New Dielectric-Covered Waveguide-to-Microstrip Transitions for Ka-band Transceivers

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Abstract — **New dielectric-covered waveguide-to-microstrip transitions at Ka-band have been developed. These transitions are probe-type, but the dielectric material completely covers the waveguide opening in order to provide moisture barrier and robustness. These transitions are also designed to be less sensitive to fabrication tolerances. The transition structures have been comprehensively analyzed using a 3-D EM software. The resonance phenomena caused by the discontinuity of waveguide-wall have been removed by placing vias around the waveguide aperture. These transitions have also been fabricated and measured. The measured insertion loss of the transition is less than 0.4 dB and the return loss is about 15 dB over entire Ka-band.**

I. INTRODUCTION

In order to provide broadband communications for fast-evolving multimedia services, digital microwave/millimeter-wave radio systems such as LMDS (Local Multipoint Distribution System) at Ka-band have been deployed in Europe, USA, and Japan [1]-[2]. One of key factors for the success of commercial microwave radio systems is low-cost implementation of microwave transceivers. To date, the hybrid fabrication method is the most cost-effective method for these transceivers [3]-[4]. Since the input or output power of these transceivers is often provided through the waveguide, waveguide-to-microstrip transitions are required. The requirements for these transitions for commercial applications would be low-cost, broadband performance, tolerance to fabrication errors, robustness, and moisture-barrier.

Previously, design data for simple waveguide-to-microstrip probe-type transitions for millimeter-wave applications have been reported [5]-[6]. Even though these transitions feature low-cost, simplicity, and broadband performance, they are fragile and sensitive to fabrication tolerances, and lack a moisture barrier.

In this paper, new dielectric-covered probe-type waveguide-to-microstrip transitions are presented. With these transitions, the dielectric material completely covers the whole waveguide opening and extended beyond the waveguide wall for the proper attachment of the probe section to the housing. Therefore, these transitions provide robustness and moisture barrier, which are required for commercial transceivers. Also, the probe feeding structure has been simplified in order to perform less sensitively to the fabrication tolerances. The resonance behavior due to the discontinuity of the waveguide wall has been removed by placing vias around the waveguide aperture.

The new transitions have been comprehensively analyzed using Ansoft HFSS™, which is a 3-D EM simulation software. The transitions have also been fabricated and measured. The overall performance of these transitions over entire Ka-band with a single configuration shows the insertion loss less than 0.4 dB and the return loss of ~15 dB. However, for the narrow-band applications, lower insertion loss of 0.3 dB and better return loss of 18 dB have been obtained.

II. INPUT IMPEDANCE AND BASIC PROBE TRANSITIONS

A. Input Impedance of Probe Transitions

For Ka-band probe-type transitions, the RT/Duroid 5880® with 10 mil thickness is chosen for the substrate material. In order to match the probe section to the 50 Ohm microstrip transmission line, firstly, the input impedance of the probe transition has been determined. The cross-sectional view of the input impedance measurement set-up is shown in Figs. 1(a) and (b). The depth of the waveguide back-short is set at 80 mil.

For the basic probe-type transition presented in [5], the quarter-wave transformer begins right at the edge of the waveguide, which will cause performance degradation if slight misalignment of the probe edge occurs due to fabrication tolerances. To the contrary of the findings in [5], it is observed that the input impedance of the probe transition is determined by the characteristic impedance of the feeding microstrip line. For example, even if a very short 50 Ohm microstrip line section—e.g., 1 mil long—is attached to the probe section of which the width is that of a 75 Ohm microstrip line (15.6 mil), the input impedance becomes approximately 50 Ohm. Also, with different probe widths, the input impedance of the probe transitions is determined by the attached microstrip line.

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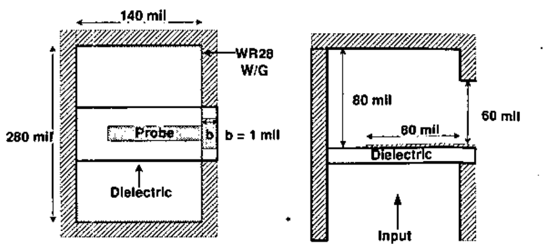
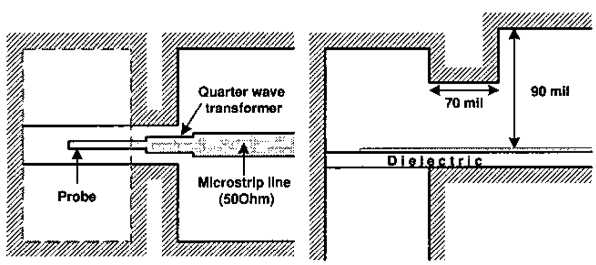


(a) (b)

Fig. 1. The cross-sectional view of the input impedance measurement set-up: (a) top view, (b) side view

These results enable a simple design of the matching section. The line width of a probe transition can be extended to the microstrip line by a proper length (e.g., 30 mil in this paper). A quarter-wave transformer section is then inserted between the extended transmission line and the 50 Ohm microstrip line as shown in Fig. 2. In this paper, the quarter-wave transformer is designed at 33 GHz, which is the center frequency of Ka-band. Since the probe width (15.6 mil) is chosen as that of the 75 Ohm microstrip line, the quarter-wave transformer is 66 mil long and 21.8 mil wide.



(a) (b)

Fig. 2. The cross-sectional view of modified basic probe transition: (a) top view, (b) side view

B. Characteristics of the Basic Probe Transition

With the above design guideline, the basic probe transition in [5] has been modified as shown in Fig. 2. This transition design simplifies assembly of the module, and alleviates the performance degradation due to the fabrication tolerances. These basic probe transitions have been analyzed as varying the probe length. Figures 3 (a) and (b) show the frequency response of the insertion loss and return loss of the probe transitions. In this analysis, the depth of waveguide back-short is fixed at 80 mil, and the probe length is varied by 10 mil steps from 60 mil to 110 mil. In this example, insertion loss less than 0.2 dB and return loss better than 15 dB have been obtained with the probe length of 80 mil for frequencies less than 32 GHz, and with the probe length of 70 mil for frequencies greater than 32 GHz.

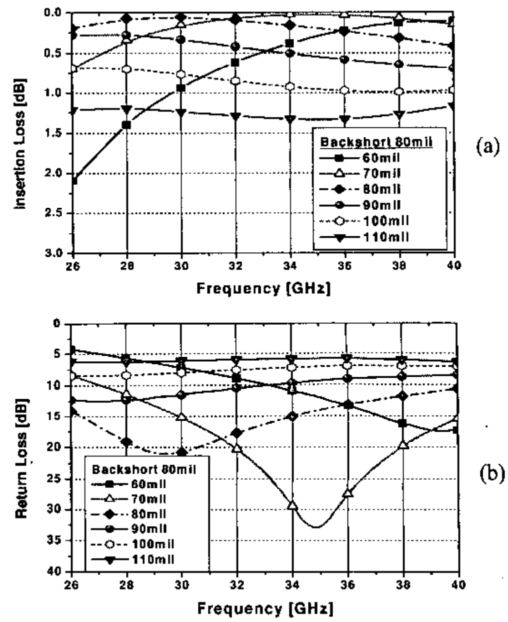
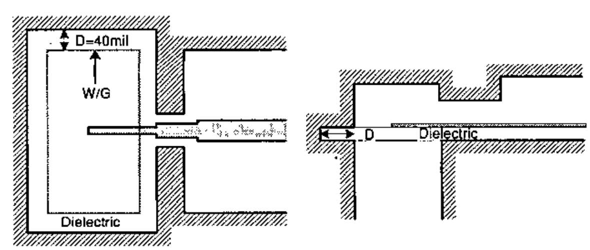


Fig. 3. (a) Insertion loss and (b) return loss of the modified basic transitions.

III. DIELECTRIC-COVERED PROBE TRANSITIONS

A. Dielectric-Covered Probe Transitions without Vias

The cross-sectional view of a new dielectric-covered probe transition without vias is shown in Figs. 4 (a) and (b).



(a) (b)

Fig. 4. The cross-sectional view of the dielectric-covered probe transition without vias: (a) top view, (b) side view

The insertion loss and input return loss for these transitions are shown in Figs. 5 (a) and (b). In this analysis, the depth of the waveguide back-short is fixed at 80 mil, and the probe length is varied from 60 mil to 110 mil. The waveguide-wall penetration depth (D) is 40 mil. In these figures, rapid performance degradation is observed near 40 GHz due to the resonance behavior caused by discontinuity of the waveguide wall. Except the resonance near 40 GHz, the transition performance is comparable to that of the basic probe transitions: insertion loss less than 0.2 dB and return loss better than 15 dB can be obtained with the probe length of 80 mil below 32 GHz, and with the probe length of 70 mil above 32GHz.

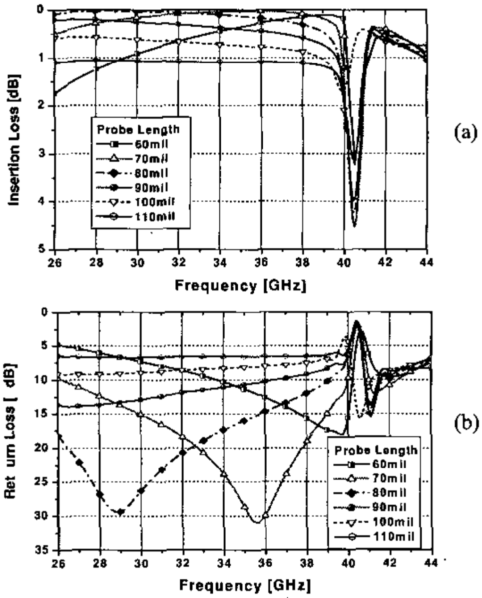


Fig. 5. (a) Insertion loss and (b) return loss of the dielectric-covered transitions without vias.

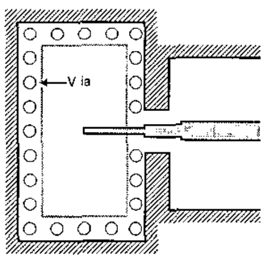


Fig. 6. Top view of the dielectric-covered probe transition with vias.

B. Dielectric-Covered Probe Transitions with Vias

In order to remove the resonance behavior near 40 GHz, electrical vias have been placed around the waveguide aperture as shown in Fig. 6. The diameter of the vias is 20 mil, and the center-to-center distance of the vias is 40 mil. The insertion loss and input return loss are plotted in Figs. 7 (a) and (b). In this example the probe length is fixed at 70 mil, and the depth of waveguide back-short is varied. In these figures, it is observed that the resonance behavior near 40 GHz has been disappeared, and excellent probe performance is maintained up to 42 GHz. With the probe length of 70 mil and the back-short depth of 80 mil, the insertion loss is less than 0.2 dB and the return loss is better than 15 dB between 30 GHz and 40 GHz. Through the entire Ka-band frequencies, the insertion loss is less than 0.4 dB and the return loss is better than 10 dB. However, for the most microwave/millimeter-wave transceivers for digital microwave radios, the bandwidth is less than 20%. Therefore, an optimal probe length for the moisture-sealed probe transition can be determined for a specific application.

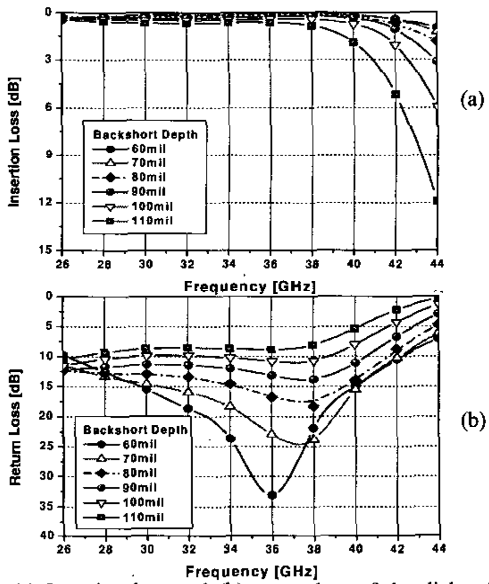


Fig. 7. (a) Insertion loss and (b) return loss of the dielectric-covered transitions with vias.

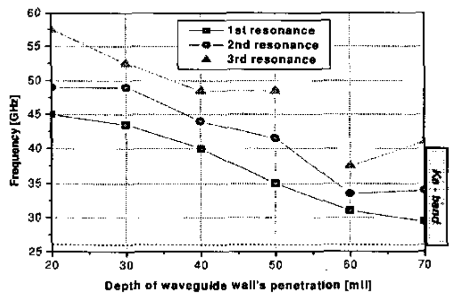


Fig. 8. Change of resonance frequencies as varying waveguide-wall penetration depth.

C. Resonance as Function of Wall-Penetration Depth

Figure 8 shows the changes of resonance frequencies as the depth of the wall-penetration varies by 10 mil steps. As can be seen in the figure, the resonance does not occur in

Ka-band frequencies if the wall-penetration depth is kept less than 40 mil. As the wall-penetration depth increases, the resonance frequencies tend to lower down into Ka-band frequencies. This resonance behavior is caused by the lack of current continuity on the waveguide-wall as can be verified through the simulations. The role of vias is to connect the current flow on the waveguide wall across the probe layer. In practical design of the probe transitions, it might be useful to determine the maximum distance of vias providing allowable performances of the probe transition at Ka-band. For example, with the 40-mil wall-penetration depth, the maximum via separation distance was 130 mil.

IV. Transition Measurements

In order to test the performance of the dielectric-covered probe transitions, two transitions are connected back-to-back with 1001 mil long microstrip line between the transitions. Back-to-back connection of probe transitions installed on a bottom test fixture for the measurements is shown in Fig. 9.

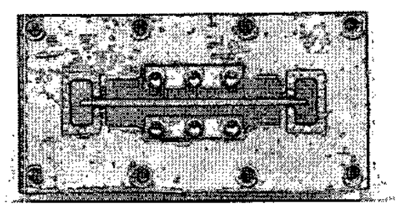


Fig. 9. Back-to-back connection of dielectric-covered probe transitions on a bottom test fixture.

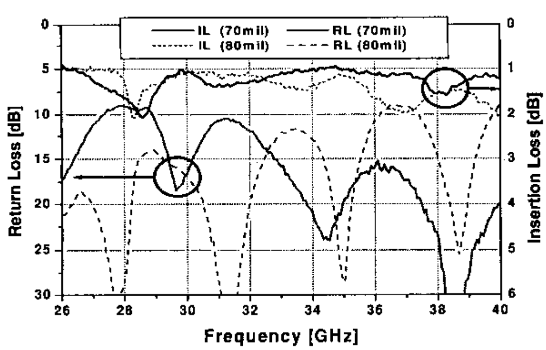


Fig. 10. Measured frequency response of the insertion loss and return loss for the dielectric-covered transitions with vias.

For the measurements, input waveguide ports were fully calibrated with the Ka-band waveguide calibration kit using the Agilent 8510 Vector Network Analyzer. The measured frequency response of the insertion loss and return loss for the dielectric-covered probe transitions with vias is shown in Fig. 10. The back-short depth is 80 mil. In agreement with simulation results, the probe transition performs better with length of 70 mil above 32 GHz, and with length of 80 mil below 32 GHz. Small dips of the insertion loss near 28.5 and 38 GHz are caused by the test fixture interference not directly related to the probe performance. The average insertion loss of the back-to-back measurements is about 1.2 dB. Since the theoretical insertion loss of microstrip line (1001 mil) is about 0.4 dB, the insertion loss per transition is estimated as 0.4 dB.

V. Conclusion

New dielectric-covered waveguide-to-microstrip probe transitions have been designed and comprehensively analyzed in this paper. These probe transitions provide excellent electrical and mechanical properties as wave-guide-to-microstrip transitions. The resonance behavior due to discontinuity of waveguide-wall current has been removed by introducing vias around the waveguide aperture. Also, resonance frequency changes related to the wall penetration depth have been analyzed. From the measurements, insertion loss less than 0.4 dB and return loss better than 15 dB have been obtained. These probe transitions have shown to provide additional features to the basic probe transitions in [5]: moisture-barrier, less sensitivity to fabrication errors, and robustness, which are required for commercial millimeter-wave transceiver applications.

Acknowledgement

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