A METAL-TO-DIELECTRIC WAVEGUIDE TRANSITION WITH APPLICATION TO MILLIMETER-WAVE INTEGRATED CIRCUITS

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Abstract

In this paper we describe the development of an efficient, low-loss transition from a conventional metal waveguide to a planar dielectric guide of rectangular cross section. Such a transition finds important application in millimeter-wave integrated circuits. We show that for a given length of the flared horn used for launching energy into the dielectric waveguide, the insertion loss of the transition can be reduced to a very low figure by choosing the flare angle of the horn appropriately.

Introduction

There is little information available in the current literature on the design and performance of transitions from metal-to-dielectric waveguides with application to millimeter-wave integrated circuits. At millimeter wavelengths, it is desirable to devise a transition which is as short as possible so that the effect of the metal horn used to launch the energy from the metal to the dielectric waveguide is minimal on the other parts of the circuit. However, in order to be useful, the insertion loss of the transition must be acceptably small. The combination of these two constraints presents a great challenge to the designer. After a large number of initial experiments, the choice for the transition configuration was narrowed down to the dielectric tapered section fed by a flared metal horn. The parameters investigated were the shape of the dielectric taper and the dimensions of the metal horn. The results of this study are discussed next.

Parametric Study of The Transition Section

As a first step, two tapered dielectric waveguide sections were constructed, one of which was tapered both in the E- and H-planes and the other in the H-plane only. The dielectric material used was Teflon with $\varepsilon_r = 2.057$ and $\tan \delta = 6.0 \times 10^{-4}$. A sketch of the tapered dielectric waveguide is shown in Figure 1a. The solid lines correspond to a taper in the H-plane only, whereas the dotted line shows the taper in both planes. A study of these two tapered guides revealed that for taper lengths on the order of $4\lambda_g$ or greater the two configurations performed essentially identically. Hence, in future experiments, the length of the tapered section was chosen to be about $5\lambda_g$, and the guide was tapered only in the H-plane. The single-plane taper greatly simplified the fabrication of the transition region.

Next, we turned our attention to the design of the metal launching horn shown in Figure 1b. In order to keep the length of the metal horn as small as possible, the horn length L was always chosen to be less than $2\lambda_0$. Thus, the principal design parameter of the horn that needed investigating is its flare angle θ.

Typically, for the dielectric waveguides of the type being considered here, a large percentage of the power in the propagating modes is carried by the medium external to the guide.[1] For a moderate-to-large aspect ratio of the cross section of the guide, the energy is principally concentrated above and below the guide. Consequently, the flare angle in the E-plane has a dominant effect on the behaviour of the transition. Experimental studies confirm that only the flare angle in the E-plane had a significant effect on the performance of the transition. For this reason, the horn angle in the H-plane was fixed, and the angle of the E-plane taper was used as the variable parameter. The return loss, which was measured as a function of frequency for various E-plane taper angles θ, is shown in Figure 2. When the flare angle θ was varied from 22-39 degrees for a fixed horn length, the return loss remained less than 16 dB (VSWR < 1.4) throughout the frequency range. For the sake of clarity, we have only plotted the return loss for the transitions for flare angles θ = 22, 30 and 39 degrees, although many other angles were studied. In order to illustrate the significant improvement achieved by a proper choice of the range of the flare angle, the results for the two extreme cases, viz., θ=0 and θ=90 degrees, are also presented in Figure 2.

The total transmission loss comprises the dielectric loss of the waveguide and the loss due to the transitions. In order to isolate the dielectric losses, the system was measured for two different lengths of the guide, and the loss figure for the shorter length was subtracted from that of the longer one. This procedure served to eliminate the loss contribution due to the two metal transitions, thus yielding the loss figure for the dielectric waveguide alone [2],[3]. Figure 3 shows the computed and experimental results for a 3.06 mm wide and 1.52 mm high dielectric waveguide made of Teflon with ε_r=2.057 and $\tan \delta$=6.0 x 10^{-4}.

The total transmission loss for a dielectric waveguide section of $40\lambda_g$ long and two transitions is shown in Figure 4 as a function of frequency for various flare angles θ. The total transmission loss is seen to be remarkably invariant within the optimum range of θ. The loss due to the two transitions alone was obtained by subtracting the loss of the dielectric waveguide from this total loss. From this figure, the loss due to the transitions is shown to be less than 1 dB throughout the frequency range.

On the basis of this study, the flare angle θ in the E-plane was henceforth fixed at 31 degrees. Using the ratio of E- and H-plane dimensions of an ordinary horn as a guide, the corresponding flare angle in the H-plane was chosen to be 35 degrees. The final design of the horn obtained in this manner is shown in Figure 5.

The metal-to-dielectric transition described above also finds useful applications, e.g., excitation of integrated dielectric antennas. This is illustrated with the example of a slow-wave dielectric rod antenna excited with a metal waveguide. As may be expected, an inefficient transition causes undesirably high sidelobes to appear in the radiation pattern of the antenna. To demonstrate the significant improvement achieved by the use of a well-designed antenna, a slow-wave antenna 40 mm ($\approx 11\lambda_0$) in length was excited by the transition horn described above and by an ordinary metal waveguide. The results are shown in Figure 6a. The antenna with the horn launcher has more than a 2 dB gain over the ordinary launching waveguide. Figure 6b compares the radiation patterns of a 25 mm long dielectric antenna when the horn and an ordinary metal waveguide are used as launchers. For the antenna with the horn transition, the directive gain is more than 24 dB and the sidelobe suppression is clearly evident. It is interesting to observe that the metal horn, when used as an antenna, has a lower directive gain than the short dielectric antenna using the same metal horn as a transition. The null-to-null bandwidth of the metal horn is also 40 degrees broader than the dielectric antenna employing the metal horn transition as shown in Figure 7.

Conclusion

A metal-to-dielectric waveguide transition has been designed for application in millimeter-wave integrated circuits and antennas. Loss figures of less than 0.5 dB per transition with good return loss performance have been achieved for a broad frequency range with a relatively small transition length.

References

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[2] T. Itanami and S. Shindo, "Channel dropping filter for millimeter-wave integrated circuits," IEEE Trans. Microwave Theory Tech., vol. MTT-26, pp. 759-764, Oct. 1978.

[3] P. P. Toulios and R. M. Knox, "Rectangular dielectric image lines for millimeter integrated circuits," Western Electronics Show and Convention, Los Angeles, California, Aug. 1970.

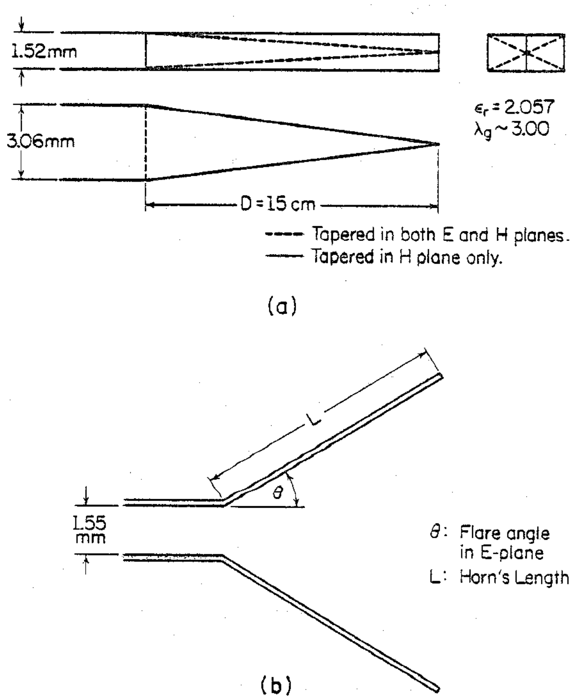

Figure 1. Transition Mechanism:
(a) Dielectric Taper
(b) Metal Horn

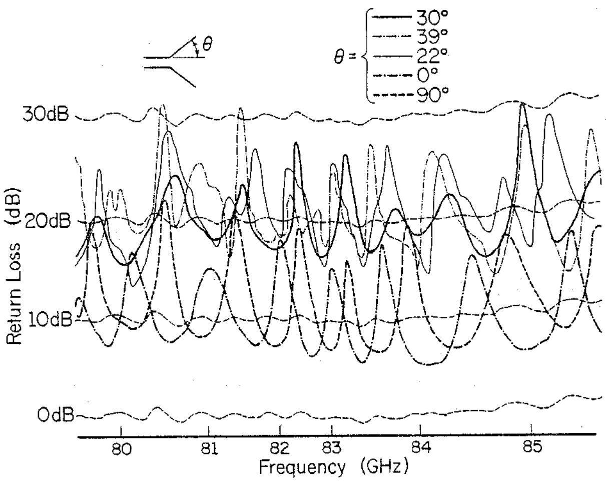

Figure 2. Return Loss vs. Frequency

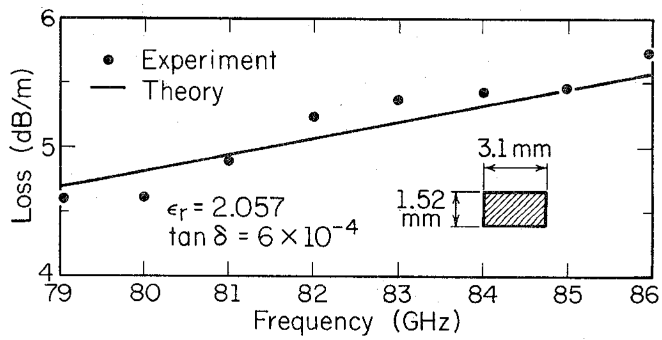

Figure 3. Transmission Loss of Dielectric Waveguide

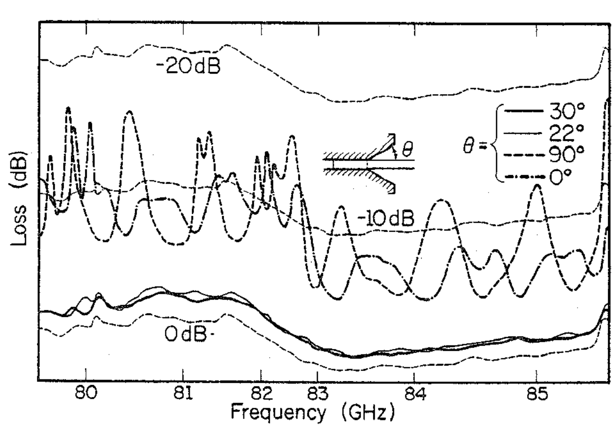

Figure 4. Total Transmission Loss

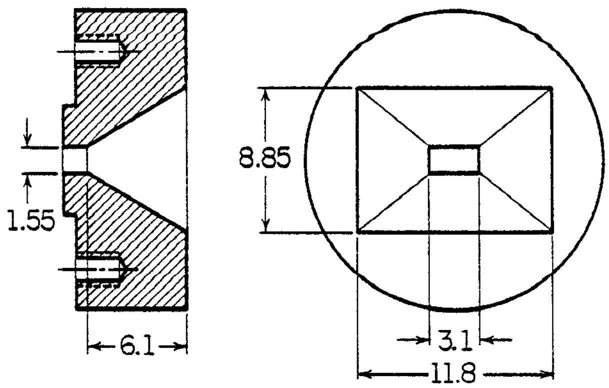

Figure 5. Inside Dimensions of the Designed Horn

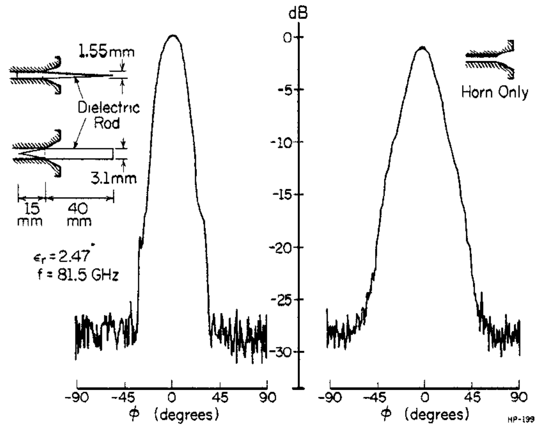

Figure 7. Comparisons of the radiation patterns of the metal horn and the short dielectric rod antenna using the same metal horn as transition.

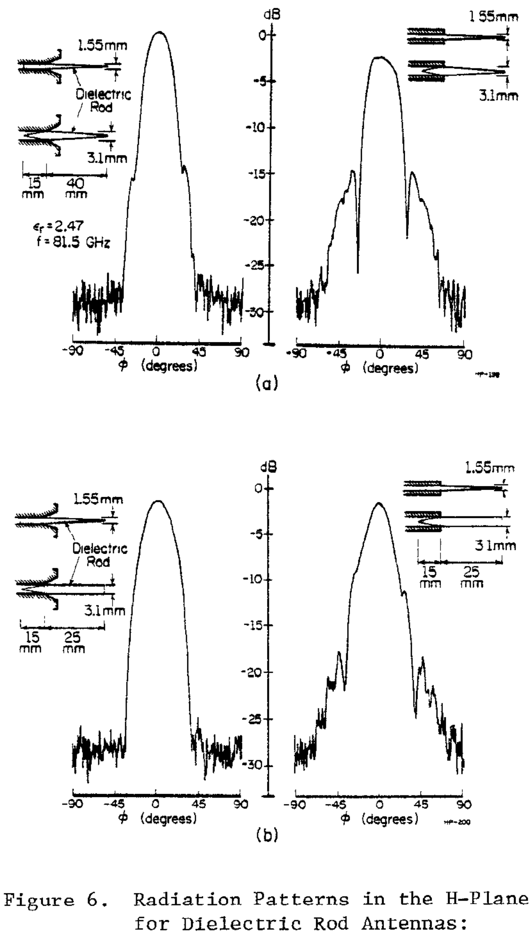

Figure 6. Radiation Patterns in the H-Plane for Dielectric Rod Antennas:
(a) 40 mm
(b) 25 mm, using two types of transitions.