A METHOD FOR REDUCING RADIATION LOSSES AT BENDS IN OPEN DIELECTRIC STRUCTURES

M. Desai and R. Mittra
Coordinated Sciences Laboratory
and
Electrical Engineering Department
University of Illinois
Urbana, Illinois 61801
USA

Abstract

In this paper we present the results of an experimental study of a scheme for reducing the radiation losses from bends in open dielectric waveguides used in millimeter-wave integrated circuits. We show that the radiation losses can be reduced significantly using an optimally designed, open shield placed near the guide. The shielding concept is especially useful for designing integrated circuit components, e.g., couplers and ring resonators. Illustrative examples are presented for a 180° bend and a ring resonator.

Summary

Dielectric based millimeter-wave integrated systems have received a great deal of attention in recent years [1-3]. In such systems, the realization of active as well as passive components is achieved by utilizing planar dielectric structures, e.g., the insular guide [3], the image guide [4], or the inverted strip guide [5].

Regardless of the type of dielectric guide used in the system, all of the open planar designs have the following common dificulty. The bends, corners and curved sections that are invariably introduced in the system while building certain passive components, e.g., couplers and resonators, produce radiation losses and concomitant degradation in performance. These problems have been theoretically investigated in the past by several authors [6-7], and the concept of a minimum curvature radius has been introduced [8-9] as a possible means of alleviating the problem. However, this approach can be cumbersome and is not conducive to compact designs.

The purpose of this paper is to present a novel experimental design for a shield that substantially reduces the radiation losses at the bends. Basically, the shield configuration is a copper strip, about five wavelengths in height that follows around the bend on the outside. It was experimentally determined that varying the shield height beyond five wavelengths did not yield any noticeable improvement in the loss-performance of the shielding; hence, all further experiments were performed with approximately a 5λ high shield. The separation distance between the guide and the shield is an important design parameter and must be appropriately chosen in order to achieve optimal performance. We will demonstrate this point shortly.

Initial experiments were conducted on semicircular bends with dielectric waveguides of rectangular cross section, using the arrangement shown in Figure 1. A short metal section of rectangular cross section located at the input and the output of the dielectric bend provided the transition between the metallic and dielectric guides. The design for the transition was adapted from a recent work by Trinh, et al. [10]. Note that the copper shield is introduced only around the curved section since further extensions of the shield into the straight region of the guide do not enhance the power received at the output port 2. The shield is flared outward at the ends in order to provide a gradual transition from the dielectric guide to the curved region where the shield is located. It was determined experimentally that a second shield introduced in the inner region of the bend did not yield any noticeable improvement. Hence, in future experiments, only the external shield was employed.

To evaluate the performance of the shield, the experimental setup shown in Figure 1 was used. The separation distance s between the outer periphery of the dielectric bend and the shield was varied, and the output power at port 2 was recorded as a function of s. The enhancement of the received output power in the presence of the shield is evident from Figure 2, as is the dependence on the separation distance s. It was also found that the optimum separation for which the shielding provides a maximum enhancement of the output power varies with the operating frequency since the exponential decay of the field distribution external to the dielectric region is a function of frequency. As seen from Figure 2, a teflon waveguide ($\varepsilon_r = 2.057$), 2.8 mm wide and 1.32 mm high, the optimum distance is approximately 1 mm at 84 GHz. It is also evident that the presence of the shield resulted in an improvement of the radiation loss performance by more than 7 dB.

The design of the shield developed above was applied next to a single-pole ring resonator whose geometry is shown in Figure 3. The frequency response of the arrangement with and without the shield is shown in Figure 4. Note that the frequency response curve of the shielded filter has a narrower bandwidth, or higher Q, than the corresponding response for the unshielded case. Note also that the introduction of the shield alters the propagation constant of the isolated guide, as observed from the 0.4 GHz difference between the resonance peaks of the unshielded and shielded cases. The change in the propagation constant in the ring section, caused by the presence of the shield, introduces a corresponding change in the coupling between the straight guide and the resonant ring. The change in the resonant characteristics of the shielded resonator can be attributed to this factor also. Away from the resonant peaks, the response of the ring resonator is more directly dependent on the radiation losses.

Further experiments to determine the effects of shielding were conducted on a ring resonator whose geometry is shown in Figure 5. When the shield was introduced, the following effects were observed: (1) when the output power level of the non-shielded resonator were low as seen at port 2 (about -10 dB), the intorduction of the shield significantly improved the performance of the resonator as seen from the plot in Figure 6; (2) when the output power level of the non-shielded resonator was high (about -2 dB) the introduction of the shield only provided a very slight improvement in the Q of the resonator; (3) As observed earlier, the introduction of the shield introduced a shift in a resonance frequency.

These observations lead us to conclude that the introduction of the shield improves the performance of the resonator when the output power-levels are low.

In conclusion, we have demonstrated that an appropriately designed shield placed outside a bend in an open dielectric waveguide, and located at an optimum distance from the guide, can be effective in significantly reducing the radiation losses from the bend. This concept of shielding finds useful application in the design of several passive components in dielectric-based millimeter-wave integrated circuits, some examples being 180° bends and ring resonators. An extension of the basic idea of shielding might also lead to the development of overmoded waveguides suitable for quasi-optical and submillimeter frequencies where conventional metal or dielectric waveguide dimensions become too small to be practical.

References

[1] R. M. Knox, "Dielectric Waveguide Microwave Integrated Circuits — An Overview," IEEE Trans. Microwave Theory Tech., vol. MTT-24, no. 11, pp. 806-814, Nov. 1976.

[2] N. Deo and R. Mittra, "Millimeter Wave ICs Spring from the Lab," Microwaves, vol. 18, no. 10, pp. 38-42, Oct. 1979.

[3] M. J. Aylward and N. Williams, "Feasibility Studies of Insular Guide Millimeter Wave Integrated Circuits," AGARD Conference Proc., no. 24, Millimeter-Wave Propagation & Circuits, Munich 1978.

[4] J. A. Paul and Y. W. Chang, "Millimeter-Wave Image Guide Integrated Passive Devices," IEEE Trans. on Microwave Theory Tech., vol. MTT-26, no. 10, pp. 751-754, Oct. 1978.

[5] R. Rudokas and T. Itoh, "Passive Millimeter-Wave IC Components Made of Inverted Strip Dielectric Waveguides," IEEE Trans. on Microwave Theory Tech., vol. MTT-24, no. 12, pp. 978-981, Dec. 1976.

[6] E.A.J. Marcatili, "Bends in Optical Dielectric Guides," Bell System Tech. J., vol. 48, no. 7, pp. 2103-2131, 1969.

[7] E.A.J. Marcatili and S. E. Miller, "Improved Relations Describing Directional Control in Electromagnetic Wave Guidance," Bell Syst. Tech. J., vol. 48, no. 7, pp. 2161-2188, 1969.

[8] S. E. Miller, "Directional Control in Light-Wave Guidance," Bell Syst. Tech. J., vol. 43, no. 4, pp. 1727-1739, 1964.

[9] E. G. Newmann and H. D. Rudolph, "Radiation from Bends in Dielectric Rod Transmission Lines," IEEE Trans. Microwave Theory and Tech., vol. MTT-23, no. 1, pp. 142-149, Jan. 1975.

[10] T. N. Trinh, J.A.G. Malherbe and R. Mittra, "Transition from a Metal to a Dielectric Waveguide of Rectangular Cross-Section," to appear.

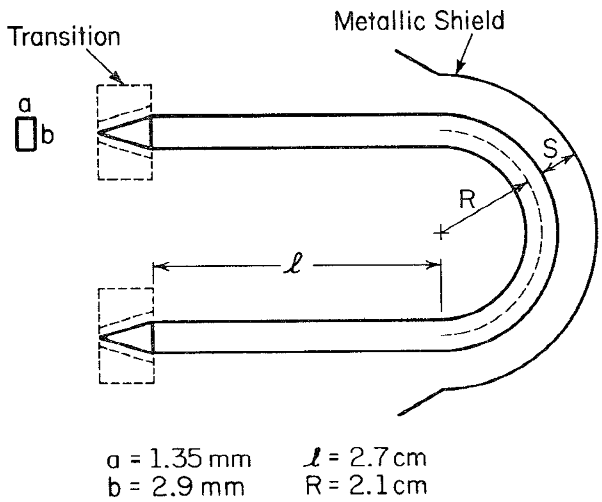

Figure 1. Dielectric Band with a Shield Around the Curved Section.

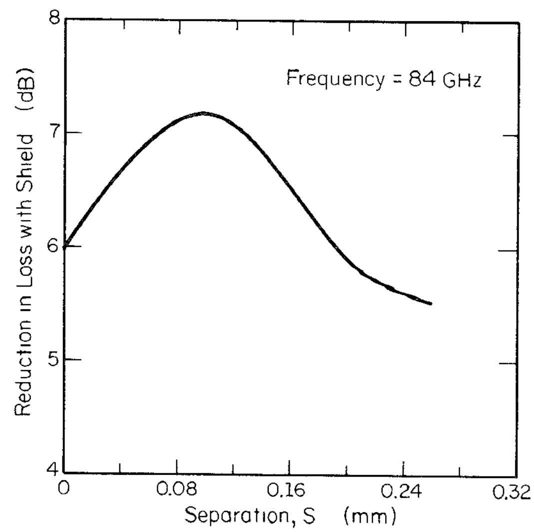

Figure 2. Performance Characteristics of the Shielded Bend Shown in Figure 1.

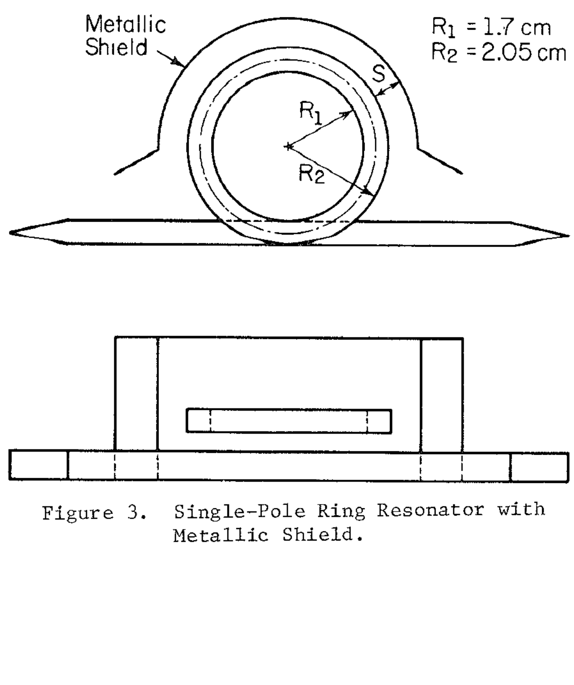

Figure 3. Single-Pole Ring Resonator with Metallic Shield.

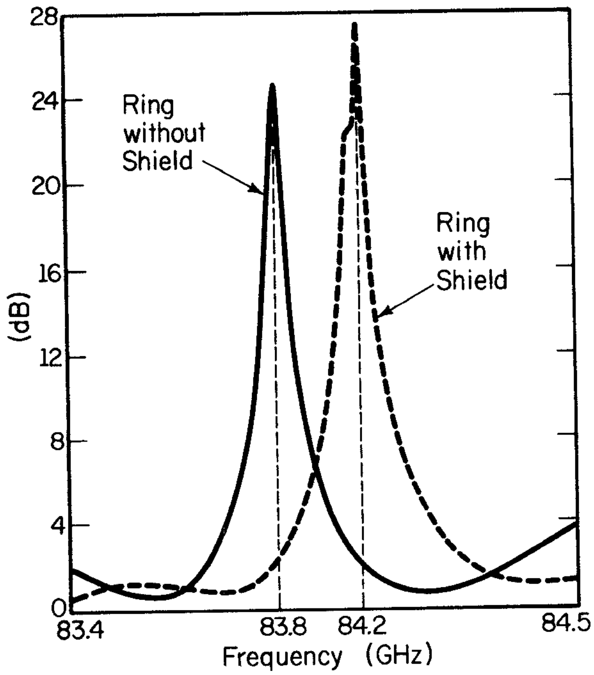

Figure 4. Frequency Response of the Single-Pole Ring Resonator Shown in Figure 3.

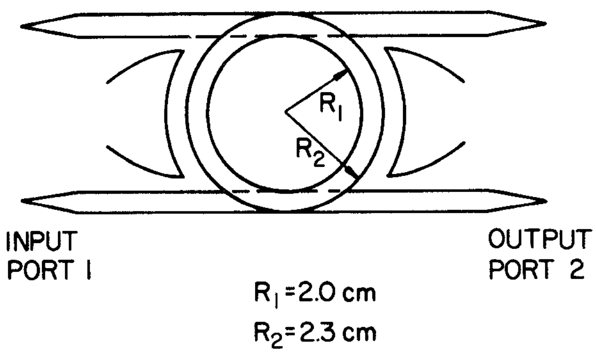

Figure 5. Ring Resonator with Metallic Shield.

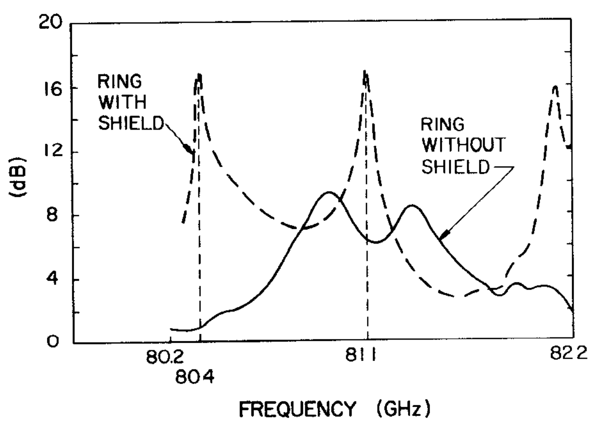

Figure 6. Frequency Response of the Ring Resonator Shown in Figure 5.