr

1. Introduction

Electromagnetic wave penetration into and scattering from circumferential slots on a circular conducting cylinder are canonical problems in diffraction theory. There have been extensive studies on the penetration into some specific structures including a dielectric-filled conducting cylinder [1], cylindrical multiple apertures [2], conducting cylinders with partial slots [3]- [4], and a slotted circular cylinder with lossy and lossless inner coating [5]. While the radiation from circumferential slots on a conducting circular cylinder has recently been investigated by utilizing Fourier transform and mode-matching techniques [6]–[8], studies on the penetration into circumferential slots on a conducting circular cylinder are few. In this paper, we analyze the penetration into narrow circumferential slots on a conducting circular cylinder that is excited by an electric point current outside of the circular cylinder. The Fourier transform and mode-matching techniques are used to obtain simultaneous equations for modal coefficients. Solutions of simultaneous equations are represented in rapidly convergent series that is numerically very efficient. A brief theoretical summary is given and the penetration characteristics of narrow circumferential slots on a conducting circular cylinder are investigated.

2. Theory

Consider multiple narrow circumferential slots on a conducting circular cylinder that is excited by an electric point current source. The geometry of the problem is shown in Fig. 1. The cylindrical coordinates (ρ, ϕ, z) are used for analysis. The width and the period of the slot (slot spacing) are d and T. Regions (I), (II), and (III) denote the exterior of a circular cylinder ($\rho > b$), a slotted aperture ($a < \rho < b$ and $T^{(q)} < z < T^{(q)} + d$), and the interior of a circular cylinder ($0 < \rho < a$), respectively. The notation $T^{(q)}$ specifies the displacement from $z = 0$ to the bottom of the qth slot. The wave numbers of regions (I), (II),

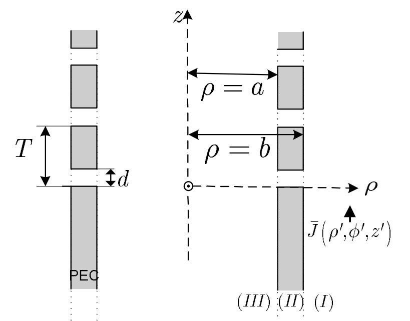

Figure 1: Multiple Narrow Circumferential Slots on a Conducting Circular Cylinder

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and (III) are $k_1 = \omega\sqrt{\mu_1\epsilon_1}$, $k_2 = \omega\sqrt{\mu_2\epsilon_2}$, and $k_3 = \omega\sqrt{\mu_3\epsilon_3}$, respectively. The z-oriented electric point current source $\bar{J} = \hat{z}\frac{J}{\rho}\delta(\rho-\rho')\,\delta(\phi-\phi')\,\delta(z-z')$ is placed in region (I), where $\delta(\cdot)$ is the Dirac delta function. The total field in region (I) consists of the incident and scattered components. The incident magnetic vector potential A_z^i resulting from $\bar{J}$ is [9]

$$A_z^i(\rho,\phi,z;\rho',\phi',z') = -i\frac{\mu_1 J}{8\pi}\int_{-\infty}^{\infty}\sum_{p=-\infty}^{\infty}$$

$$\begin{cases} \dfrac{H_p^{(1)}(\kappa_1\rho')\,\Omega_p(\kappa_1\rho)}{H_p^{(1)}(\kappa_1 b)}e^{ip(\phi-\phi')-i\zeta(z-z')}d\zeta & for\;\; b<\rho<\rho' \\ \dfrac{\Omega_p(\kappa_1\rho')\,H_p^{(1)}(\kappa_1\rho)}{H_p^{(1)}(\kappa_1 b)}e^{ip(\phi-\phi')-i\zeta(z-z')}d\zeta & for\;\; \rho>\rho' \end{cases} \tag{1}$$

where $\Omega_p(\kappa_1\rho) = H_p^{(1)}(\kappa_1\rho)J_p(\kappa_1 b) - J_p(\kappa_1\rho)H_p^{(1)}(\kappa_1 b)$ and $\kappa_1 = \sqrt{k_1^2-\zeta^2}$. Note that $H_p^{(1)}(\cdot)$ and $J_p(\cdot)$ are the Hankel and Bessel functions of the first kind, respectively. The scattered magnetic and electric vector potentials in regions (I) and (III) are similar to those in [7]. The slot is assumed to be narrow such that the electric field is approximately given by a constant E_z component. The vector potentials in region (II) are simplified as

$$A_z^{II}(\rho,\phi,z) = \sum_{n=-\infty}^{\infty} R_n^{(q)}(k_2\rho)e^{in\phi} \tag{2}$$

$$F_z^{II}(\rho,\phi,z) = 0 \tag{3}$$

where $R_n^{(q)}(k_2\rho) = A_n^{(q)}\frac{J_n(k_2\rho)}{J_n(k_2 a)} + B_n^{(q)}\frac{N_n(k_2\rho)}{N_n(k_2 b)}$. This approximation is valid as long as the width of slot is very small compared to the wavelength ($d \ll \lambda$). We enforce the boundary conditions on the field continuities from regions (I) through (III). The tangential E_z component continuity at $\rho = b$ gives

$$\tilde{A}_z^I(\zeta) = \frac{\mu_1\varepsilon_1 k_2^2}{\mu_2\varepsilon_2\kappa_1^2}\sum_{q=0}^{Q-1}\frac{R_n^{(q)}(k_2 b)G^{(q)}(\zeta)}{H_n^{(1)}(\kappa_1 b)}. \tag{4}$$

where $G^{(q)}(\zeta) = \frac{\left(e^{i\zeta d}-1\right)}{i\zeta}e^{i\zeta T^{(q)}}$. The tangential E_ϕ component continuity at $\rho = b$ requires $E_\phi^I(b,\phi,z) \approx 0$. The tangential H_ϕ component continuity at $\rho = b$ in the qth slot requires

$$H_\phi^i(b,\phi,z) + H_\phi^I(b,\phi,z) = H_\phi^{II}(b,\phi,z) \quad for\;\; T^{(q)} < z < T^{(q)}+d,\; 0 \leqq \phi < 2\pi. \tag{5}$$

which yields a set of simultaneous equation for $A_n^{(q)}$ and $B_n^{(q)}$ [10]. It is necessary to obtain another set of simultaneous equation for $A_n^{(q)}$ and $B_n^{(q)}$ by using the boundary conditions at $\rho = a$. It is trivial to solve the simultaneous equations for the unknown coefficients $A_n^{(q)}$ and $B_n^{(q)}$ by matrix inversion.

3. Calculations

In order to check the validity of this computation, our numerical results are compared with the CST MicroWaveStudio (MWS) results in Fig. 2. Our scattered far-field patterns agree well with the CST MWS results. The penetration patterns of the interior of the conducting circular cylinder are also investigated. Figure 3 shows the dependence of the penetration pattern on the frequency with respect to z-direction. As the frequency increases from 5.5 to 11.5 GHz, overall penetrating electric field intensity becomes higher.

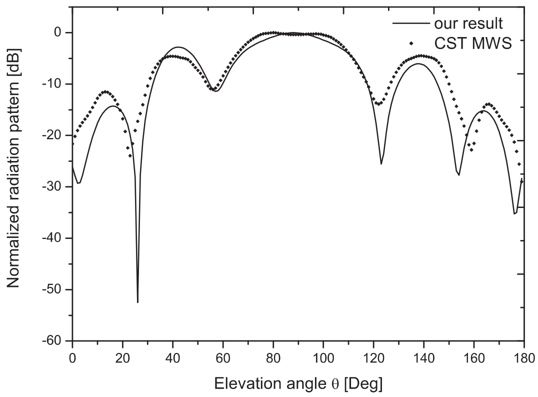

Figure 2: Normalized Scattered Far-fields Versus the Elevation Angle θ in the Plane of $\phi = 0°$: f=8.5GHz, $\epsilon_{r1} = \epsilon_{r2} = \epsilon_{r3} = 1.0$, $a = 1.7\lambda$, $b = 1.8\lambda$, $T = 0.5\lambda$, $d = 0.1\lambda$, $\rho' = 3\lambda$, $\phi' = 0$, $z' = 75$mm, number of slots=10.

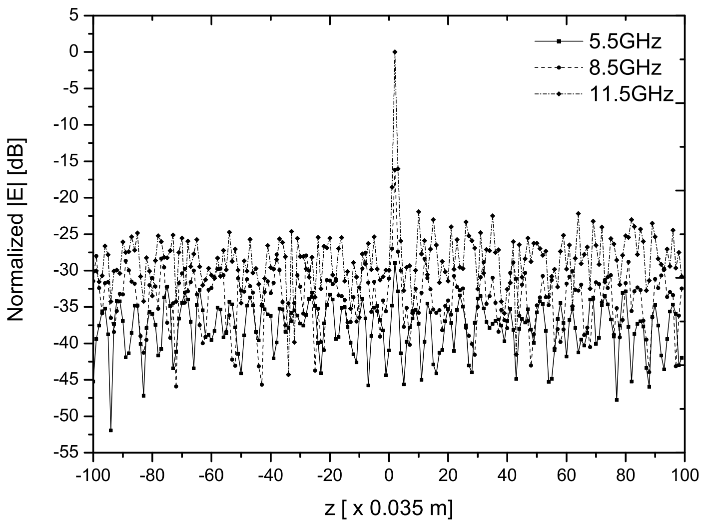

Figure 3: Effects of Frequency on the Penetration Patterns in the Plane of $\rho = 30$mm, $\phi = 0°$: $\epsilon_{r1} = \epsilon_{r2} = \epsilon_{r3} = 1.0$, $a = 60$mm, $b = 63.53$mm, $T = 17.65$mm, $d = 3.53$mm, $\rho' = 10.59$cm, $\phi' = 0$, $z' = 75$mm, number of slots=10.

4. Conclusion

The penetration pattern of narrow circumferential slots on a conducting circular cylinder has been investigated by using the Fourier transform and mode-matching techniques. The electric point source was assumed and the Green's function was utilized. The solution was formulated in terms of the fast convergent series form. Our formulation is useful for the EMI analysis associated with slots on a conducting circular cylinder.

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