Millimeter-Wave Vertical Transitions Between Ridge Gap Waveguides and Microstrip Lines for Integration of MMIC with Slot Array

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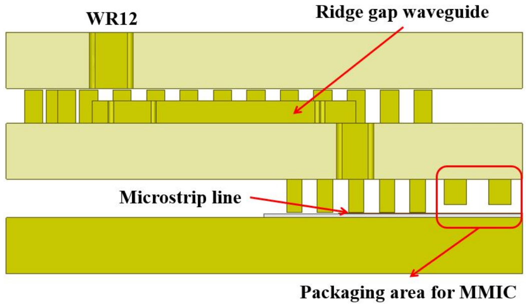
***Abstract*—This paper presents two low-loss vertical transitions between ridge gap waveguides and microstrip lines. The transitions can be utilized as packaging techniques for system level integration of MMICs with waveguide components such as slot array antennas. Both vertical transitions feature microstrip lines being the bottom layer but facing opposite directions. The first vertical transition consists of a microstrip line facing upwards with a patch in the end. Simulation results show that the reflection coefficient is better than -15 dB from 74 to 82 GHz. The second transition of microstrip line facing downwards features E-plane probe with back-short cavity surrounded by periodic pins. Simulation results show that the reflection coefficient is better than -15 dB from 71 to 86 GHz. Comparing with other same layer transitions, the vertical solutions provide more flexibility for the routing of antenna feeding line and have the ability of implementing a more compact design.**

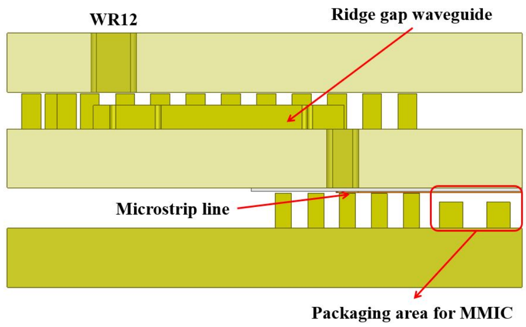
***Index Terms*—gap waveguide, mm-wave, packaging, transition, integration**

I. Introduction

Gap wave technology has the potential to become more cost-effective than conventional rectangular waveguide and more power-efficient than PCB-based microstrip and coplanar waveguide for communication and radar applications in mm-wave frequency bands [1]–[2]. Passive gap waveguide components, like filters and diplexers, have been realized successfully [3]–[4]. Also, several low-loss and high-gain gap waveguide based planar antennas have been demonstrated at mm-wave frequency [5]–[7]. Moreover, system-level packaging solutions based on gap waveguide technology have been investigated in [8]. It has been shown that gap waveguide technology has promising performance in antennas and mm-wave passive networks, as well as system-level packaging. In most cases, gap waveguide antennas consist of feeding layer and radiating layer, and microstrip lines are commonly used for integration of active components. Thus, a direct transition from microstrip to the antenna feeding layer is of high interest. The integration of active components with passive gap waveguide devices has been introduced in [8]–[10]. However, such integrations are within the scope of same-layer solution, which makes the layout of active components, as well as the routing of antenna feeding line more challenging and complex. To have a more compact and efficient solution, especially for mm-wave automotive radar system-level integration, this paper presents two cross-layer vertical transitions between microstrip and gap waveguide transmission line.



(a) Configuration A: microstrip line facing upwards



(b) Configuration B: microstrip line facing downwards

Fig. 1. Configurations of vertical transitions between ridge gap waveguide and microstrip line.

II. Design of the Transitions

Two configurations of vertical transitions between ridge gap waveguide and microstrip line have been proposed in this work, as shown in Fig. 1. Both configurations feature bottom layer being microstrip line but towards opposite directions.

A. *Configuration A*

Vertical transition between microstrip line and waveguide is one of the candidates for integration of slot array with

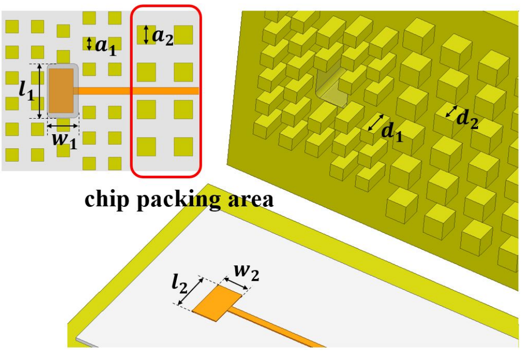


Fig. 2. Vertical transition between packaged microstrip and rectangular waveguide in configuration A. (a_1 = 0.55 mm, d_1 = 1.2 mm, a_2 = 0.8 mm, d_2 = 0.9 mm, l_1 = 2.33 mm, w_1 = 1.34 mm, l_2 = 1.89 mm, w_2 = 1.04 mm)

MMICs which have microstrip outputs. Conventionally, a back-short cavity is necessary for the typical vertical transition between microstrip line and waveguide. This brings complexity for manufacturing in mm-wave frequency band. Instead of using E-plane probe, resonant patch coupling has been proposed in this work without the presence of back-short cavity, as shown in Fig. 2. Periodic pins on the top plate have formed a specific cavity above the patch fed by input microstrip line. The resonance from the cavity and the resonance from the microstrip patch have been carefully optimized for efficient coupling of EM signal from the microstrip line to the top cavity. The MMICs will be packaged by pins with different dimensions which are able to block interference signals and bring favorable space for assembly. To reduce the sensitivity of resonance resulting from manufacturing and assembly tolerance, zero-gap waveguide has been utilized in this work [11].

Ridge gap waveguide is more commonly used than groove gap waveguide in mm-wave antenna design as a result of more wideband and compact properties. A probe transition between ridge gap waveguide and conventional rectangular waveguide has been proposed, as shown in Fig. 3.

A transition between standard WR12 rectangular waveguide and ridge gap waveguide is necessary as well in practice, as shown in Fig. 3. The simulation results of this transition implemented in a back-to-back structure is shown in Fig. 4. The reflection coefficient is around -30 dB from 65 to 90 GHz.

The microstrip line used in this design is based on 0.127 mm Rogers 3003 substrate and length of the line is 6.1 mm. The simulation results of configuration A are shown in Fig. 5. The reflection coefficient is better than -15 dB from 74 to 82 GHz. The insertion loss, including the piece of microstrip line and a piece of ridge gap waveguide with length of 5.7 mm, is around 0.5 dB from 74 to 82 GHz.

B. Configuration B

In the previous section, the vertical transition of microstrip line facing upwards has been introduced. However, due to the patch resonance, the transition of configuration A is

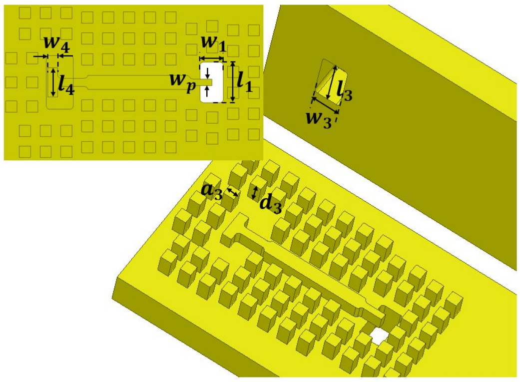


Fig. 3. Vertical transition between ridge gap waveguide and rectangular waveguide in configuration A. (w_3 = 1.55 mm, l_3 = 3.1 mm, a_3 = 0.65 mm, d_3 = 1.2 mm, w_4 = 0.57 mm, l_4 = 1.7 mm, w_p = 0.39 mm)

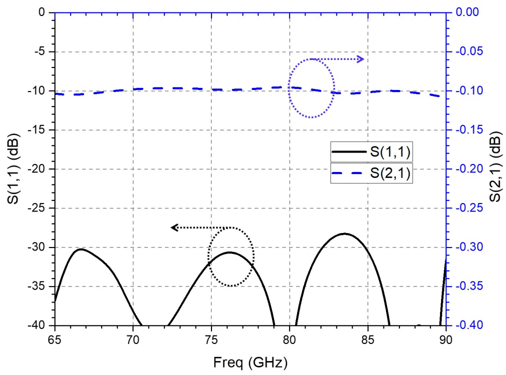


Fig. 4. Simulation results of vertical transition between ridge gap waveguide and standard WR12 rectangular waveguide.

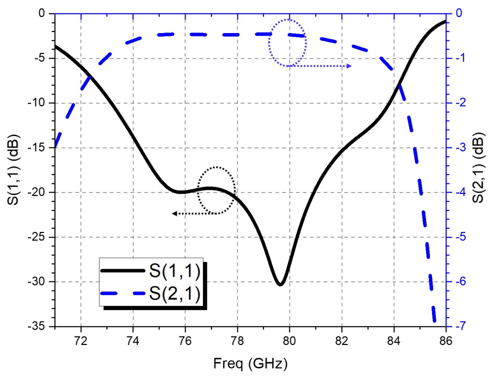


Fig. 5. Simulation results of the vertical transition of configuration A.

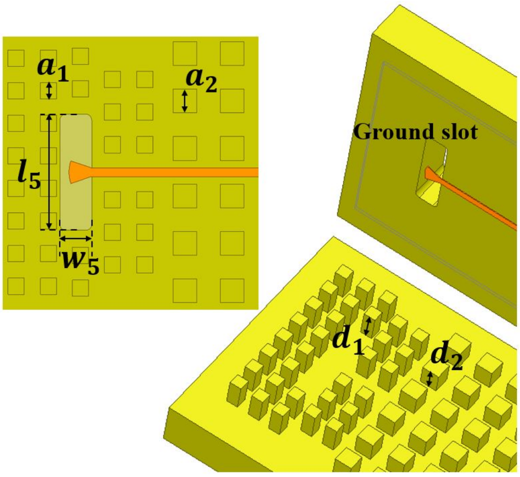


Fig. 6. Probe transition between microstrip and rectangular waveguide in configuration B. (w_5 = 1.08 mm, l_5 = 3.92 mm)

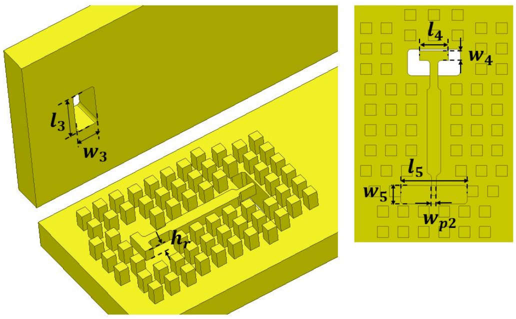


Fig. 7. Vertical transition between ridge gap waveguide and rectangular waveguide in configuration B. (w_{p2} = 0.3 mm, h_r = 0.8 mm)

inherently narrow band. In this section, a broadband solution of microstrip line facing downwards is presented.

A probe transition between microstrip line and rectangular waveguide is shown in Fig. 6. Utilizing the packaging pins on top of the microstrip line, a back-short cavity has been employed for the broadside probe transition. By the ground slot of the microstrip line, EM signal could be coupled vertically up to the rectangular waveguide. The same transition that couples the EM signal from the rectangular waveguide to the ridge gap waveguide has been utilized here, as shown in Fig. 7.

The simulation results of configuration B are shown in Fig. 8. The length of the microstrip line utilized in the transition is 5.57 mm. The transition features a reflection coefficient better than -15 dB and an insertion loss approximately 0.4 dB, including the piece of microstrip line and a piece of ridge gap waveguide with length of 5 mm, over the frequency band from 71 to 86 GHz.

Comparing with the transition of configuration A, the transition of configuration B has advantages of wider bandwidth and lower insertion loss. However, in system-level design, if the PCB board to be integrated is of multi-layer, it would be difficult to have a waveguide window underneath the RF layer. This makes the vertical transition of configuration A, a

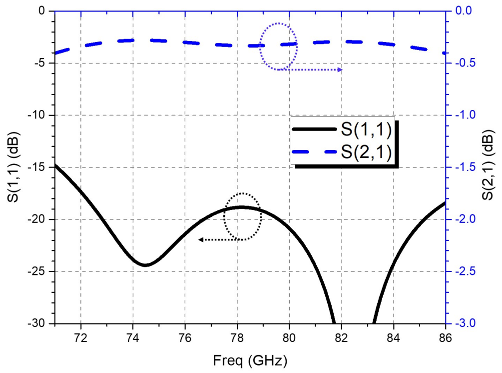


Fig. 8. Simulation results of the vertical transition of configuration B.

transition without the presence of back short cavity, a better candidate for integration of multi-layer PCB boards.

III. Conclusion

Two vertical transitions between microstrip line and ridge gap waveguide have been presented in this paper. The first transition design with microstrip line facing upwards utilizes resonant patch to couple the signal from microstrip to the ridge gap waveguide. It can be observed from the simulation results that the reflection coefficient is better than -15 dB from 74 to 82 GHz and the insertion loss is around 0.5 dB from 74 to 82 GHz. The second transition design with microstrip line facing downwards utilizes microstrip probe in the presence of back-short cavity. The simulation results show that the reflection coefficient is better than -15 dB from 71 to 86 GHz and insertion loss is approximately 0.4 dB from 71 to 86 GHz. The two proposed transitions have novel vertical structures that will make the integration of gap waveguide slot array with MMICs more compact and more flexible for the system layout.

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