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Electromagnetic Field Plot of an Inductive Window by the Moment Method

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Abstract — A moment method is used to plot the electromagnetic field of an inductive window in a TE$_{10}$-mode rectangular waveguide. Green’s dyadic functions are derived based on Tai’s approach, which is a modified form of Hansen’s vector wave functions. Based on the computed electric fields, the $S$ matrix and the equivalent aperture reactance of the waveguide window are calculated. This calculation agrees with the previously published closed-form results of Marcuvitz.

I. INTRODUCTION

The objective of this paper is to show a plot of electromagnetic field of an inductive window obtained by the moment method. Waveguide windows are widely used in filter and impedance matching sections in rectangular waveguide systems. Although the impedance of this window has been investigated in the past, the electromagnetic fields in close proximity to the window have not been studied well [1]–[4]. To the authors’ knowledge, no field plots are available. This paper proposes a method to obtain the field plots in a rectangular waveguide with a window using Green’s functions [4]–[6]. Specifically, the total field near the window may be divided into two field contributions by the induction theorem [4]–[6]. These fields are the incoming field and the scattered field which is generated by an equivalent mathematical source which is used to represent the window.

II. PLOT OF ELECTRIC FIELDS

In Fig. 1, a conducting iris of $d \times b$ to form a waveguide window of $(a-d) \times b$ is illustrated.

A graphical representation of the incoming, scattered, and total fields in the waveguide was obtained by plotting the instantaneous fields at a given point in time as a function of position $r$ in the domain of the waveguide.

The instantaneous fields in general are expressed by

$$ E(r,t) = \text{Re} \{E(r)e^{j\omega t}\} $$

$$ H(r,t) = \text{Re} \{H(r)e^{j\omega t}\} $$

Only plots of the electric fields shall be shown in this paper.

Consider first the case with only the TE$_{10}$ dominant mode propagating in the waveguide as the incoming field. The incoming electric field for this mode has only a $y$ component. Since the incoming electric field $E^i_y(r,t)$ is independent of the position $y$, its magnitude is independent of $y$ for $0 < y < b$. The amplitude $H_0$ of the longitudinal component of the incoming magnetic field was set to

$$ H_0 = \frac{1}{\omega \mu} \frac{\pi}{a} \left( A/m \right) $$

such that the amplitude of $E_y^i$ was normalized to 1 (V/m). The width, $a$, and the height, $b$, of the waveguide were chosen for X-band rectangular waveguide. The operating frequency, $f$, was chosen such that all modes were in cutoff except for TE$_{10}$. The waveguide wavelength, $\lambda_k$, was determined by common waveguide theory [1]–[4]. Calculations are performed using a VAX computer [8].

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Fig. 2. Scattered electric field: $\omega t = 0.00 \pi$, $f = 10.00 \text{GHz}$, $\lambda_g = 4.87 \text{ cm}$, $a = 1.905 \text{ cm}$, $b = 0.952 \text{ cm}$, diaphragm width = 0.762 cm.

Fig. 3. Total electric field: $\omega t = 0.00 \pi$, $f = 10.00 \text{GHz}$, $\lambda_g = 4.87 \text{ cm}$, $a = 1.905 \text{ cm}$, $b = 0.952 \text{ cm}$, diaphragm width = 0.762 cm.

Fig. 4. Magnitude of $\Gamma_{11}$ and $T_{21}$ of the window: $a = 1.905 \text{ cm}$, $f = 10.00 \text{ GHz}$, $\lambda_g = 4.87 \text{ cm}$. 
The scattered electric field for the TE$_{10}$ incident field is given by

$$E_y^s(r) = \sum_{i=1}^{N} \left[ G_y^i(r/r_i) \right] \cdot \left[ j\omega\mu I_y^i(r_i) - k_z - \frac{\omega\mu a}{\pi} H_0 \sin \left( \frac{\pi}{a} x_i \right) e^{-jk_z z_i} \right] u_y.$$  \hspace{1cm} (4)

The Green’s function, $G_y^i(r/r_i)$, is given by

$$G_y^i(r/r_i) = \frac{j}{ab} \sum_{m,n} \left\{ \frac{2 - \delta_0}{k_z^2} \left[ \frac{\pi}{a} \right]^2 - \left( \frac{k_z}{a} \right)^2 \left( \frac{m\pi}{a} \right) \right\} \cdot \sin \left( \frac{m\pi x}{a} \right) \cos \left( \frac{m\pi y}{a} \right)$$

\hspace{1cm} $\cdot \sin \left( \frac{n\pi y_i}{a} \right) \cos \left( \frac{n\pi y_i}{b} \right) e^{-jk_z(z - z_i)}$  \hspace{1cm} (5)

where $k^2 = \omega^2 \varepsilon \mu$. The infinite summation over $m$ must be truncated. For $m > 1$, the scattered field is in cutoff and is an evanescent field which is localized at $r'$, being attenuated as a function of $e^{-k_z(z - z')}$. The amplitude of Green’s function of each mode of this evanescent field is, from (5),

$$A_y^i(m) = \frac{2}{ab} \sqrt{\left[ \frac{m\pi}{a} \right]^2 - k_z^2}$$  \hspace{1cm} (6)

which decreases as $m$ increases and converges to zero as $m$ approaches infinity. The summation of $A_y^i$ over $m$ will approach infinity as $m$ approaches infinity. To determine the number of modes at which to truncate, the percent difference between the $m$ and $m-1$ amplitude of the summation was determined by choosing the value of $m = 197$, giving a percent difference of 0.1.

The coefficients $I_y^i(r_i)$ of the total current were calculated as follows:

$$\left[ I_y^i \right] = \left[ G_y^i \right]^{-1} \left[ E_y^i \right].$$  \hspace{1cm} (7)

The instantaneous scattered electric field, $E_y^i(r, t)$, was plotted for $\omega t = 0$, as shown in Fig. 2. The instantaneous total electric field, $E_y(r, t)$, was plotted for the same $\omega t$, as shown in Fig. 3. The discrete set of lines in the figures indicate the position $r'$ of the sources and thus the diaphragm position in the waveguide. The number $N$ of current filaments chosen to represent the impressed sources and their positions is also indicated by these lines. For this case, $N = 13$ and the width, $d$, of the diaphragm was 0.4a, as shown. The magnitude scale was increased to 1.7 (V/m) compared with a maximum magnitude of 1.0 (V/m) for the incoming electric field.

The plot of the total field shows that the wave reflected from the diaphragm, as shown in Fig. 3 for $z < 0$, is in phase to some degree with the incoming field such that the magnitude of the total field is greater than 1.0 (V/m).

A. Scattering Matrix of the Window [1], [2], [4]

The following scattering coefficients can be determined:

$$S_{22} = \Gamma_{11} = \frac{E_y^i(r)}{E_y^i(r)} \bigg|_{z = -p_1}$$  \hspace{1cm} (8)

$$S_{12} = S_{21} = T_{21} = \left[ \frac{E_y^i(r) + E_y^s(r)}{E_y^i(r)} \right] \bigg|_{z = -p_1}$$  \hspace{1cm} (9)

where $\Gamma_{11}$ is the reflection coefficient at port 1 at $z = P_1$; $T_{21}$ is the transmission coefficient from $z = P_1$ to port 2 at $z = P_2$ of the two-port structure of this window; and $E_y^i(r)$ is given by

$$E_y^i(r) = - j\omega\mu \frac{a}{\pi} H_0 \sin \frac{\pi x}{a} e^{-jk_z z} u_y.$$  \hspace{1cm} (10)

$E_y^i(r)$ is given by (4). The reference planes $P_1$ and $P_2$ were chosen to be several integral number of waveguide wavelengths, $n\lambda_g$, away from the plane $z = z'$, where the window is located. The planes must be far enough from the window that the magnitudes of the evanescent scattered fields are near zero.

Both $S_{11}$ and $S_{21}$ are calculated as functions of the diaphragm to waveguide width ratio, $d/a$, for $0.1 <$
The results of this method agree well with published  

REFERENCES


John R. Natke (S’89) was born in Manilla, IA, on August 28, 1963. He received the B.S.E.E. degree from the Milwaukee School of Engineering in 1985 and the M.S.E.E. degree from Marquette University, Milwaukee, WI, in 1988. He is presently a Ph.D. candidate in electrical engineering at the University of Michigan, Ann Arbor. His research interests include electromagnetic theory, scattering problems, and numerical methods applied to these areas.

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Computer programs are available from the authors.
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