Letters

Comments on "Analysis and Design of a Circular Disc 3-dB Coupler"

M. D. Abouzahra

In a recent paper, [1], Bialkowski and Jellett discussed the design of a broadband 3-dB quadrature hybrid. This hybrid is comprised of 4-port microstrip disc. It appears that the authors were able to increase the operational bandwidth of the circular disc 3-dB quadrature coupler [2] to about 20%. Open and short-circuited stubs were introduced to the periphery of the coupler in order to realize a broader bandwidth. This technique was applied previously by Riblet [3] and Ohta [4] on planar components and broader operational bandwidth were realized. In addition to listing few corrections, I would like to respond to some inaccurate statements made in [1] by offering the following comments.

1) Contrary to the introductory comments in [1] regarding the narrow operational bandwidth of rectangular-disc-shaped hybrids, Ohta and his coworkers in Japan [4]–[7] have shown that such hybrids can offer 20–27% in operational bandwidth. Ohta's results are indeed very comparable to, and perhaps better than, the results presented in Figs. 5 and 6 of [1].
2) The analysis as well as (9) in Section II is not new. The disc results have been reported earlier, first by Ohta in [8] and later by myself in a tutorial chapter [9]. Reference [10] provides an update to the results that were presented in [9]. Incidentally (9) appears to be missing a 2π factor in the denominator of the term preceding the summation sign. The term $p_m(kr)$ in (5) also need to be changed to $P'_m(kr)$. Furthermore, in the interest of clarity it would have been worthwhile mentioning that the derivative in (5) is with respect to the argument of the Bessel function.
3) The spikes (around $f = 2.3$ GHz) in Figs. 3 and 4 are peculiar; it is unfortunate that the authors did not comment on them.

ACKNOWLEDGMENT This work is supported by the Department of the Army. The views expressed are those of the author and do not reflect the official policy or position of the U.S. Government.

References

[1] M. E. Bialkowski and A. T. Jellett, "Analysis and design of a circular 3 dB coupler," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 1437–1442, Aug. 1994.
[2] M. J. Page and S. R. Judah, "A microstrip planar disk 3-dB quadrature hybrid," *1989 IEEE MTT-S Int. Microwave Symp.*, Long Beach, CA, pp. 371–374.
[3] G. Riblet, "Techniques for broad-banding above resonance circulators without the use of matching networks," *IEEE Trans. Microwave Theory Tech.*, vol. 28, pp. 125–129, Feb. 1980.
[4] I. Ohta, H. Kinoshita, T. Kaneko, and K. Fujiwara, "Rectangular disk 3 dB hybrids," *1989 IEEE MTT-S Int. Microwave Symp.*, Long Beach, CA, pp. 235–238.

Manuscript received August 24, 1994.
The author is with Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA 02173-9108 USA.
IEEE Log Number 9406805.

[5] T. Kawai, I. Ohta, and T. Kaneko, "3-dB quadrature hybrids using rectangular disk configuration," in *Proc. 3rd Asia-Pacific Microwave Conf.*, 1990, Tokyo, pp. 125–128.
[6] T. Kawai, I. Ohta, M. Nishimara, and T. Kaneko, "A rectangular disc 3 dB quadrature hybrid with flat coupling," in *Proc. 1992 Asia-Pacific Microwave Conf.*, pp. 673–676.
[7] T. Kawai and I. Ohta, "Planar-Circuit-Type 3 dB Quadrature Hybrids," *1994 MTT-S Int. Microwave Symp.*, San Diego, CA, pp. 205–208.
[8] I. Ohta, I. Hagino, and T. Kaneko, "Improved Circular Disk 3-dB Hybrids," *Electronics and Communication in Japan, part 2,* vol. 70, no. 12, pp. 66–77, 1987.
[9] K. C. Gupta and M. D. Abouzahra, "Planar Circuit Analysis," in *Numerical Techniques for Microwave and Millimeter-Wave Passive Structures.* New York: Wiley, T. Itoh, Ed., pp. 214–233, 1989.
[10] K. C. Gupta and M. D. Abouzahra, *Analysis and Design of Planar Microwave Components.* New York: IEEE Press, ch. 2, 1994, pp. 49–73.

Reply to Comments on "Analysis and Design of a Circular Disc 3-dB Coupler"

M. E. Bialkowski and S. T. Jellett

As mentioned by M. D. Abouzahra, our work presented in [1] concerned the analysis and design of a 3-dB quadrature hybrid in the form of a circular disc that has increased operational bandwidth. Because our investigations primarily involved a 3-dB quadrature circular disc hybrid, we did not attempt to provide a full list of references on disc hybrids (these generally include 180° hybrids, 90° hybrids, and other useful hybrids in the form of 4-ports, 5-ports, etc). In comparison with the material presented in [1], Abouzahra in his comments provides a more thorough listing of references on this broad topic, which we will now comment on.

The work of Ohta *et al.* in [3] and [4] concerned 180° hybrids, and these should not be confused with the 3-dB 90° hybrids discussed in our paper [1]. Around the same time as Ohta *et al.* were performing investigations, 3-dB hybrids again of the 180° type were being discussed by Gupta and Abouzahra [5]. An investigation into 3-dB *quadrature* hybrids in the form of circular discs, however, was not really commenced until the work presented in [2]. Subsequently, a discussion on 3-dB *quadrature* hybrids, but now in the form of *rectangular discs*, was continued by Ohta and his co-workers in [6]. Both designs in [2] and [6] were narrow-band. The results of the work being done on 3-dB quadrature hybrids in the form of rectangular discs with increased operational bandwidth appeared in [7] and [8].

In the above context, we feel that we have provided a valid contribution, as our work in [1] was concerned with 3-dB *quadrature* hybrids with increased operational bandwidth in the form of a *circular* disc.

Our reply to the specific comments made by Abouzahra are as follows:

Manuscript received September 12, 1994.
The authors are with the Electrical & Computer Engineering Department, University of Queensland, St. Lucia, QLD Australia 4072.
IEEE Log Number 9406818.

0018–9480/95$4.00 © 1995 IEEE

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.

References

[1] M. E. Bialkowski and S. T. Jellett, "Analysis and design of circular disc 3 dB coupler," *IEEE Trans. Microwave Theory Tech.*, vol 42, pp. 1437–1442, Aug. 1994.
[2] M. J. Page and S. R. Judah, "A microstrip planar 3 dB quadrature hybrid," in *1989 IEEE MTT-S Int. Symp.*, Long Beach, CA, pp. 371–374.
[3] I. Ohta, I. Hagino, and T. Kaneko, "Improved circular disk 3-dB hybrids," *Electronics and Commun. Japan*, vol. J70 C, no. 3, 1987, pp. 350–1987 (in Japanese; English abstract available).
[4] I. Ohta, H. Kinoshita, T. Kaneko, and K Fujiwara, "Rectangular disk 3dB hybrids," in *1989 IEEE MTT-S Int. Microwave Symp.*, Long Beach, CA, pp. 235–238.
[5] K. C. Gupta and M. D. Abouzahra, "Planar Circuit Analysis," in T. Itoh, Ed. *Numerical Techniques for Microwave and Millimeter-Wave Passive Structures:* New York: John Wiley, 1989, ch. 4, pp 214–333.
[6] T. Kawai, I. Ohta, and T. Kaneko, "3-dB quadrature hybrids using rectangular disk configuration," in *Proc. 3rd Asia-Pacific Microwave Conf.*, Tokyo, 1990, pp. 125–128.
[7] T. Kawai, I. Ohta, and T. Kaneko, "A rectangular disc 3 dB quadrature hybrid with flat coupling," in *Proc. 1992 Asia-Pacific Microwave Conf.*, pp. 673–676.
[8] T. Kawai and I. Ohta, "Planar-circuit-type 3 dB quadrature hybrids," in *1994 IEEE MTT-S Int. Symp.*, San Diego, CA, pp. 205–208.
[9] M. E. Bialkowski and S. T. Jellett, "A 3dB planar coupler in the form of an elliptically shaped disc," *1994 IEEE MTT-S Int. Symp.*, San Diego, CA, pp. 209–212.

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

Manuscript received July 19, 1994.
The author is with the Dept. of Electrical and Computer Engineering, California State Univ., Northridge, CA 91330-8346 USA.
IEEE Log Number 9406802.