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Characterizations of Moisture-Sealed Waveguide-to-Microstrip Transitions for Ka-band Transceivers

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Abstract

New high-performance Ka-band waveguide-to-microstrip transitions for millimeter-wave transceiver applications have been developed and characterized. These transitions are probe-type, but the dielectric material completely covers the whole waveguide aperture, thus providing moisture-barrier and robustness in the probe section. The new probe transitions are also designed to be less sensitive to fabrication tolerances. Further performance enhancements have been obtained by placing vias around the waveguide aperture. Also, the resonance phenomena associated with waveguide wall-penetration have been identified. The developed probe transitions provide insertion loss less than 0.4 dB over entire Ka-band frequencies, but can be optimized for narrowband applications with insertion loss less than 0.2 dB.

Key words : Waveguide-to-Microstrip Tansition, Ka-band, Transceiver, Moisture-Sealed, Probe Transition

Ⅰ. Introduction

Due to recent surge of request for faster multimedia services, broadband communication systems have attracted significant attentions. As a recent entry of wireless broadband systems, microwave/millimeter-wave radio systems such as LMDS (Local Multipoint Distribution System) in Ka-band (26.5~40 GHz) have become popular in Europe, USA, and Japan[1],[2].

One of the key factors for the success of these microwave radio systems is the low-cost implementation of microwave/millimeter-wave transceivers. To date, the most cost-effective fabrication method for these transceivers is still the hybrid technique which assembles the MMIC modules and the microwave/mm-wave circuit components in the microstrip form on a softboard substrate[3],[4]. For these transceivers, RF input/output power is often provided through the waveguide, thus necessitating a transition between the waveguide and microstrip.

Previously, design data for a simple waveguide-to-microstrip probe-type transition for millimeter-wave applications have been reported[5],[6]. The implementation of these transitions is relatively simple and thus they have been widely used for low-cost millimeter transceiver applications. The advantages of these transitions are low-cost, broadband performance with low insertion loss, simplicity, and good integrability with hybrid circuits. Disadvantages of these transitions are lack of moisture barrier and fragility of the probe section. Other types of waveguide-to-microstrip transitions are also used in microwave/mm-wave transceivers; a ridged waveguide transition[7], slot transition[8], and other novel transitions[9],[10].

In this paper, we present the modified version of the basic probe transition reported in [5]. In addition, a new dielectric-covered waveguide-to-microstrip probe transition in Ka-band is presented, which provides robustness and a moisture barrier from the waveguide opening. Design data and performance analysis of this dielectric-covered probe transition have been presented. Furthermore, placement of vias on the dielectric substrate around the waveguide aperture has proven to provide performance improvement by removing resonances. The resonance frequencies associated with waveguide wall-penetration have been calculated as function of wall penetration depth and via distances.

The remainder of this paper is as follows: Section II describes the characteristics of the modified basic probe transitions in Ka-band. Section III presents the design and characteristics of the new moisture-sealed probe transitions. Finally, Section IV concludes this paper by summarizing the results and presenting future plans.

Ⅱ. The Basic Probe Transitions

For the substrate of waveguide-to-microstrip probe-type transitions in Ka-band frequencies, Rogers RT/Duroid 5880^R material with 10 mil (0.254 mm) dielectric thickness has been used. The relative dielectric constant for this substrate is 2.2, and the loss tangent is 0.0009.

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2-1 Characterization Method of the Probe Transitions

In this paper, the Ansoft HFSS^{TM}, which is an FEM(Finite Element Method)-based 3-D electromagnetic simulation software, is used for the analysis and design of these waveguide-to-microstrip transitions. Center lines of the Ka-band waveguide aperture and of the microstrip line are selected as the ports for these calculations. The input impedance of the line is calculated as

$$Z_{VI} = \sqrt{(P/I \cdot I^*)(V \cdot V^*/P)}$$

which provides less dependency on the number of meshes used for the calculation.

The results of the HFSS calculation can be dependent on the number of meshes in the 3-D structure. In order to check the calculation accuracies associated with the number of meshes, the insertion loss (S_{21}) of the probe transition has been obtained by varying the number of meshes as shown in Fig. 1. With 50,000 meshes, the calculation took about 8 hours with a Pentium IV processor with 640 Mbytes of RAM, while, with 20,000 meshes, the calculation time was about 2~5 hours. In the figure, it is observed that, between the results of 50,000 and 20,000 meshes, the calculation accuracy is within 0.1 %, which should be accurate enough for the characterization of the probe transitions. Therefore, number of meshes around 20,000 are kept for the following results presented in this paper. A typical mesh configuration for the waveguide section is shown in Fig. 2.

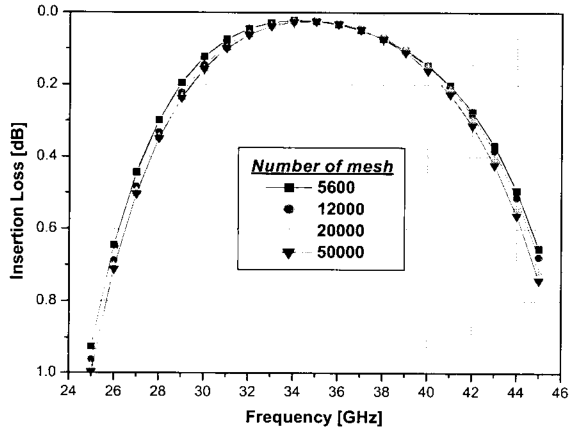


Fig. 1. Insertion loss (S_{21}) of the basic probe transition as changing the number of meshes.

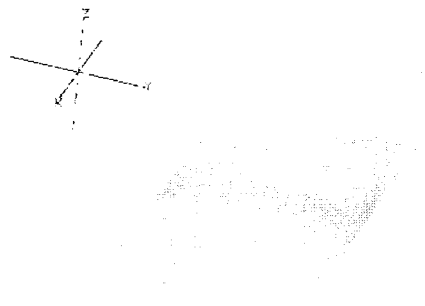


Fig. 2. Typical mesh configuration on the surface of the waveguide.

2-2 Input Impedance of the Basic Probe Transition

In order to match the probe section to the 50 Ohm microstrip transmission line, firstly, the input impedance of the probe transition has been analyzed. The cross-sectional view of the input impedance measurement set-up is shown in Figs. 3(a) and (b). In this paper, the probe width is chosen as 15.6 mil, which is the width of a 75 Ohm microstrip transmission line on the 10 mil RT/Duroid 5880$^{®}$ substrate. In this case the depth of the waveguide back-short is 80 mil. If a very short microstrip line

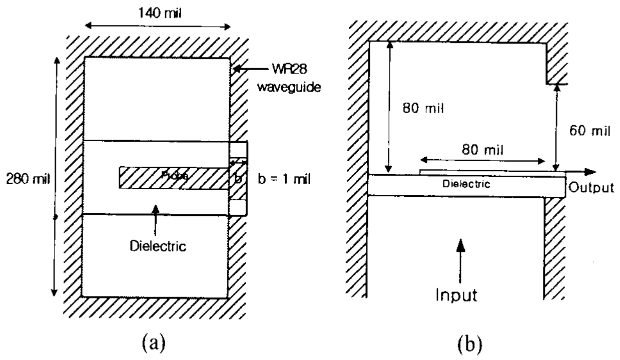


Fig. 3. Cross-sectional view of the input impedance measurement set-up.

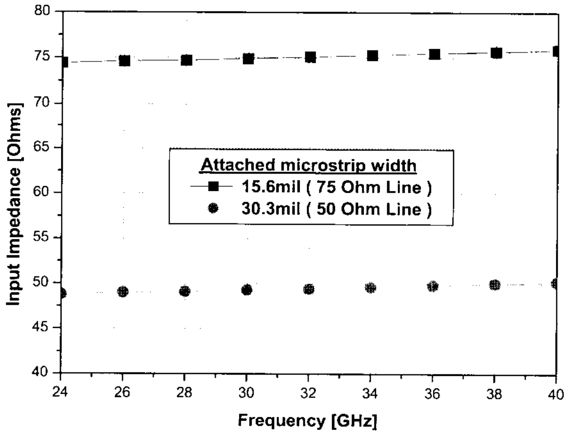


Fig. 4. Input impedance of the probe transition.

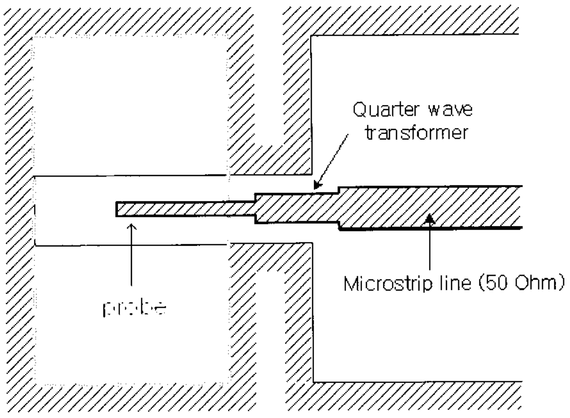


Fig. 5. Cross-sectional view of the modified basic probe transition.

section—e.g., 1 mil 50 Ohm transmission line section—is attached to the probe, the input impedance becomes ~50 Ohm as shown in Fig. 4. Conversely, when a short 75 Ohm transmission line section is attached to the probe section with the width of 50 Ohm microstrip line (30.3 mil), the input impedance now changes to ~75 Ohm as shown in Fig. 4.

In [5], the input impedance of the probe transition was reported to be constant (~75 Ohm) regardless of the probe width. Therefore, in [5], a quarter-wave transformer was attached right at the edge of the waveguide aperture. In practice, the probe section cannot not be aligned exactly with the edge of the waveguide aperture due to fabrication tolerances, and the performance of the probe transition might be seriously degraded. However, in this paper, the input impedance of the probe transition is found to be dependent *only* on the characteristic impedance of the microstrip transmission line attached to the probe section, *not* on the probe width. This result conflicts with the statement in [5]. With the modified probe transition design, the probe width is simply maintained in the microstrip line section, which simplifies the module assembly and alleviates the performance degradation due to the actual fabrication tolerances.

These results simplify the design process for the matching section as follows: The line width of a probe transition can be extended to the microstrip line by a proper length (e.g., 30 mil used in this paper). Since the input impedance of the probe transition is approximately equal to the characteristic impedance of the attached microstrip line, a quarter-wave transformer section can be inserted between the probe and the 50 Ohm microstrip line as shown in Fig. 5. In this case, 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.

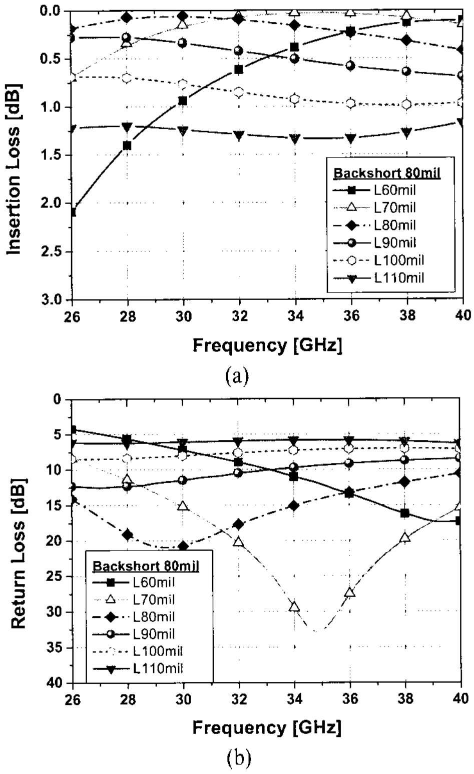


Fig. 6. (a) Insertion loss, (b) return loss of the modified basic probe transition.

2-3 Characteristics of the Modified Basic Probe Transition

The modified version of the basic probe transition shown in Fig. 5 has been analyzed as varying the probe length. In this calculation, the probe width is chosen as 15.6 mil. Figures 6(a) and 6(b) show the insertion loss and return loss of the probe transition as a function of frequencies, respectively. With 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, excellent probe transition performances of 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. With either probe length, the insertion loss of the probe transition is less than 0.5 dB over entire Ka-band frequencies.

Ⅲ. The Moisture-Sealed Probe Transitions

3-1 Design and Characteristics of the Moisture-Sealed Probe Transition

With the new moisture-sealed probe transition, the dielectric material completely covers the waveguide opening, and pene-

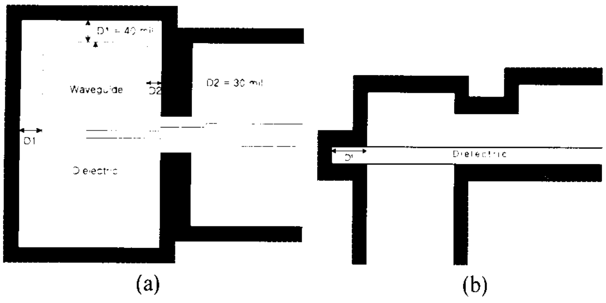


Fig. 7. Cross-sectional view of the moisture-sealed probe transition. (a) top view, (b) side view

trates through the waveguide wall for the firm attachment of the probe section on the housing as shown in Figs. 7 (a) and (b). The insertion loss and input return loss of the modified basic probe transition and the dielectric-covered transition are compared in Figs. 8 (a) and (b). In the figures, the performance of the dielectric-covered probe transition is comparable to that of the basic probe transition. However, rapid performance degradation is observed near 40 GHz, which is caused by the resonance behavior due to discontinuity of the waveguide wall due to the penetration of the dielectric substrates as shown in Fig. 7 (b). These resonance phenomena are further discussed in Sections 3-2 and 3-3.

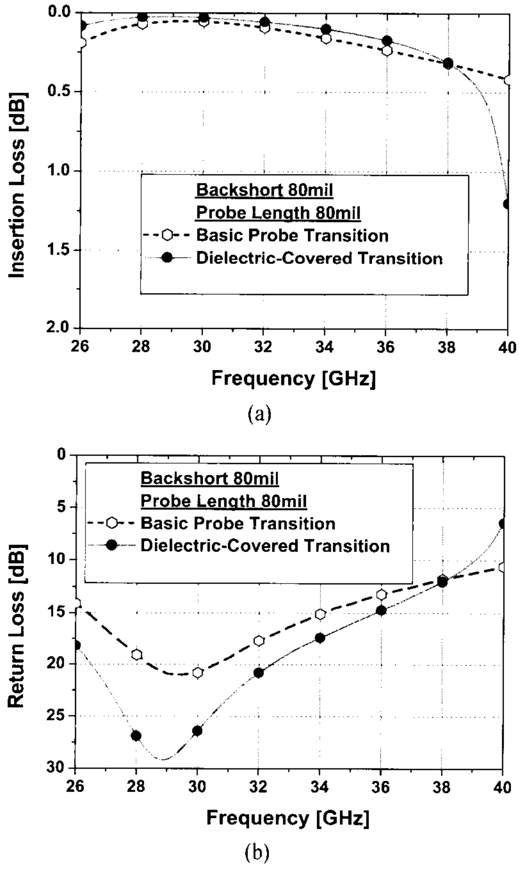


Fig. 8. Comparison of (a) insertion loss, (b) return loss between the modified basic probe transition and the dielectric-covered probe transition.

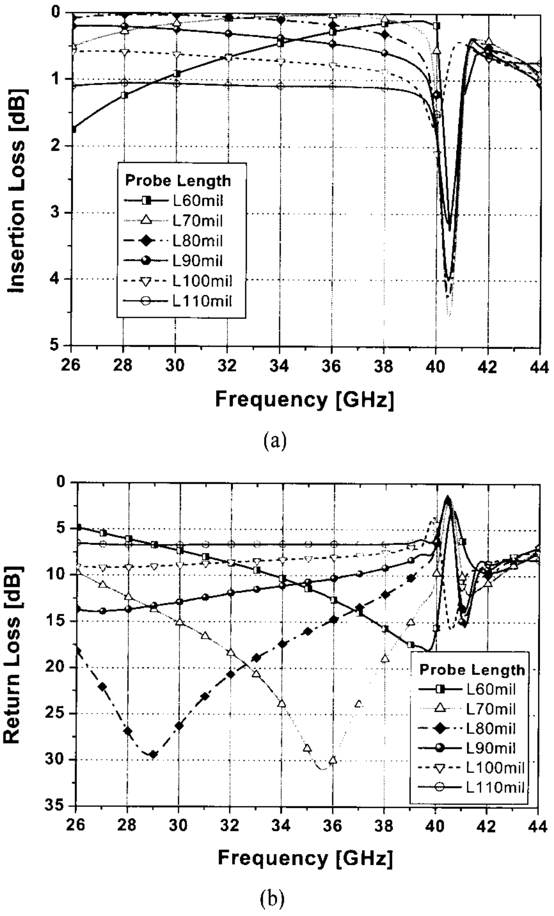


Fig. 9. (a) Insertion loss, (b) return loss of the moisture-sealed probe transition. The depth of back-short is 80 mil.

The insertion loss and input return loss for the dielectric-covered transition are shown in Figs. 9 (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. These figures clearly show the resonance behavior occurring near 40 GHz. In this configuration, the excellent performance has 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, which agrees with the performance of the modified basic probe transition.

3-2 Characteristics of the Moisture-Sealed Probe Transition with Vias

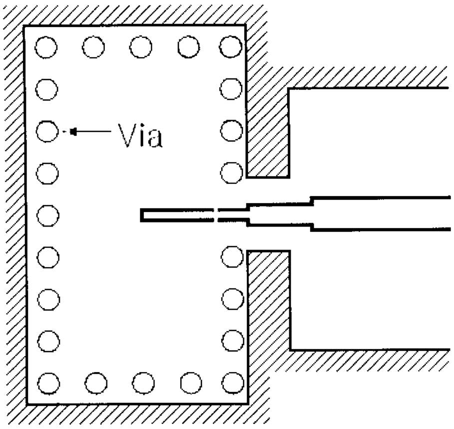
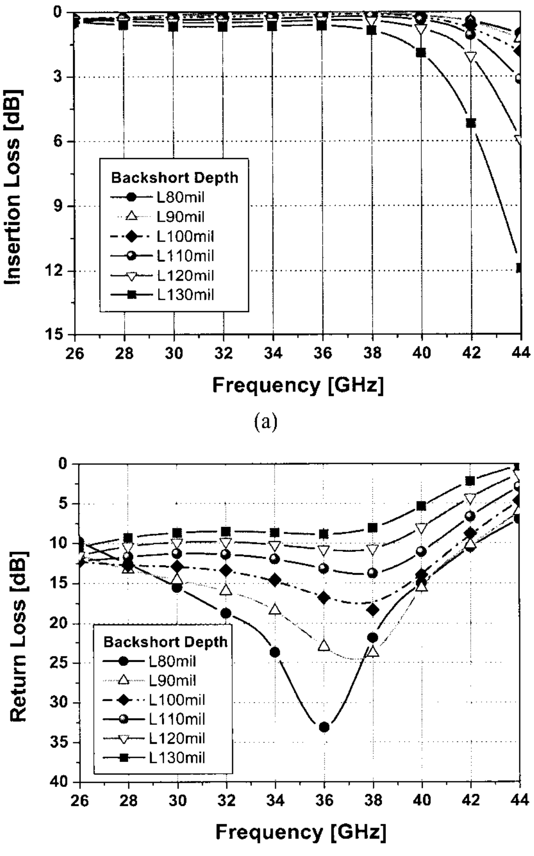


Fig. 10. The cross-sectional view of the moisture-sealed probe transition with vias.



(a)

(b)

Fig. 11. (a) Insertion loss, (b) return loss of the moisture-sealed probe transition with vias.

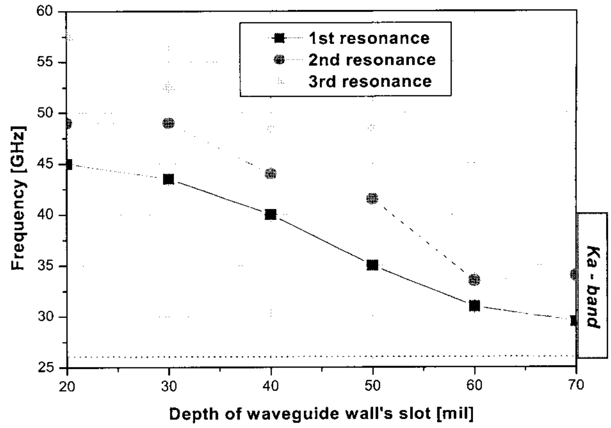
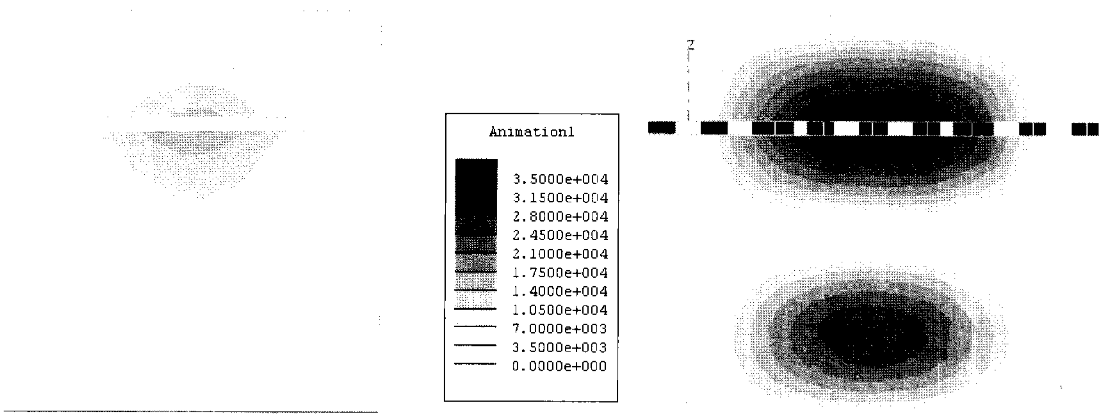


Fig. 12. Changes of resonance frequencies as varying waveguide wall-penetration depths.

In order to remove the resonance behavior near 40 GHz, electrical vias have been placed around the waveguide aperture as shown in Fig. 10. 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. 11(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, in 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.

3-3 Behavior of Resonance Associated with Wall-Penetration and Vias

Changes of resonance frequencies as function of wall-penetration depth have been obtained. Figure 12 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. Figure 13(a) shows the calculated magnitude of current density on the wall in the presence of 40 mil wall-penetration at 40 GHz. In the figure, we can clearly observe the discontinuity of the current density on the wall across the probe layer.



(a) (b)

Fig. 13. Magnitude of current density on the waveguide wall across the probe layer: moisture-sealed probe transition with (a) with no vias, (b) with vias.

The resonance in the Ka-band frequencies can be removed by introducing electrical vias as shown in Fig. 10. The role of vias is considered to connect the current flow on the waveguide wall across the probe layer, which is shown in Fig. 13(b). 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 in the Ka-band frequencies. For a given wall-penetration depth, the maximum distance between vias at which the probe transition provides the insertion loss less than 0.5 dB and return loss greater than 10 dB has been determined and shown in Table. 1. Figure 14 shows the probe performances with wall-penetration depth of 40 mil and via distance of 90 mil. The insertion loss is less than 0.5 dB and the return loss is greater than 10 dB over entire Ka-band frequencies. From 29 to 40 GHz, the insertion loss is less than 0.2 dB and return loss greater than 17 dB. It is noted that the length of this probe transition can be optimized for narrow-band applications.

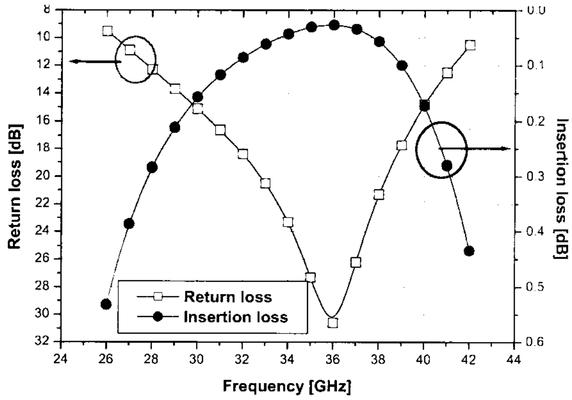


Fig. 14. Insertion loss and return loss of the moisture-sealed probe transition with waveguide wall-penetration depth of 40 mil and via distance of 90 mil.

Table 1. Maximum separation distance of vias associated with wall penetration depth.

Wall-Penetration Depth	Number of Vias	Separation Distance of Vias
40 mil	6	130 mil
50 mil	8	110 mil
60 mil	10	90 mil

Ⅳ. Conclusion and Future Plans

New waveguide-to-microstrip probe transitions have been designed and comprehensively analyzed in this paper. With these probe transitions, the dielectric substrate completely covers the waveguide aperture and penetrated into the waveguide wall for proper attachment of the probe transition section on the housing. By introducing vias on the dielectric substrates around the waveguide aperture, the resonance behavior of the probe transition has been removed. Also, the performance degradation due to resonance phenomena associated with waveguide wall-penetration have been identified and analyzed. The developed moisture-sealed probe transition provides excellent electrical and mechanical properties as a waveguide-to-microstrip transition. As compared with the basic probe transition[5], this probe provides moisture-barrier, less sensitivity to fabrication errors, and robustness, which are required for commercial millimeter-wave transceiver applications. This probe can easily be integrated with the microwave/ millimeter-wave transceivers for digital microwave radios.

Currently, various probe transitions are being fabricated and will be tested to compare with the calculated results. Also, the probe transitions will be designed in other frequency bands such as K-band (18~26.5 GHz) and Q-band (33~50 GHz).

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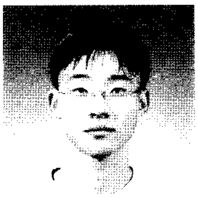

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