ON THE REDUCTION CHARAACTERISTICS OF ELECTROMAGNETIC PENETRATION THROUGH NARROW SLOTS BY WIRE LOADING

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1. Introduction

The electromagnetic field penetrations through an aperture in a planar conducting plane of infinite extent are studied by many researchers [1]-[5]. Electromagnetic coupling through slot apertures is important when considering shielding of electronic equipments and systems. It has been reported on the reduction of electromagnetic penetration through narrow slot in conducting screen by parallel wires [6, 7].

In this paper, a reduction characteristic of the penetrated electromagnetic field through a narrow slot when a plane wave is excited into the slot on an infinitely large conducting screen is considered. The reduction technique described is using the installing parallel wires on the narrow slot in conducting screen. The integral equation for the electric field on the slot aperture is derived and solved by applying Galerkin's method of moments.

When the plane wave is excited into the narrow slot, the aperture electric field is controlled by the two parallel wires connected on the slot. The results show that the magnitude of the penetrated electromagnetic field is effectively reduced by installing the parallel wires on the slot. To verify the theoretical analysis, the calculated electric field penetrations are compared with experiments.

2. Theoretical Analysis

Figure 1 shows the coordinate system of the infinitely large conducting screen with a narrow slot. The conducting screen is located in the *xy*-plane with the origin at the center of the slot aperture. The slot aperture is parallel to the *x*-axis. Two parallel wires with length *l* are connected along the *x*-axis by a distance *c* and

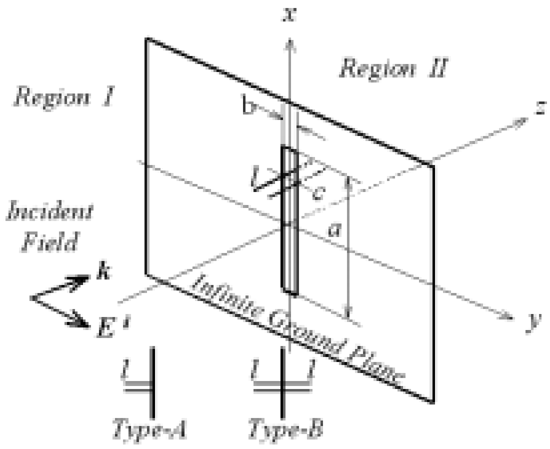

Fig. 1 Aperture in planar conducting screen of infinite extent.

are parallel to the *z*-axis. As shown in Fig. 1, there are two kinds of the wire installation: type-A and type-B.

The problem can be divided into two regions as illustrated in Fig. 1. Region Ⅰ(z<0) is defined as the half-space containing the incident plane wave and bounded by the conducting screen as shown in Fig. 1. The incident electromagnetic fields is penetrated into Region Ⅱ(z>0). The two regions are assumed to be free-space.

The magnetic current sheet with the width *b* can be replaced by the magnetic current cylinder with the equivalent radius *b*/4 when *b* is much smaller than the wavelength. If the plane wave is incident into the narrow slot, the integral equation for the unknown aperture electric field $\boldsymbol{E}_a$ in the narrow slot can be written as

$$\hat{z}\times\left[H^i+H^r+\hat{y}I_y\{\delta(x-c)+\delta(x-c)\}+\frac{1}{j\varpi\mu_0}\iint_{S_a'}\bar{K}^I_{maa}\cdot[\hat{z}\times E_a]dS_a'\}\right]$$

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$$= \hat{z} \times \frac{1}{j\omega\mu_0} \iint_{S'_a} \overline{\boldsymbol{K}}^{II}_{maa} \cdot \left[-\hat{z} \times \boldsymbol{E}_a \right] dS'_a \quad (1)$$

where $\delta(\cdot)$ is the Dirac delta-function. The time dependence *exp(jωt)* is assumed and omitted throughout this paper. The superscripts I and II denote region I and region II, respectively. $\hat{y}$ and $\hat{z}$ are a unit vector in the *y* and *z* direction. dS'_a denotes an element of area on the slot aperture, $\overline{\boldsymbol{K}}^{I}_{maa}$ and $\overline{\boldsymbol{K}}^{II}_{maa}$ are the dyadic Green function of the half-space, and I_y is the current at the connecting position of the two parallel wires.

$$I_y = \frac{V_L}{Z_L} \quad (2)$$

where V_L is the voltage of loading point, Z_L is the impedance of the two parallel wries with a length *l*.

The incident and reflected magnetic fields are expressed as follows.

$$\boldsymbol{H}^{i} = -\hat{x} \frac{1}{Z_0} E^{i}_{0y} e^{-jkz} \quad (3a)$$

$$\boldsymbol{H}^{r} = -\hat{x} \frac{1}{Z_0} E^{i}_{0y} e^{jkz} \quad (3b)$$

To solve the integral equation for the unknown, the aperture electric field $\boldsymbol{E}_a$ is expanded as

$$\boldsymbol{E}_a(x) = \hat{y} \sum_{n=1}^{N} V_n F_n(x) \quad (4)$$

where V_n are coefficients to be determined, and F_n are the piecewise sinusoidal expansion functions. Substituting the assumed basis function into the integral equation (1) and employing Galerkin's method of moments, we obtain a set of linear equations for the unknown expansion coefficients.

$$\sum_{n=1}^{N} V_n (Y_{n'n} - Y^{L}_{n'n}) = I_{n'} \quad (5)$$

where

$$Y_{n'n} = \frac{-2}{j\omega\mu_0} \iint F_{n'}(x)(k^2 + \frac{\partial^2}{\partial x^2}) \frac{e^{-jkR}}{2\pi R} F_n(x') dx' dx \quad (6)$$

$$Y^{L}_{n'n} = \frac{-b}{Z_L} F_n(\pm c) \int F_{n'}(x) \delta(x \pm c) dx \quad (7)$$

$$I_{n'} = -(H^{i}_{x} + H^{r}_{x}) \int F_{n'}(x) dx \quad (8)$$

When a plane wave is excited toward the narrow slot aperture, the penetrated electric field in region II is obtained in the following form.

$$E_y = -\frac{1}{2\pi} \sum_{n=1}^{N} V_n \frac{1}{\sin k \Delta x_n} [S_L + S_U] \quad (9)$$

where

$$S_L = \int_{x_{n-1}}^{x_n} \frac{\partial}{\partial z} \left(\frac{e^{-jkR}}{R} \right) \sin k(x' - x_{n-1}) dx' \quad (10)$$

$$S_U = \int_{x_n}^{x_{n+1}} \frac{\partial}{\partial z} \left(\frac{e^{-jkR}}{R} \right) \sin k(x_{n+1} - x') dx' \quad (11)$$

3. Numerical Results and Discussion

The slot used in the calculation is a narrow slot compared to the wavelength. The dimensions of the slot are *a*=15 cm and *b*=1 mm.

Figure 2 shows the magnitudes of the electric field penetration at *z*=5 cm when the plane wave with frequency of 1 GHz is incident into the slot aperture with two parallel wires of type-A. The penetrated electric fields for various values of the two parallel wires position are shown with the various dashed and solid lines.

As shown in Fig. 2, the amount of reduction is a function of the parallel wires length [7]. The magnitude of the penetrated electric field is reduced to zero by selecting the two parallel wires length of around 0.27λ ~ 0.3λ.

Figure 3 shows the magnitudes of the electric field penetration at *z*=5 cm when the plane wave with frequency of 1 GHz is incident into the slot aperture with two parallel wires of type-B. The magnitude of the penetrated electric field is effectively reduced by the parallel wires of type-B than the parallel wires of type-A on the slot.

Figure 4 shows the frequency characteristics of the penetrated electric field at *z*=5 cm when the two parallel wires of type-A with length of 8.25 cm (0.275λ at 1 GHz) are connected at *c*=0 cm on the slot aperture. As shown in Fig. 4, the magnitude of the penetrated

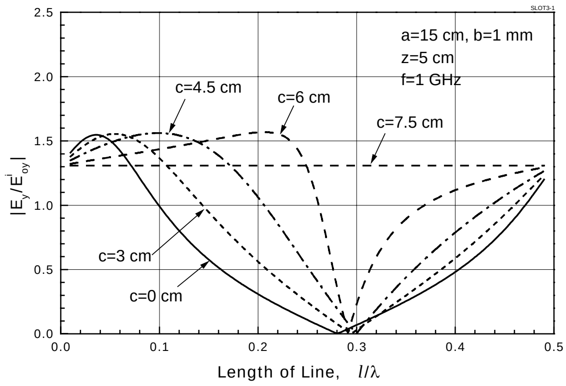


Fig. 2 Penetrated electric fields versus length of the two parallel lines (type-A.).

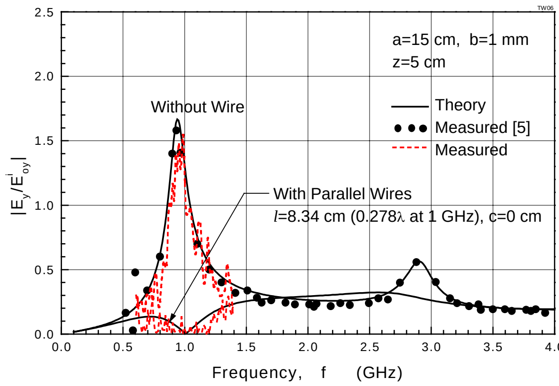


Fig. 4 Frequency characteristics of the penetrated electric fields for type-A wire installation.

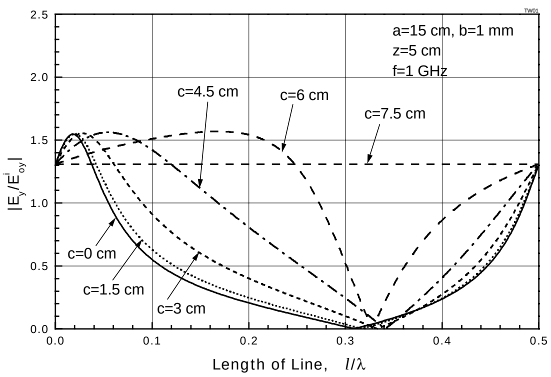


Fig. 3 Penetrated electric fields versus length of the two parallel lines (type-B).

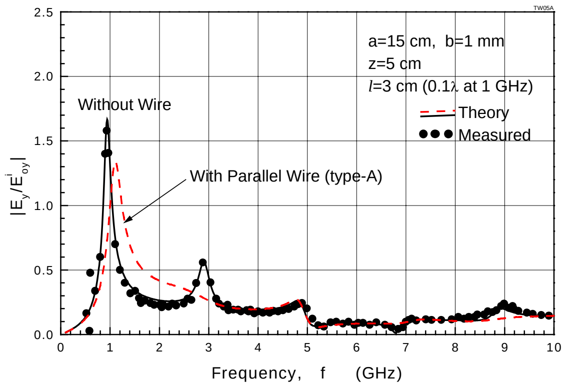
electric field is reduced to zero by selecting the two parallel wires length of 8.25 cm, but the length of 8.25 cm is too long for a real installation. So we can consider to use short wires with l=3 cm (0.1λ at 1 GHz) for type-A and type-B wire installation.

Figure 5(a) and (b) show the frequency characteristics of the penetrated electric field at z=5 cm when the two parallel wires of type-A and type-B with length of 3 cm (0.1λ at 1 GHz) are connected at c=0 cm on the slot aperture. The magnitudes of the electric field penetration through the slot with l= 3 cm parallel wires is smaller than the case of without parallel wires, as shown in Fig. 5(a) and (b). The magnitude of the electric field penetration for the type-B wire installation is smaller than the case of the type-A wire installation. In Fig. 5(a) and (b), the solid line represents the penetrated electric field when no parallel wires are present on the slot. In this case the maximal penetrated electric fields occur at frequencies of 0.94 GHz and 2.9 GHz. These frequencies correspond to the resonant frequencies of the slot aperture with the length of 15 cm.

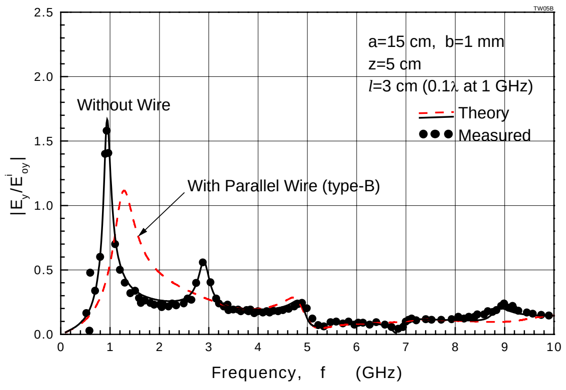
In order to verify the validity of the numerical calculations, the experimental results are provided. A measurement setup comprised of Wiltron 37225A network analyzer and a large ground plane (2 x 4 m) attached with narrow slot (1 mm x 15 cm) in the anechoic chamber. The broadband double-ridged horn antenna made by ICU (model No. ICU-MA-04-2, 0.75 ~ 6 GHz) was used to the transmitting antenna and the shielded small loop antenna was used to the receiving antenna. Its measured results are shown in Fig. 4. In Fig. 4, we described the reference [5]'s and our experimental results. The solid circles present the [5]'s measured results until the 10 GHz. In this paper, we experimented near the resonance frequency of 1 GHz, the most important frequency range, in order to confirm the reduction characteristics of the penetrated electric field near the resonance. It is shown that the calculated electric fields in Region II are in good agreement to experimental results.

4. Conclusions

This paper presents a reduction characteristic of electromagnetic field penetrations through a narrow slot on a infinite conducting screen. It is found that the magnitude of the penetrated electromagnetic field can be reduced by adjusting the length of the two parallel wires on the slot aperture in conducting screen. The experimental and theoretical results show that the penetrated electric field is effectively reduced by installing the two parallel wires on the slot.



(a) type-A



(a) type-B

Fig. 5 Frequency characteristics of the penetrated electric fields for type-A and type-B wire installations.

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