1) In discussing narrowband rectangular and circular couplers, we were referring only to the designs proposed in [1] and [2] of the original paper [1]. We agree that there are other designs of rectangular disc couplers in existence that have improved performance.

2) We agree that not all aspects of our analysis were new. The concept of treating the device as an 8-port network should, however, be considered as novel. We also feel that the use of two varieties of tuning stubs is new in relation to circular 3-dB quadrature hybrid couplers. Recently, we proved that short-circuited stubs can be eliminated by changing the shape of the disc from circular to elliptical [9].

In [5], the author refers to a 180° hybrid in the form of a circular disc. This is different from our case, which involves a 90° hybrid coupler. The two types of hybrids should not be confused in the present discussion.

Our derivation of (9) in [1] concerns both circular- and ring-shaped discs. The formula given in (162) [5] concerns only circular discs and is incorrect. The sinc function in (162) [5] should not be squared, but it should appear as in our equation, (9) [1]. Otherwise, Z_{ik} is not equal to Z_{ki}. We agree that there is a factor of 2π missing in the denominator of (9) in [1]. Also we agree that the letter p in the term $p'_m(kr)$ should be in uppercase. These are simply typographical errors.

3) The spikes (around $f = 2.3$ GHz) in Figs. 3 and 4 of our paper [1] are interesting, and we consider them to represent higher-order resonances. In [1], we did not pay much attention to these spikes as we were mainly concerned with the frequency region between 1 and 2 GHz. We were also not concerned about them because the theory agreed well with the experimental measurements. In the experimental results, however, the broadening of the resonant curves observed could be due to circuit and radiation losses, which were not covered by the present theory.

Conclusion

In summary, we can state that the paper we presented gives an alternative design of a 3-dB quadrature disc hybrid. Previously, for a number of years, only rectangular-shaped hybrids had been fully investigated. Additionally, we investigated the behavior of the device when it is frequency scaled, and we suggested a suitable design procedure.

On a positive note, we feel that Abouzahra has provided valuable comments to our paper [1] and we appreciate his efforts.

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

Sembiam R. Rengarajan

We wish to comment on a recent publication in the *IEEE Transactions on Microwave Theory and Techniques* [1]. The authors claim that our paper [2] has not considered the contribution of TE_{00} mode in the scattered fields in the waveguide region and imply that the Green's function employed in our paper is incomplete. It was recognized as far back as in 1973 that the eigenfunction expansion of the dyadic Green's functions in terms of the waveguide modes is incomplete in the source region and that there is an additional singular term [3]. The source region singularity of the dyadic Green's functions in waveguides and cavities was a topic of discussion in several papers in seventies, and it is well understood now by the electromagnetics community. The singular term was interpreted as TE_{00} mode contribution by Vu Khac and Carson [4]. In our paper, the Green's functions in the waveguide region *do indeed* include the source region singularity. The correct form of waveguide Green's functions are found in many papers in the literature, and hence for brevity they were not reproduced in our paper. We wonder how a reader could conclude that the singular terms are not treated in our paper since there is a discussion on the singular contribution with a mathematical expression containing the appropriate Dirac delta function. It is also obvious that the specific terms of the cavity Green's functions that treat the waveguide wall thickness in our analysis do not have such a singular contribution present. Therefore, Green's functions employed in our paper are complete and rigorous.

Some additional comments on the paper [1] are also in order. It is not clear what the authors mean by "the derived expressions are valid for slots of zero width," since zero width is irrelevant. There is no need to approximate the rectangular slot into a parallelogram-shaped element. We have presented a very accurate analysis of a centered inclined slot coupler in the common broad wall of crossed rectangular waveguides, which is a widely used coupling element in planar slot array applications [5]. In that analysis, moment matrix elements are expressed in terms of a double summation. Such an analysis can also be applied to the sidewall slot coupler problem. Many other coupling slot geometries have been treated in the literature very accurately

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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.

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

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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

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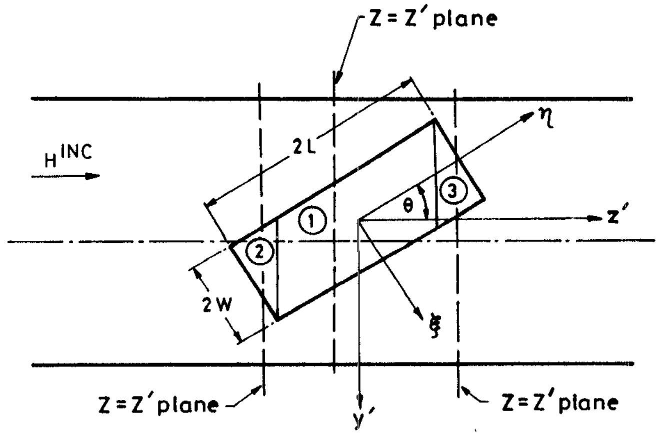

Fig. 1. Inclined slot on the wall of a rectangular waveguide.

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.

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