without approximating the shape of the slot geometry. In modern high-performance antenna and microwave circuit applications, such accurate analyses are required.

The authors in [1] claim in their title that they have analyzed the *wide* slot coupling problem. Further in the abstract, it is stated that they have presented an analysis of the wide slot coupler employed in high-power applications. However, in their analysis they have employed the conventional "narrow slot" approximations, i.e., the longitudinal component of the aperture electric field is ignored. In addition, the boundary condition for the longitudinal magnetic field component only is enforced. The transverse distribution is assumed to be uniform. The results presented are for slots with a length to width ratio of 16, which are clearly narrow slots. For wide slots characterized by a length to width ratio of 7 or less, it is generally known that the "narrow slot" approximations are not good. In the analyses of wide slot problems, one has to solve for both the longitudinal and transverse components of the aperture electric field by enforcing the boundary conditions for both components of tangential field across the slot aperture. In addition, one has to solve for the field distribution in the transverse and longitudinal directions. An example of such an analysis is found for the weak slot problem in [6], which is also applicable to wide slots.

REFERENCES

[1] D. Satyanarayana, and A. Chakraborty, "Analysis of wide inclined slot coupled narrow wall coupler between dissimilar rectangular waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. 42, no. 5, pp. 914–917, May 1994.

[2] S. R. Rengarajan, "Compound radiating slots in a broad wall of a rectangular waveguide," *IEEE Trans. Antennas Propagat.*, vol. AP-37, no. 9, pp. 1116–1123, Sept. 1989.

[3] C. T. Tai, "On the eigenfunction expansion of dyadic Green's functions," *Proc. IEEE*, vol. 62, pp. 480–481, 1973.

[4] T. Vu Khac and C. T. Carson, "$m = 0$, $n = 0$ mode and rectangular waveguide slot discontinuity," *Electron. Lett.*, vol. 9, pp. 431–432, Sept. 1973.

[5] S. R. Rengarajan, "Analysis of a centered-inclined waveguide slot coupler," *IEEE Trans. Microwave Theory Tech.*, vol. 37, no. 5, pp. 884–889, May 1989.

[6] C. Peterson and S. R. Rengarajan, "Rigorous analysis of weakly excited broadwall slots," *Electron. Lett.*, vol. 30, no. 12, pp. 921–922, 1994.

Reply to Comments on "Analysis of Wide Inclined Slot Coupled Narrow Wall Coupler Between Dissimilar Rectangular Waveguides"

D. Satyanarayana and Ajay Chakrabarty

The authors wish to thank Sembiam R. Rengarajan for his comments on our recent publication [1]. In replying to the comments, we wish to stress the following points.

It is not clear from the paper [2] whether TE_{00} mode was considered or not. The Green's function used in the scattered field evaluation [2, (4)] has been referred to the literature [3], [4]. The Green's function used by Stevenson [3] does not include the TE_{00} mode. Moreover, the Green's function used through (4) in [3] needs to be used more carefully. The authors feel that it is more appropriate to replace the primed derivative and double differential operators inside the integral by similar unprimed operators located outside the integral. With this modification, the Green's function will be correct and foolproof. This aspect should also be looked into by researchers working in this area, to avoid further confusion. The technical report [4] is not readily available in the open literature for proper reference.

Manuscript received August 18, 1994.

The authors are with the Department of Electronics and Electrical Communication Engineering, I.I.T., Kharagpur 721302 India.

IEEE Log Number 9406817.

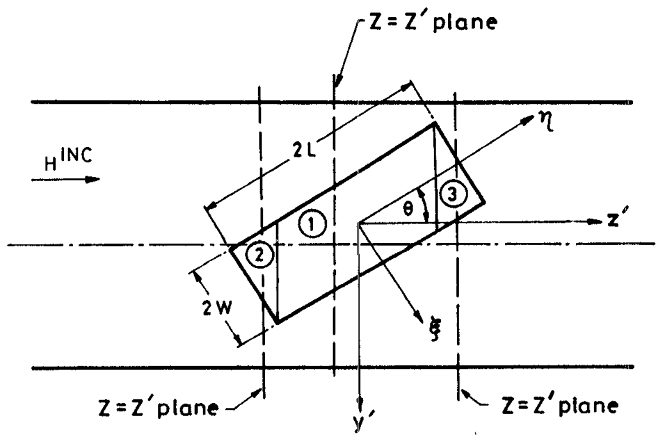

Fig. 1. Inclined slot on the wall of a rectangular waveguide.

From the paper [5], it is understood that the inclusion of TE_{00} mode improves the scattered field computed within the slot region of the waveguide. Also, it is no way connected with the singularity as pointed out in the comments. A statement made by Vu Khac and Carson [5] is given here for convenience:

"It can be seen that if 00 mode is not taken into consideration, a discontinuity in H_z would arise. This is clearly incorrect, since H_z should be analytic in the source free region. The addition of this mode removes the discontinuity and confirms the necessity for its inclusion in a complete set of basis functions used to expand the field."

The testing function [2, (12)] used in evaluation of matrix elements consists of a sinusoidal variation in the longitudinal direction and a dirac delta function along the width of the slot. So, it is basically considered as a point matching technique satisfying the boundary conditions on the center line of the slot in its own direction, making it more appropriate for the narrow width case.

It is true, as pointed out in the comments, that the internal scattered field due to an inclined slot on the wall of a rectangular waveguide has been evaluated without approximating the slot geometry [6], [7], but not from approximations for reducing the complexities, as mentioned below:

1) Hsu and Chen [6] assumed a dirac delta function transversely for both basis function and testing function to reduce the quadruple integral to a double integral.

2) Hanyang and Wei [7] in their paper did not mention complete details about the internal scattered field evaluation.

The slot geometry has been approximated as a parallelogram just to reduce the complexity in separating the integrands on either side of the region of discontinuity. This can be easily be explained using Figs. 1 and 2. In Fig. 1, the slot geometry is divided into three different regions. The evaluation of the scattered field in region 1 is easy as the two halves on either side of the line $z = z'$ are symmetrical, whereas the field evaluation in either region 2 or

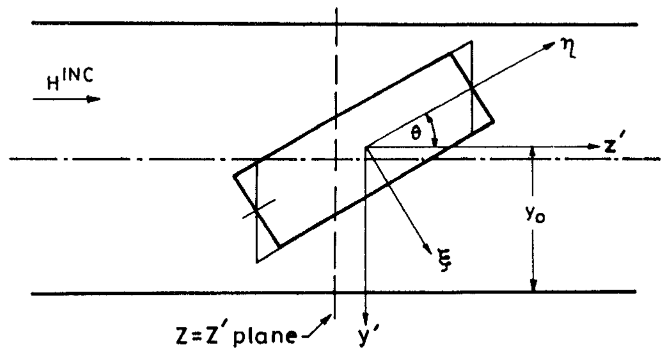

Fig. 2. Modified geometry of the inclined slot.

region 3 is complicated because of the asymmetry of the regions on either side of the line $z = z'$, which increases the dimension of the computation for scattered field evaluation. By modifying the slot geometry as a parallelogram (keeping the area same), as shown in Fig. 2, the integral limits and the integrands can be easily written for the regions on either side of the line of discontinuity $z = z'$.

For wide slots, characterized by length to width ratios of 7 or less, these methods can be equally applicable. However, this computation and experimental verification have not been performed for lack of any practical requirement at this moment. The authors would like to agree that both longitudinal and transverse components of aperture fields have to be accounted for accurate analysis of such wide slots where the same parallelogram approximation is found to be useful for finding out the closed-form expression for scattered field evaluation.

REFERENCES

[1] D. Satyanarayana and A. Chakraborty, "Analysis of wide inclined slot coupled narrow wall coupler between dissimilar rectangular waveguides," *IEEE Trans. Microwave Theory Tech.*, vol. 42, no. 5, pp. 914–917, May, 1994.

[2] S. R. Rengarajan, "Compound radiating slots in a broad wall of a rectangular waveguide," *IEEE Trans. Antenna Propagat.*, vol. AP-37, no. 9, pp. 1116–1123, Sept. 1989.

[3] A. F. Stevenson, "Theory of slots in rectangular waveguides," *J. Appl. Phys.*, vol. 19, pp. 24–38, Jan. 1948.

[4] R. S. Elliott *et al.*, "The scattering properties of slot cut in the broad wall of a rectangular waveguide," TIC 56B1.30/111 Hughes Missile Syst. Group, Canoga Park, CA, Nov. 1983.

[5] T. Vu Khac and C. T. Carson, "$m = 0, n = 0$ mode and rectangular waveguide slot discontinuity," *Electron. Lett.*, vol. 9, pp. 431–432, Sept. 1973.

[6] P. Hsu and S. H. Chen, "Admittance and resonant length of inclined slots in the narrow wall of a rectangular waveguide," *IEEE Trans. Antennas Propagat.*, vol. AP-37, pp. 45–49, no. 1, Jan. 1989.

[7] W. Hanyang, W. Wei, "Moment method analysis of a feeding system in a slotted waveguide antenna," *Proc. IEE, pt. H*, vol. 135, pp. 313–318, Oct. 1988.

Comments on the "Criterion of Leakage from Printed Circuit Transmission Lines" [1], [2]

Ricardo Marqués, Francisco Mesa, and Nirod K. Das

Leakage of power in printed transmission lines can be due to the excitation of both volume and surface waves. Depending on the frequency of operation several surface waves can be excited in the background waveguide, contributing to the transversal leakage of power. A crucial point in the analysis is to determine how many of these surface modes contribute to the leakage. In [1] and [2], it is established that only surface modes satisfying the following condition (see (42) of [1]):

$$\mathrm{Re}\,(k_x) < \mathrm{Re}\,(k_\rho) \tag{1}$$

are excited for a given frequency (in the above equation, k_x is the propagation constant of the leaky transmission line mode and k_ρ is the wavenumber associated to the considered surface wave mode). The above condition is called the *phase match constraint* (see also (26) and (48) of [1]), and it is deduced from the fact that leakage of power occurs *when the transmission line mode propagates faster than the substrate mode*. Nevertheless, a careful mode-matching analysis shows that condition (1) is deduced from the above fact only in a perturbation sense and may not be rigorous in general leakage situations. In this letter, we try to discuss the possibility of excitation of surface-wave modes exponentially growing transversally, but with a wave number lesser than the phase constant of the transmission line. These exponentially growing surface modes would satisfy the phase match constraint, although they may not satisfy (1).

Let a leaky mode be propagating in a lossless line, with *complex* propagation constant k_l. The main idea underlying the *phase match* criterion (and an apparent requirement of the mode-matching analysis) is that any background waveguide mode, which forms the leaky field, must have a propagation constant matching the leaky mode propagation constant. However, since the leaky mode propagation constant is complex and the wavenumbers of the different lossless background waveguide modes are either real or purely imaginary quantities, it does not seem possible to *match* the entire *complex* leaky mode propagation constant if only *uniform* waveguide modes are considered. Therefore, the *phase match constraint* (1), if blindly applied to general situations, may lead to possible contradictions.

Actually, the background waveguide modes present in the field expansion of the leaky mode are *nonuniform*. Nonuniform modes are the most *general* solutions to the wave equation inside the waveguide. Nonuniform plane waves in free space are well-known solutions to the Maxwell equations (see, for example, [3] pp. 320–334), and they are similar to the nonuniform waveguide modes mentioned here. The *complex* wavevectors of these modes satisfy

$$\boldsymbol{k}_n \cdot \boldsymbol{k}_n = \gamma_n^2 \tag{2}$$

Manuscript received August 15, 1994.
R. Marqués is with the Department de Electronica & Electromagnetismo, Universidad de Fisica, 41012 Sevilla, Spain.
N. Das is with the Department of Electrical Engineering, Polytechnic University, New York, NY 11735, USA.
IEEE Log Number 9406801.