REDUCTION CHARACTERISTICS OF ELECTROMAGNETIC PENETRATION THROUGH NARROW SLOTS IN CONDUCTING SCREEN BY WIRE ARRAY LOADING

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Abstract: This paper presents a reduction characteristic of penetrated electromagnetic fields through a narrow slot aperture with parallel wire arrays in a planar conducting screen of infinite extent. An integral equation for the aperture electric field on narrow slots is derived and solved by applying Galerkin's method of moments. When a plane wave is excited to the narrow slot, the aperture electric field is effectively controlled by parallel wire arrays connected on the slot. The results show that the magnitude of the penetrated electromagnetic field can be effectively reduced by installing the parallel wire arrays on the slot.

Key words: Narrow slot, reduction of electromagnetic fields, N-wire arrays

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 was reported that the research was reduction technique of electromagnetic penetration through narrow slot in conducting screen by single and double two 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 N-wire parallel arrays on the narrow slot. When the plane wave is excited into the narrow slot, the aperture electric field is controlled by the N-wire parallel arrays connected on the slot. The integral equation for the electric field on the slot aperture is derived and solved by applying Galerkin's method of moments. The results show that the magnitude of the penetrated electromagnetic field is effectively reduced by installing the N-wire parallel arrays than single or double 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. The parallel wire arrays with length \( l \) are connected along the x-axis by a distance \( nd \) and \(-nd \) (\( n=1,2, \cdots, N \)), and are parallel to the z-axis.

The problem can be divided into two regions as illustrated in Fig. 1. Region I (\( z<0 \)) is defined as the
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 [8]. If the plane wave is incident into the narrow slot, the integral equation for the unknown aperture electric field \( E_s \) in the narrow slot can be written as

\[
\dot{z} \times [\mathbf{H} + \mathbf{H}']
+ \frac{1}{j\omega\mu_0} \int \mathbf{K}^{' }_w \cdot \{ - \dot{z} \times E_s \} dS'
= \dot{z} \times \frac{1}{j\omega\mu_0} \int \mathbf{K}^{' }_w \cdot \{ - \dot{z} \times E_s \} dS' 
\]

where

\[
\mathbf{K}^{' }_w (r, r') = (\mathbf{i}k - \nabla \nabla \cdot \mathbf{G}^{' }_w (r, r') 
\]

(2)

\( \dot{I} \) is unit dyadic, \( \delta (\cdot) \) is the Dirac delta-function, \( \omega \) represents the angular frequency, and \( k = \omega / \sqrt{\mu_0 \varepsilon_0} \). The superscripts I and II denote region I and region II, respectively. \( \dot{y} \) and \( \dot{z} \) are a unit vector in the \( y \) and \( z \) direction. And position vectors \( r \) and \( r' \) are for the observation and source points, respectively. \( dS' \) denotes an element of area on the slot aperture, \( \mathbf{G}^{' }_w \) and \( \mathbf{G}^{' }_s \) are the dyadic Green function of the half-space, and \( I \) is the current at the connecting position of the \( N \)-wire parallel arrays.

\[
\dot{I}_s (\pm nd) = \frac{V_s (\pm nd)}{Z_s} 
\]

(3)

where \( V_s (\pm nd) \) is the voltage of loading point, \( Z_s \) (\( \approx jX_s \)) is the impedance of the two parallel wires with a length \( l \). \( Z_s \) is the impedance of the two parallel wires with a length \( l \), the expression for the value of impedance is given by

\[
Z_s = - jZ_s \cot (k l) 
\]

(4)

where \( k \) is the propagation constant of the parallel wires. The characteristic impedance of the two parallel lines can be expressed as

\[
Z_s = 120 \ln \left[ \frac{h}{r} + \sqrt{\left( \frac{h}{r} \right)^2 - 1} \right] 
\]

(5)

where \( h \) and \( r \) denote half-spacing and radius of the two parallel lines, respectively.

The incident and reflected magnetic fields are expressed as follows.

\[
\mathbf{H}' = - \dot{x} \frac{1}{Z_0} \mathbf{E}_s , e^{-jkr} 
\]

(6a)

\[
\mathbf{H} = - \dot{x} \frac{1}{Z_0} \mathbf{E}_s , e^{-jkr} 
\]

(6b)

To solve the integral equation for the unknown, the aperture electric field \( E_s \) is expanded as

\[
E_s (x) = \sum_{n=1}^{N} V_n F_n (x) 
\]

(7)

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.

\[
\sum_{n=1}^{N} V_n (Y_{n,s} - Y_{n,s}') = I_n 
\]

(8)

where

\[
Y_{n,s} = \frac{1}{j\omega\mu_0} \int F_n (x) (k^2 - \frac{\partial^2}{\partial x^2}) \frac{e^{-jkr}}{2\pi} F_n (x) dx dx 
\]

(9)

\[
Y_{n,s}' = \frac{1}{Z_s} \int F_n (x) \delta (x \pm nd) dx 
\]

(10)

\[
I_n = -(H' + H) \int F_n (x) dx 
\]

(11)

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

\[
E_i = -\frac{1}{2\pi} \sum_{n=1}^{N} V_n \frac{1}{\sin k\Lambda} [S_n + S_n'] 
\]

(12)

where

\[
S_n = \int \frac{\partial}{\partial x} \left( \frac{e^{-jkr}}{R} \right) \sin k(x' - x_n) dx' 
\]

(13)

\[
S_n' = \int \frac{\partial}{\partial x} \left( \frac{e^{-jkr}}{R} \right) \sin k(x_n - x') dx' 
\]

(14)
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 a single two parallel wires. The penetrated electric fields for various values of the single 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. The magnitude of the penetrated electric field is reduced to zero by selecting the two parallel wires length of around 0.27λ ~ 0.3λ. The length of 8.25 cm (0.275λ at 1 GHz) is too long for a real installation. So we can consider to use $N$-wire parallel arrays with a short line.

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 an $N$-wire parallel arrays. The penetrated electric fields for various values of the $N$-wire parallel arrays position are shown. The magnitude of the penetrated electric field is effectively reduced by the loaded short parallel wires as the $N$ increases. We can consider to use $N$-wire parallel arrays with $l=0.05\lambda$ and $l=0.1\lambda$.

Figure 4(a) and (b) show the frequency characteristics of the penetrated electric field at $z=5$ cm when the $N$-wire parallel arrays with length of $l=0.05\lambda$ (1.5 cm at 1 GHz) and of $l=0.1\lambda$ (3.0 cm at 1 GHz) are connected at $d=\lambda/(N+1)$ cm on the slot aperture. As shown in Fig. 3, the penetrated electric field decreases gradually with increasing array number $N$. 

Fig. 2. Penetrated electric fields versus length of the single two parallel lines. $c$: position of parallel lines.

Fig. 3. Penetrated electric fields versus length of the $N$-wire parallel arrays.

Fig. 4. The frequency characteristics of penetrated electric fields by $N$-wire parallel arrays.
The magnitudes of the electric field penetration through the slot with \( l=0.05 \lambda \), N-wire arrays is larger than the case of \( l=0.1 \lambda \). But it is smaller than the case of without wires. 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 resonance frequencies of the slot aperture with the length of 15 cm.

In order to verify the validity of the numerical calculations, the experimental result for no parallel wires is provided [5]. It is shown that the calculated electric fields in Region II are in good agreement to experimental results.

4. Conclusion

In this paper, a reduction technique of electromagnetic field penetrations through a narrow slot on an infinite conducting screen is proposed and analyzed by the method of moments. As the results, it is found that the magnitude of the penetrated electromagnetic field can be effectively reduced by adjusting the length of the N-wire parallel arrays on the slot aperture. Therefore, connecting the short N-wire parallel arrays on the slot is an effective way to control the level of the electromagnetic field penetration through a narrow slot in a planar conducting screen.

References