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Electric Fields of an H-Plane Tapered Iris

John R. Natzke
George Fox University, jnatzke@georgefox.edu

T. Koryu Ishii

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***Abstract*— Microwave electric fields of an X-band H-plane tapered iris are calculated and plotted using the moment method for the first time. The moment method results are compared with previously obtained experimental measurements and numerical results based on an equivalent circuit approach, giving confirmation that the tapered iris is both a reciprocal and asymmetrical network. The moment method results now reveal that the asymmetry stems from the asymmetry in the phase of the input and output voltage reflection coefficients, their magnitudes being equal.**

I. Introduction

Since the H-plane tapered iris exhibits reciprocal but asymmetrical transmission within a certain frequency range, it has attracted technological curiosity [1]–[3]. The past work has either been experimental [1], [2] or based on an equivalent circuit approach [3] and has not considered the electromagnetic field behavior in the proximity of the tapered iris. Until this is actually done, the reciprocal and asymmetrical transmission characteristics cannot be fully understood.

This paper presents the calculation of the electromagnetic fields of an H-plane tapered iris by the moment method using the Green's function derived for rectangular waveguide [4]. Given the total electric field distribution in the waveguide, the scattering matrix (S-matrix) is determined. The moment method results are compared with the previously published results [2], [3] by obtaining the input and output impedance and insertion loss from the S-matrix elements of the tapered iris. Thus a theoretical explanation of the reciprocal but asymmetrical transmission characteristics of the H-plane tapered iris is introduced in this paper.

II. Calculation of Electric Fields

Consider the H-plane tapered iris structure defined by its length L and aperture width d as shown in Fig. 1. The rectangular waveguide of width a and height b is assumed to be in TE_{10} dominant mode operation, which gives an incident field component

$$E_y^i = \sin \frac{\pi x}{a} e^{-jk_z z} \tag{14}$$

where the propagation constant $k_z = \sqrt{k^2 - (\pi/a)^2}$ and the wavenumber $k = \omega\sqrt{\mu\varepsilon}$. A time dependence of $e^{j\omega t}$ is assumed and suppressed. Taking the surface current induced on the surface S_d' of the (infinitesimally thin) diaphragms to be the source of the scattered field E_y^s, the total electric field in the waveguide is $E_y = E_y^i + E_y^s$. On applying the moment method, the Green's function for rectangular waveguide is used with N impulse basis functions over S_d' to obtain the scattered field expression [5], [6]

$$E_y^s(x, z) = -\frac{\omega\mu}{a} \sum_{i=1}^{N} \left\{ I_i \sum_{m=1}^{\infty} \frac{1}{k_{zm}} \sin\left(\frac{m\pi}{a} x\right) \cdot \sin\left(\frac{m\pi}{a} x_i\right) e^{-jk_{zm}|z-z_i|} \right\} \tag{15}$$

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J. R. Natzke is with the Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, MI 48109-2122.

T. K. Ishii is with the Department of Electrical and Computer Engineering, Marquette University, Milwaukee, WI 53233.

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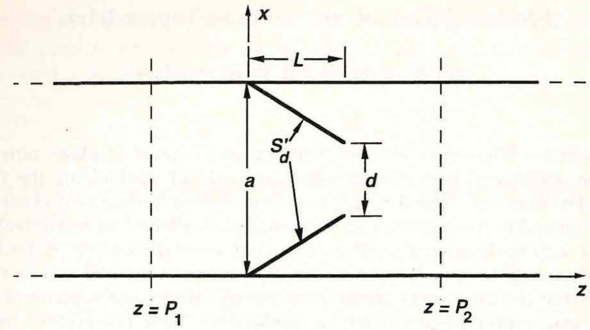

Fig. 1. H-plane tapered iris structure in rectangular waveguide (top view).

where the modal wavenumbers are

$$k_{zm} = \sqrt{k^2 - \left(\frac{m\pi}{a}\right)^2} \tag{16}$$

with $\text{Im}(k_{zm}) \leq 0$ and I_i are the coefficients of the current filaments located at (x_i, z_i), $i = 1, \cdots, N$, comprising the equivalent source of the diaphragms. The current coefficients are determined by point matching E_y^s with $-E_y^i$ over S'_d, thus enforcing the boundary condition that the total electric field E_y is zero on S'_d. Upon solution of the coefficients I_i, the total field behavior is known throughout the waveguide from (1) and (2).

The instantaneous electric field intensity in the proximity of the H-plane tapered iris can be represented graphically by magnitude plots in the x-z plane of the rectangular waveguide. The theoretical analysis is not restricted to any specific dimensions, but for the sake of later comparison to experimental data measured in an X-band system we set $a = 2.286$ cm, $b = 1.016$ cm, $d/a = 0.394$, and $L = 0.960$ cm. These waveguide dimensions give a frequency range of $6.562 < f < 13.123$ GHz for TE_{10} mode operation, and for a center frequency of $f = 9.5$ GHz, the waveguide wavelength is $\lambda_g = 4.367$ cm. The summation limits in (2) were set to $N = 64$ and $m = 107$, based on the optimum convergence criteria of $N/m \simeq 0.6$ and $m_{\min} = 99$ from [4]. Given these parameters, the total instantaneous electric field is plotted in Fig. 2(a) for forward transmission. To consider the total electric field of the reverse transmission case, the iris is tapered in the opposite direction, as shown in Fig. 2(b). Upon comparison of Fig. 2(a) and 2(b), the asymmetrical transmission through the tapered iris structure is visually confirmed.

III. Transmission Line Analysis

Once the electric fields of the tapered iris are calculated, the S-matrix elements are given by [6], [7]

$$S_{11} = \left.\frac{E_y^s}{E_y^{i+}}\right|_{z=P_1} \tag{17}$$

$$S_{21} = \frac{(E_y^{i+} + E_y^{s+})|_{z=P_2}}{E_y^{i+}|_{z=P_1}} \tag{18}$$

$$S_{22} = \left.\frac{E_y^{s-}}{E_y^{i-}}\right|_{z=P_2} \tag{19}$$

$$S_{12} = \frac{(E_y^{i-} + E_y^{s-})|_{z=P_1}}{E_y^{i-}|_{z=P_2}} \tag{20}$$

where $+/-$ denote the forward/reverse transmission cases and $z = P_1, P_2$ are the reference planes shown in Fig. 1. The S-matrix for a two-port network is defined in terms of traveling waves only, and thus the references planes are chosen to be several (integral) waveguide wavelengths from the iris such that the magnitudes of the evanescent scattered fields $(m > 1)$ are negligibly small [6]. The S-matrix elements of the tapered iris structure in Fig. 2 were calculated as a function of frequency and plotted in Fig. 3. The reciprocal nature of the tapered iris is evident from the equality of transmission coefficients, $S_{21} = S_{12}$, which is expected for a linear, lossless, and passive network. It is also evident from Fig. 3 that the asymmetry of the tapered iris stems from the difference in the phase of the reflection coefficients S_{11} and S_{22}, their magnitudes being equal.

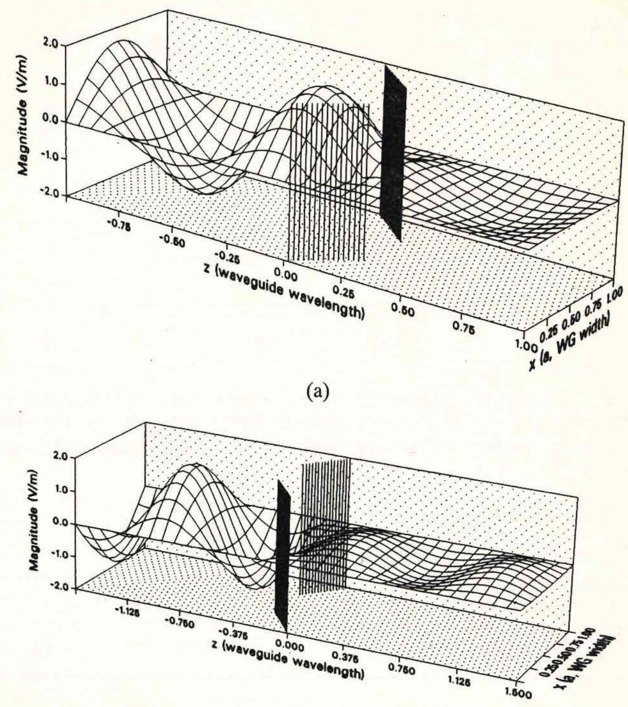

Fig. 2. Total instantaneous electric field of the X-band tapered iris with $f = 9.5$ GHz, $\omega t = 0.5\pi$, $d/a = 0.394$, and $L = 0.960$ cm. (a) forward and (b) reverse transmission.

Although no energy is lost in the system, the incident field power is attenuated due to reflection from and energy storage at the iris. This is quantified by the insertion loss, defined as [8]

$$IL^+(dB) = -20\log|S_{21}| \tag{21}$$

and for a reciprocal device, $IL^- = IL^+$. The insertion loss of (8) is compared with the experimental data of Brewer and Ishii [2] as shown in Fig. 4. The moment method result gives an average value over the frequency range of the available data.

The normalized input and output impedance of the tapered iris can be determined directly by plotting the magnitude and phase of the reflection coefficients in (4) and (6) on a Smith chart, for which a characteristic impedance Z_o of the waveguide is assumed. Using the data in Fig. 3, the input and output impedances are presented in Fig. 5(a) and 5(b) with the earlier finding of Brewer and Ishii [2] and Chen and Ishii [3] for $9.0 < f < 10.0$ GHz. The asymmetry of the tapered iris is again evident, and the moment method results correct the equivalent circuit solution [3] by a slight shift on the Smith chart.

IV. Summary

The electric fields in the proximity of an H-plane tapered iris in an X-band rectangular waveguide were calculated and plotted using the moment method. The theoretical results demonstrated that the tapered

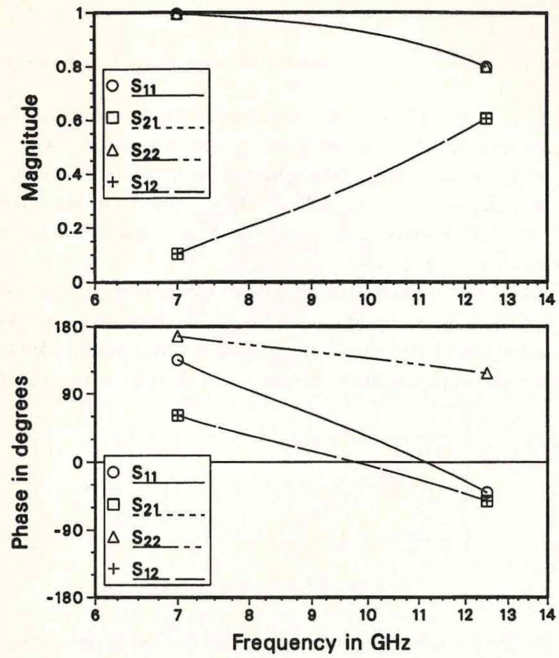

Fig. 3. Reflection and transmission coefficients of the S-matrix for the X-band tapered iris of Fig. 2.

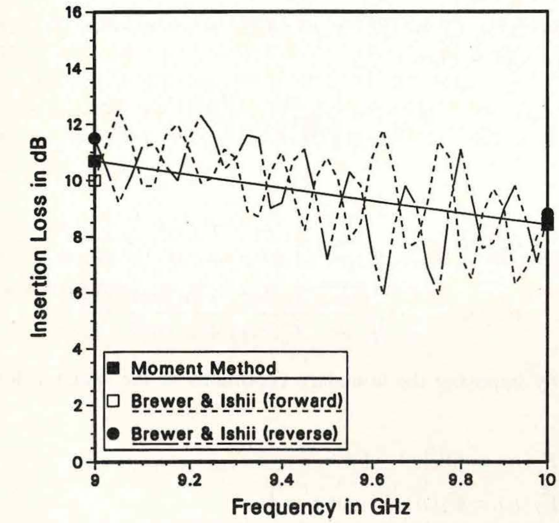

Fig. 4. Insertion loss of the X-band tapered iris.

iris is indeed a reciprocal and asymmetrical network. The reciprocal nature was verified in that the forward and reverse insertion loss (or transmission coefficients) were found to be equal. The moment method calculation also revealed that the asymmetrical transmission of the tapered iris is manifested only in the phase of the input and output reflection coefficients. This resulted in the asymmetry of the input and output impedances, as observed in the previous investigations.

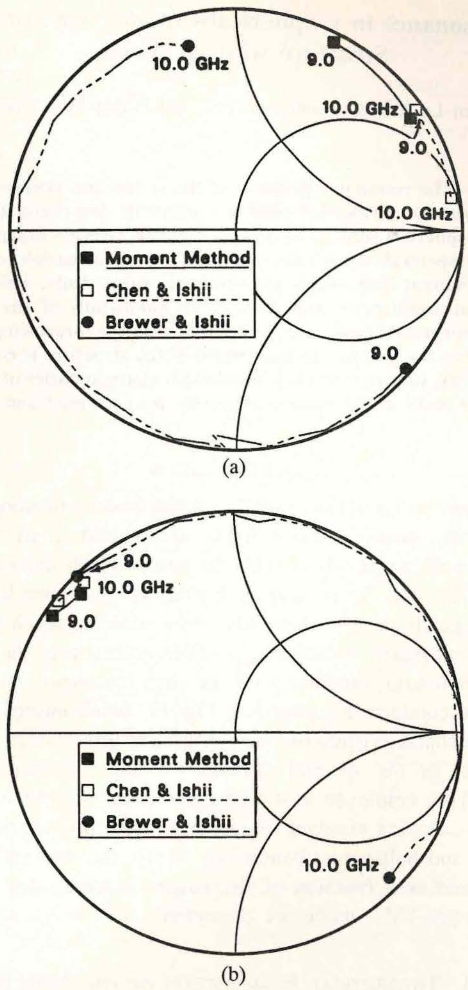

Fig. 5. Normalized (a) input and (b) output impedance of the X-band tapered iris.

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