of Maxwell's equations," *Int. J. Numer. Meth. Eng.*, vol. 19, pp. 13–30, 1980.

[11] S. Akhtarzad and P. B. Johns, "Generalized elements for the TLM method of numerical analysis," *Proc. Inst. Elec. Eng.*, vol. 122, no. 12, pp. 1349–1352, Dec. 1975.

[12] I. S. Kim and W. J. R. Hoefer, "Effect of the stability factor on the accuracy of two-dimensional TD–FD simulation," in *Proc. 1989 IEEE AP-S Symp.*, 1989, pp. 1108–1111.

Analysis of a Transition Between Rectangular and Circular Waveguides

B. N. Das and P. V. D. Somasekhar Rao

Abstract —**This paper presents analysis of a transition between rectangular and circular waveguides coupled by a rectangular slot in a metallic wall of finite thickness in the common transverse cross section. Expressions for VSWR and admittance are obtained using a moment method formulation with entire basis and testing functions. Numerical data on the variation of input VSWR with frequency are obtained and a comparison between the theoretical and experimental results is presented. The variations in the values of minimum VSWR with change in slot dimensions are also studied.**

I. Introduction

Excitation of a circular waveguide from a rectangular waveguide has attracted the attention of scientific workers for a long time [1]–[3]. The transition which has been suggested is designed in such a way that there is a transformation of cross section from rectangular on one side to circular on the other side. The transition designed for better matching [2], [3] is quite bulky apart from the complexity in mechanical fabrication.

Investigations of coupling between waveguides through apertures in the form of a rectangular slot in the common transverse cross section have been reported [4]–[6]. To the best of the authors' knowledge, no data on the performance characteristics of this type of junction are available in the literature.

In the present work, investigations are carried out for a junction (transition) between rectangular and circular waveguides coupled through a rectangular slot. Analysis based on the method of moments with entire sinusoidal basis and testing functions taking into account the effect of the finite thickness of the transverse metallic wall in which the slot is milled is similar to that in [7]. The expressions for the elements of matrices to be inverted are different for the problem under investigation.

Expressions for the coefficient, VSWR and normalized shunt admittance seen by the rectangular waveguide are derived. A comparison between the theoretical and experimental results on the variation of input VSWR with frequency is presented for a rectangular slot of length 1.7 cm and width 0.107 cm in a metal plate of thickness 0.09144 cm. Variations in the values of minimum VSWR with change in slot parameters are also studied.

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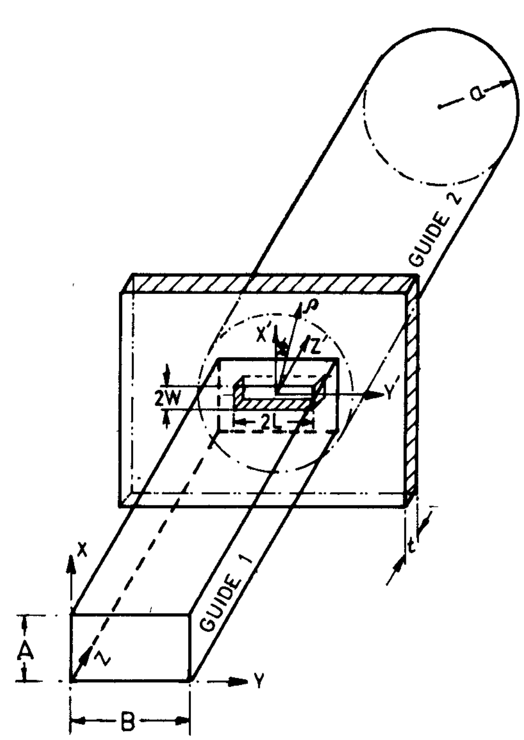


Fig. 1. Slot coupled transition between rectangular and circular waveguides.

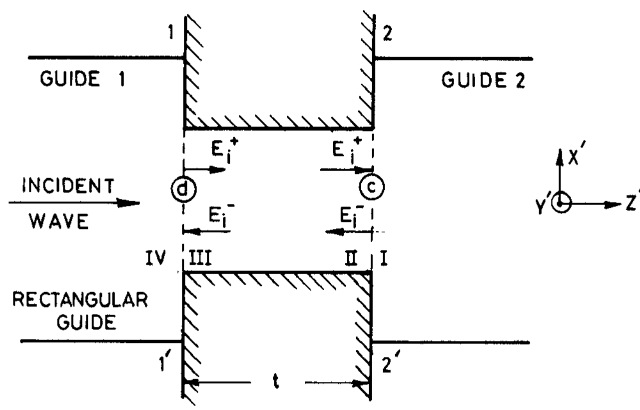


Fig. 2. Expanded view of the coupling slot represented as a slot waveguide.

II. Analysis

Fig. 1 shows the geometry of a slot coupled transition between a rectangular and a circular waveguide. The rectangular coupling slot of length $2L$ and width $2W$ is milled in a metallic plate of thickness t. An expanded view of the slot waveguide representation [7] of the coupling slot is shown in Fig. 2, together with the two interfaces and the incident and reflected waves in the slot waveguide.

Following the procedure of [7, sec. II] the column matrices representing the amplitude coefficients for the total tangential electric fields at the two interfaces of the slot waveguide are same as those given by [7, eqs. (38)–(40)]. They are reproduced

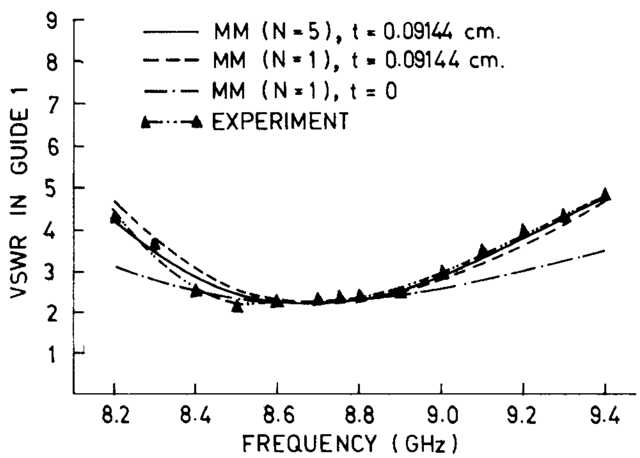


Fig. 3. Variation of VSWR seen by the rectangular guide with frequency for $2L=1.70$ cm, $2W=0.107$ cm, $t=0.09144$ cm, $A=1.016$ cm, $B=2.286$ cm, and $a=1.185$ cm.

for the sake of completeness:

$$[E^d]=\{[U]+[B][Y^{cw}]^{-1}[h^{cw}][B]\}[E^+]_{\text{III}} \quad (1)$$

$$[E^c]=\{[B]+[Y^{cw}]^{-1}[h^{cw}][B]\}[E^+]_{\text{III}} \quad (2)$$

where

$$[E^+]_{\text{III}}=\{[Y^{rw}]^{-1}[h^{rw}][B][Y^{cw}]^{-1}[h^{cw}][B]-[U]\}^{-1}\cdot[Y^{rw}]^{-1}[h^{\text{inc}}]. \quad (3)$$

The elements of the matrices $[Y^{rw}]$ and $[h^{rw}]$ are, however, different from those in [7]. The matrix elements are given by

$$Y_{qs}^{rw}=Y_{qs}^{r}-Y_q 2LW\delta_{qs} \quad (4)$$

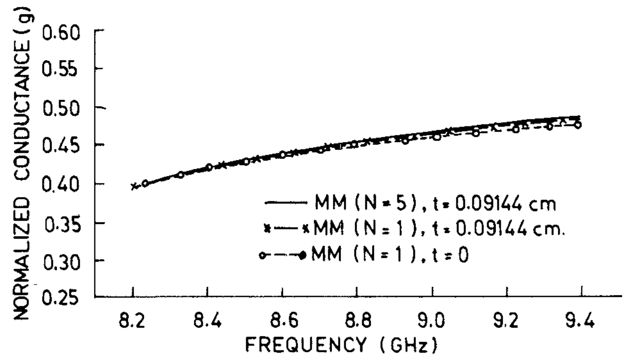
$$h_{is}^{rw}=-Y_{is}^{r}-Y_i 2LW\delta_{is} \quad (5)$$

where

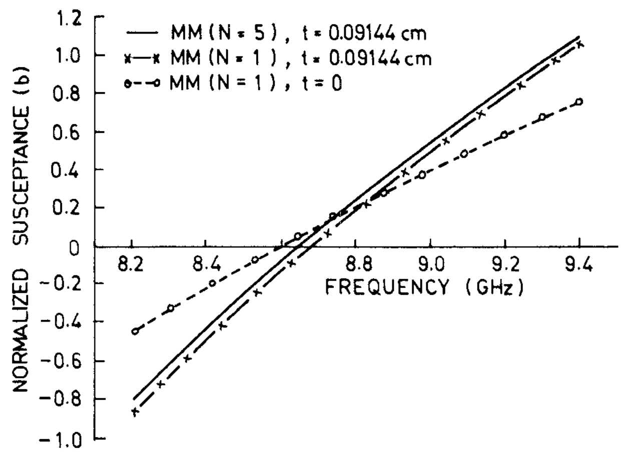
$$Y_{Js}^{r}=-\sum_m\sum_n\left[V_{mn,J}^{E}V_{mn,s}^{E}Y_{mn}^{E}+V_{mn,J}^{M}V_{mn,s}^{M}Y_{mn}^{M}\right] \quad (6)$$

and $J=q,i$. $V_{mn,i}^{E}$ (also $V_{mn,s}^{E}$) and $V_{mn,i}^{M}$ (also $V_{mn,s}^{M}$) are given by

$$V_{mn,q}^{\xi}=\sqrt{\frac{AB\epsilon_\xi}{(mB)^2+(nA)^2}}\,\frac{n}{B}\left[2W\cos(m\pi/2)\frac{\sin(m\pi W/A)}{(m\pi W/A)}\right]\cdot\frac{q\pi/2L}{(q\pi/2L)^2-(n\pi/B)^2}\,\frac{m}{B}\cdot\left[2W\cos(m\pi/2)\frac{\sin(m\pi W/A)}{(m\pi W/A)}\right]\cdot\frac{q\pi/2L}{(q\pi/2L)^2-(n\pi/B)^2}\cdot\begin{Bmatrix}2\cos(n\pi/2)\sin(n\pi L/B) & q\ \text{odd}\\ -2\cos(n\pi/2)\sin(n\pi L/B) & q\ \text{even}\end{Bmatrix} \quad (7)$$



(a)



(b)

Fig. 4. Variation of normalized conductance and susceptance with frequency for $2L=1.70$ cm, $2W=0.107$ cm, $t=0.09144$ cm, $A=1.016$ cm, $B=2.286$ cm, and $a=1.185$ cm.

where q is replaced by i or s; ξ is E or M and $\epsilon_\xi=1$ for $\xi=M$, and for $\xi=E$, $\epsilon_\xi=2$ for either of m,n equal to zero and equal to 4 for both $m,n>0$.

The elements of the column matrix $[h^{\text{inc}}]$ are obtained following (7) as

$$h_s^{\text{inc}}=Y_0\sqrt{\frac{2}{AB}}\,2W\frac{s\pi/2L}{(s\pi/2L)^2-(\pi/B)^2}\cdot\cos(\pi L/B)\,(1-\cos s\pi). \quad (8)$$

Following the formulation of [7, sec. III A], an expression for the reflection is found to be of the form

$$\Gamma=-1+\sum_{\substack{q=1\\ \text{odd}}}^{N}E_q^d\sqrt{\frac{2}{AB}}\,2W\frac{(q\pi/L)\cos(\pi L/B)}{(q\pi/2L)^2-(\pi/B)^2} \quad (9)$$

and the VSWR seen by the feed guide is given by

$$\text{VSWR}=\frac{1+|\Gamma|}{1-|\Gamma|}. \quad (10)$$

The normalized shunt admittance seen by the feed guide is of the form

$$y=g+jb=\frac{1-\Gamma}{1+\Gamma}. \quad (11)$$

III. Numerical and Experimental Results

Using (1)–(10), of present paper and [7, eqs. (28)–(31)], the VSWR and shunt admittance seen by the rectangular waveguide are evaluated for a coupling slot of length $2L = 1.7$ cm and width $2W = 0.107$ cm milled in a metal plate of thickness $t = 0.09144$ cm. The rectangular waveguide has dimensions $A = 1.016$ cm and $B = 2.286$ cm; the circular waveguide has radius $a = 1.185$ cm; and the frequency range is 8.2 to 9.4 GHz. The integrals appearing in [7, eqs. (30) and (31)] have been evaluated numerically using Gaussian quadrature [9], and the computations are carried out for different values of N.

The theoretical results on the variation of VSWR with frequency are presented in Fig. 3, together with the experimental results obtained from the measurement of return loss using an HP-8410C network analyzer and an HP-8747A waveguide reflection/transmission test set. The variations of normalized conductance and susceptance with frequency are presented in Fig. 4.

Computations are carried out for slot lengths ranging from 1.5 to 2.0 cm, for slot widths up to 0.6 cm, and for plate thicknesses up to 0.5 cm to study the effect of slot parameter variation on VSWR.

IV. Discussion

A very good agreement between the theoretical and experimental results on the variation of VSWR with frequency justifies the validity of the theoretical formulations presented above. However, the minimum VSWR obtained (2.26) for slot dimensions of $2L = 1.7$ cm, $2W = 0.107$ cm, and $t = 0.09144$ cm is not satisfactory.

By changing the parameters of the junctions, it has been possible to reduce the minimum VSWR. From the numerical results, it is found that VSWR is favorably low for a slot width of 0.6 cm and a slot length of 1.6 cm. As the plate thickness is varied from zero to 0.35 cm, the minimum VSWR is reduced from 2.104 to 1.847 at a frequency of 9.6 GHz. When t is increased to 0.5 cm, the minimum VSWR is found to be 1.741 at 9.6 GHz. The corresponding minimum insertion loss resulting from mismatch is about 2 dB. These minimum values are realized at the edge of the frequency band of interest. The VSWR and insertion loss are higher for other parameters. Since further reduction of VSWR and insertion loss using rectangular coupling slots is not possible in the frequency range of interest, it is suggested that the use of round ended slots may result in an improvement in the minimum VSWR and give rise to a better matched transition.

References

[1] C. D. Montgomery, R. H. Dickie and E. M. Purcell, Eds., *Principles of Microwave Circuits* (MIT Radiation Laboratory Series, vol. 8). New York: McGraw-Hill, 1948.

[2] D. M. Sazonov, A. N. Gridin, and B. A. Mishustin, *Microwave Circuits*. Moscow: Mir Publishers, 1982.

[3] G. L. Ragan, Ed., *Microwave Transmission Circuits*. New York: McGraw-Hill, 1948.

[4] N. Marcuvitz, *Waveguide Handbook*. New York: Dover, 1965.

[5] H. Oraizi and J. Perini, "A numerical method for the solution of the junction of cylindrical waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-21, pp. 640–642, Oct. 1973.

[6] H. Auda and R. F. Harrington, "A moment solution for waveguide junction problems," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-31, pp. 515–520, July 1983.

[7] B. N. Das, P. V. D. Somasekhar Rao, and A. Chakraborty, "Narrow wall axial slot coupled T-junction between rectangular and circular waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. 37, pp. 1590–1596, Oct. 1989.

[8] R. F. Harrington, *Time-Harmonic Electromagnetic Fields*. New York: McGraw-Hill, 1961.

[9] B. Carnaham, H. A. Luther, and J. O. Wilkes, *Applied Numerical Methods*. New York: Wiley, 1969.

LED-Induced Distributed Bragg Reflection Microwave Filter with Fiber-Optically Controlled Change of Center Frequency via Photoconductivity Gratings

Walter Platte

***Abstract*—A light-induced distributed Bragg reflection band-reject microwave filter is reported in which the grating elements are optoelectronically generated through periodic-structure photoexcitation of a silicon coplanar waveguide. The center frequency can be optically adjusted to 11 GHz and 22 GHz, respectively, by means of a pattern-controlled fiber bundle array fed from six CW-operated 50 mW, 840 nm LED's. Experimental results are in good agreement with theoretical predictions. The principle of operation demonstrated also applies to millimeter-wave integrated circuits.**

I. Introduction

It is known that the distributed Bragg reflection (DBR) characteristics of a periodic-structure waveguide or transmission line can successfully be utilized for the realization of frequency-selective microwave or millimeter-wave devices such as band-reject filters [1] and grating reflectors, e.g., in a stabilized-feedback Gunn oscillator [2], [3]. Usually, the periodic perturbation in the direction of wave propagation is achieved by abrupt changes in permittivity or cross-sectional dimensions (e.g., reduced waveguide thickness [1]–[3]), thus producing a permanent, normally noncontrollable grating structure.

However, when replacing the total dielectric (or a suitable cross-sectional portion of it) by semiconductor material, it is possible to generate the grating configuration optoelectronically [4]–[6]. For this purpose, the originally homogeneous, unperturbed semiconductor waveguide or transmission line is photoexcited by a locally varying periodic illumination, e.g. by means of a pattern-controlled LED-fed fiber bundle array of the type shown in Fig. 1, which correspondingly causes a periodic distribution of the photoinduced charge carriers inside the semiconductor material. Thus, a nonpermanent photoconductivity grating is created, exhibiting the well-known stopband phenomenon [7] within the nonradiating region of the structure. Since the lengths l_1 and l_2 of the excited and dark sections (Fig. 1(b), (c)), the period Λ, the total length of the grating structure, and the amount of photoconductivity (forming the "depth" of the grooves) can be changed by altering the illumination pattern and the intensity, the filter parameters (i.e., center frequency, bandwidth, and reflectance) can be fiber-optically controlled. The price one pays for this capability, however, manifests itself in the optically induced losses which clearly injure the reflection and selectivity characteristics. Moreover, the microwave or millimeter-wave performance of an optically CW-generated DBR structure is governed by the inherent carrier diffusion mechanisms in such a way that the transverse diffusion mainly influences the light-induced losses [8], whereas the longitudinal car-

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