Progress In Electromagnetics Research Letters, Vol. 46, 107–112, 2014

Broadband Rectangular Waveguide to GCPW Transition

Jun Dong[1, *], Tao Yang[1], Yu Liu[1], Ziqiang Yang[1], and Yihong Zhou[2]

Abstract—A broadband transition design between rectangular waveguide and GCPW is proposed and studied. The E-field of GCPW is designed to be gradually changed to that of waveguide via the simple tapered probes and metallic vias. The planar circuit of the transition is fabricated by low cost standard PCB process. The tolerance analysis for this transition is also given. A back-to-back transition prototype at Ka-band is fabricated and measured. The measurement results show that maximum insertion loss of 0.75 dB and return loss of better than 15 dB are obtained within a desired frequency range from 26.5 to 40 GHz. The measurement results agree well with simulation results, which validate the feasibility of this design.

1. INTRODUCTION

The coplanar waveguide (CPW) as one of the popular planar transmission lines that has drawn much attention due to the advantages of low cost, compact size and easy integration. The CPW lines have lower dispersion characteristics than microstrip lines, especially at millimeter-wave band. However, for many applications, conductor-backed CPW (GCPW) will be needed: the back conductor of GCPW can be used to provide added mechanical support and heat sinking ability compared to conventional CPW [1]. The GCPW can be built on many kinds of manufacturing processes, such as LTCC process [3], integrated circuits process [4], and standard PCB process [5–9]. Due to the advantages of high quality factor and power-handing capacity, the metallic waveguides still play an essential role in millimeter-wave systems. Therefore, the development of a high performance, easy integration and low cost transition between rectangular waveguide and GCPW is required in some applications.

Several waveguide-to-GCPW transitions have been presented in the open literatures [6–9] and some good performances are observed. These transitions are either along the propagation direction of the waveguide [6, 7] or perpendicular to the propagation direction [8, 9]. A uniplanar waveguide-to-GCPW transition is presented by using an open-ended strip [6], there is a need of an intermediate transition of the GCPW to the slot-line transition, and additional air-bridge is needed after the assembling of PCB which adds the fabrication steps. In [7], a reduced-height rectangular waveguide conjunction with a pin connected to the center strip of the GCPW line is employed in the design of waveguide-to-GCPW transition, and the pin serves as a wire antenna which couples CPW mode to the waveguide mode. The modified waveguide and suspended pin make the fabrication complicated. Compared with those in-line transitions, some right-angle transitions are presented [8, 9]. A double-slot antenna coupling approach is adopted for waveguide-to-GCPW transition, and this right-angle transition has a 22% bandwidth at W-band [8]. However, those transitions suffer from insufficient bandwidth [6–9].

A broadband waveguide-to-GCPW transition is proposed in this work for the application of in-line systems. The double tapered probes are adopted to transform the TE_{10} mode in the rectangular waveguide to the GCPW mode. Neither intermediate transition nor air-bridge has been used in this transition compared to conventional waveguide-to-GCPW transition [6], and a broad operation

Received 9 May 2014, Accepted 7 June 2014, Scheduled 17 June 2014

* Corresponding author: Jun Dong (jundong.ee@gmail.com).

[1] School of Electronic Engineering, University of Electronic Science and Technology of China, No. 2006, Xiyuan Ave, West Hi-Tech Zone, Chengdu 611731, China. [2] School of Physics and Electronic, University of Electronic Science and Technology of China, Jianshe Road, Chengdu 610054, China.

frequency band has also been achieved. The planar circuit of this transition is built on a low cost standard PCB process, which meets the requirement of low cost and compact size in transition circuits design. A back-to-back transition prototype has been fabricated, and the scattering parameters are measured to verify the proposed design. This transition exhibits advantages of broad bandwidth, compact profile and easy fabrication.

2. TRANSITION DESIGN AND ANALYSIS

Figure 1 shows the structure of the proposed transition between a rectangular waveguide and GCPW. The whole transition structure consists of a rectangular waveguide, double tapered probes and a GCPW. The rectangular waveguide is WR-28 standard waveguide with dimensions of 7.112×3.556 mm. A Rogers RT/Duroid 5880 substrate with relative permittivity of 2.22, loss tangent of 0.009 and thickness of 0.381 mm is used as the circuit substrate for this transition. The RT/Duroid 5880 is a laminate suitable for high-frequency applications, especially at millimeter-wave band. Same as those in [8, 9], the planar circuits of the proposed transitions are double-side circuit. Two tapered probes are fabricated on both sides of the substrate in an antisymmetric structure. Two rows of metallic vias are placed parallel to each ground plane of the GCPW.

As shown in Figure 1, the double tapered probes are inserted into the center of E-plane of a standard waveguide, which is used to rotate 90 degree of the E-field. The E-field distribution of the cross-section for the proposed transition is shown in Figure 2. Descriptions of this transition follow the propagation direction of the energy from the GCPW to the rectangular waveguide. In the GCPW part, the top and bottom ground planes are connected with each other by two rows of short circuit vias. The metallic vias play an essential role in the transition design. The first function of these vias is to suppress the unwanted parallel-mode [2]. Secondly, these vias take the place of air-bridges which are typically used to suppress the odd mode [6]. Thirdly, as shown in Figure 2, the domain modes of the GCPW at A-location include y-directed CPW mode and z-directed microstrip (MSL) mode. In the transition parts, these vias provide a vertical connection between the top and bottom ground planes of the GCPW conjunction with an extended ground plane so that the y-directed CPW mode will be gradually transformed to z-directed MSL mode at B-location. The extended ground plane can provide a better field matching. Note that the effects of these vias will be studied in subsequent section.

Based on the above discussion, the transition is designed. Figure 3(a) shows the schematic circuit

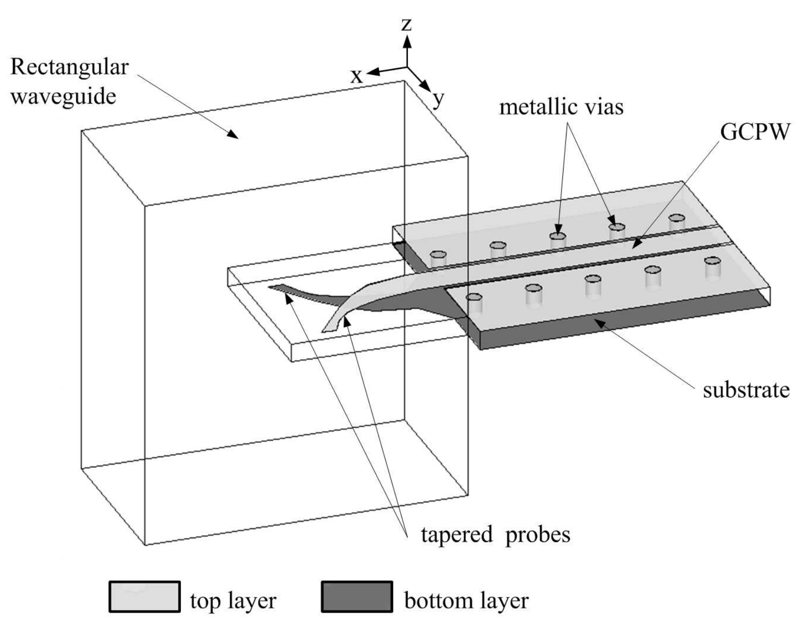

Figure 1. Structure of waveguide-to-GCPW transition.

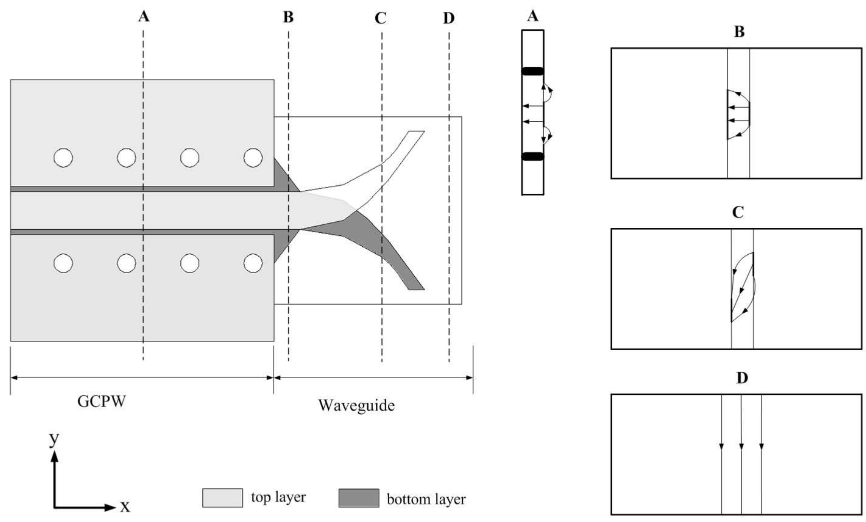

Figure 2. Cross-section for E-field distribution.

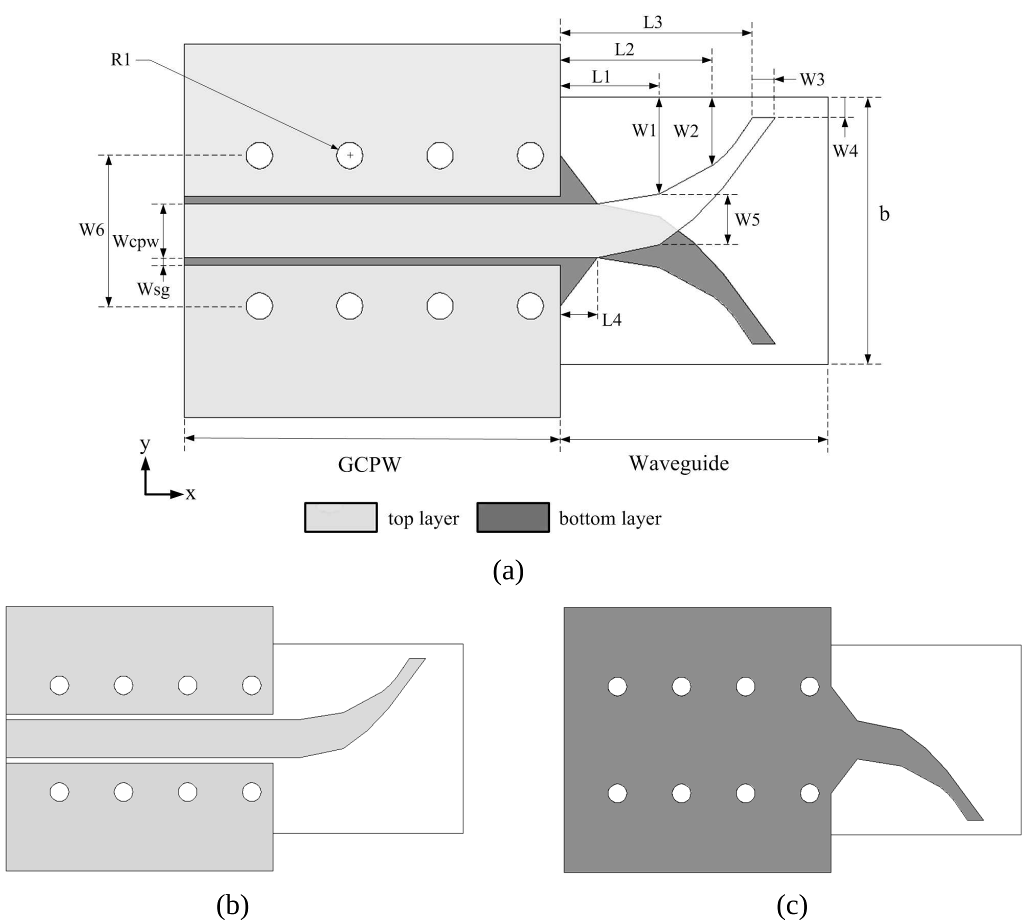

Figure 3. Layout of the proposed transition: (a) schematic layout, (b) top view, (c) bottom view.

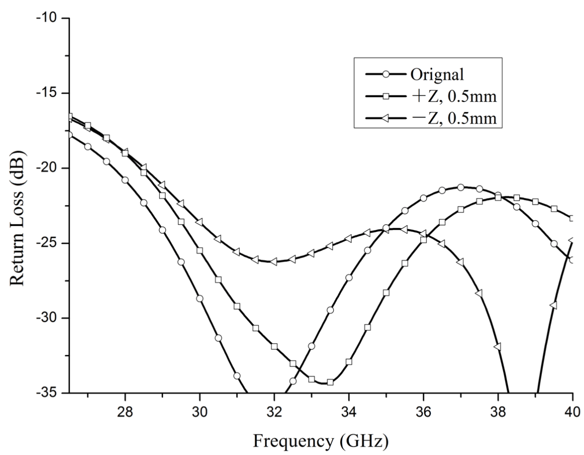

Figure 4. Simulated return loss for waveguide-to-GCPW transition with different offset value of substrate.

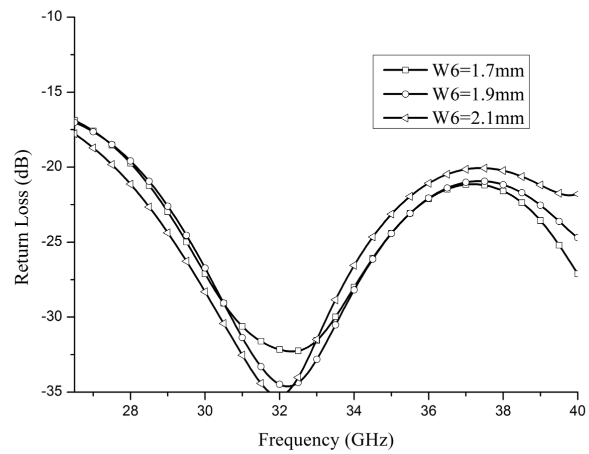

Figure 5. Simulated return loss for waveguide-to-GCPW transition with different position of metallic vias.

for the proposed transition. Figure 3(b) shows the circuit layout on top side of the substrate. Figure 3(c) depicts the circuit layout on bottom side of the substrate. The characteristic impendence of the GCPW is set to $50\,\Omega$ with $W_{cpw} = 0.72\,\mathrm{mm}$ and $W_{sg} = 0.1\,\mathrm{mm}$. The two probes are also tapered in a smooth outline to obtain good reflection coefficient. By properly choosing the dimension of the probe, a broadband performance of the transition can be achieved. After optimization with the full-wave simulation software Ansoft HFSS, the geometry parameters of the transition are obtained. The final parameters are: $W_1 = 1.29\,\mathrm{mm}$, $W_2 = 0.94\,\mathrm{mm}$, $W_3 = 0.3\,\mathrm{mm}$, $W_4 = 0.28\,\mathrm{mm}$, $W_5 = 0.68\,\mathrm{mm}$, $W_6 = 1.9\,\mathrm{mm}$, $b = 3.556\,\mathrm{mm}$, $L_1 = 1.32\,\mathrm{mm}$, $L_2 = 2.1\,\mathrm{mm}$, $L_3 = 2.55\,\mathrm{mm}$, $L_4 = 0.49\,\mathrm{mm}$. The length of the whole transition circuit is 2.85 mm.

In addition, the tolerance of mechanical assembly of the transition and the truncation error of substrate are verified by simulation. In fabrication, the rectangular waveguide needs to be split into two parts, the bottom cavity of the waveguide also sever as a support cavity to support the GPCW substrate. For this mechanical assembly consideration, the mechanical sensitivity of this design should be checked. Figure 4 shows the simulation results of waveguide-to-GCPW transition when the substrate is positioned $\pm 0.5\,\mathrm{mm}$ offset in z-direction from the center of waveguide shown in Figure 1. Although the offset we assumed is relatively large (14.1%), the bandwidths (return loss better than 16.5 dB) of the two cases are almost the same, only a frequency shift is observed. It's should be noted that the expected manufacturing error is much smaller than the simulated ones in modern technologies.

As discussed above, the metallic vias play an important role in the design of this transition. Figure 5 shows the simulation results of waveguide-to-GCPW transition with the two rows of the vias offset from the center of the GCPW with different values, while the other structure parameters are kept the same. It can be seen that the changes in return loss are not obvious and that no resonance has been found. However, the substrate truncation error is quite small in modern PCB process, and it can be substantially reduced. It is demonstrated that the position of vias is an insensitive parameter for the performance of the transition.

3. EXPERIMENT

To experimentally test the performance of the proposed transition, two identical transitions were cascaded back-to-back. Figure 6 shows a photograph of the fabricated back-to-back transition. Measurements were carried out with a vector network analyzer and a pair of coaxial line-to-waveguide adapters. A thru-reflect-line (TRL) was applied to calibrate measurements at the WR28 accesses. The simulated and measured results of the back-to-back transition are shown in Figure 7, which show good agreement. The measured results show that the insertion loss of back-to-back transition is less than

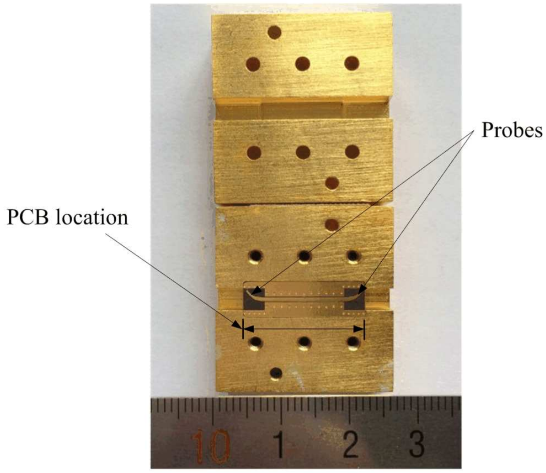

Figure 6. Photograph of the fabricated back-to-back transition.

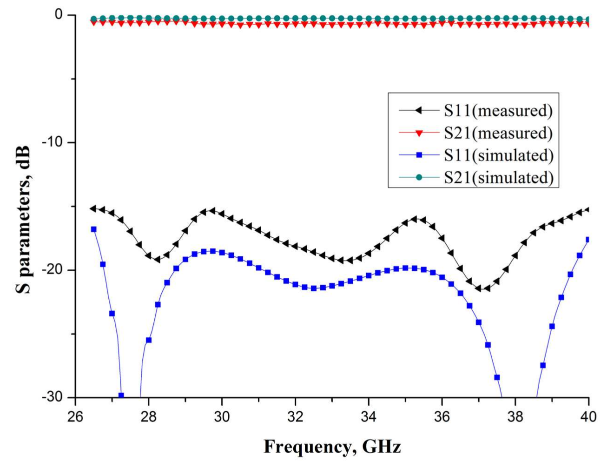

Figure 7. The simulated and measured results of the back-to-back transition.

Table 1. Comparisons with previous waveguide-to-GCPW transitions.

	Freq	BW (GHz)	Relative BW	RL (dB)	IL (dB)	Fabrication substrate	Transition direction	Transition lengths (mm)
[6]	V	55–65	17%	> 10		Al_2O_3	In-line	78.1
[7]	Ka	27.6–31.2	13%	> 10	< 1	Duroid 5880	In-line	
[8]	W	91.2–113.2	22%	> 9	< 1.8	Duroid 5880	Right-angle	
This work	Ka	26.5–40	41%	> 15	< 0.75	Duroid 5880	In-line	2.85

0.75 dB with better than 15 dB return loss from 26.5 to 40 GHz. Therefore, the insertion loss of a single transition is less than 0.4 dB at Ka band. The measured insertion loss agrees well with simulated ones in the passband, while a slight frequency shift for return loss has been observed and may contributed to the difficulty in the fabrication resolution control and measurement calibration at such a high frequency band.

Table 1 summarizes the performances of the proposed transitions along with previously published transitions for comparison. It should be noted that these results shown in Table 1 are based on measurement except the one in [7], which is a simulation result. There are two kinds of transitions sorted by the propagation direction, which are in-line [6, 7] and right-angle [8]. This work is designed for the application of in-line systems. Compared with the ones in [6–8], the bandwidth is enhanced. Besides, the transition circuit is compact compared with the one in high dielectric constant substrate [6]. It can be widely adopted in integrated models at millimeter-wave band.

4. CONCLUSION

A novel broadband waveguide-to-GCPW transition has been proposed and demonstrated. The transition is achieved based on tapered probes and metallic vias. No air-bridge or intermediate transition is needed for this transition, which makes it easy to fabricate. The tolerance analysis for this transition is also given. A Ka-band back-to-back transition is fabricated and measured. Reasonable agreements between the simulated and measured results are obtained. With its advantages of broadband, low loss and compact size, such a transition can be used in some millimeter-wave integrated models.

REFERENCES

1. Shigesawa, H., M. Tsjui, and A. A. Oliner, "Conductor-backed slot line and coplanar waveguide: Dangers and full-wave analyses," *IEEE MTT-S Int. Microw. Symp. Dig.*, 199–202, 1988.
2. Tien, C.-C., C.-K. C. Tzuang, S.-T. Peng, and C.-C. Chang, "Transmission characteristics of finite-width conductor-backed coplanar waveguide," *IEEE Trans. Microw. Theory Tech.*, Vol. 41, No. 9, 1616–1623, 1993.
3. Lee, J. J., K.-C. Eun, D. Y. Jung, and C.-S. Park, "A novel GCPW to rectangular waveguide transition for 60 GHz applications," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, No. 2, 80–82, 2009.
4. Shih, Y.-C., "Broadband characterization of conductor-backed coplanar waveguide using accurate on-wafer measurement techniques," *Microw. J.*, Vol. 34, No. 4, 95–105, 1991.
5. Lin, S., S. Yang, A. E. Fathy, and A. Elsherbini, "Development of a novel UWB Vivaldi antenna array using SIW technology," *Progress In Electromagnetics Research*, Vol. 90, 369–384, 2009.
6. Hung, C.-F., A.-S. Liu, C.-H. Chien, C.-L. Wang, and R.-B. Wu, "Bandwidth enhancement on waveguide transition to conductor backed CPW with high dielectric constant substrate," *IEEE Microw. Guided Wave Lett.*, Vol. 15, No. 2, 128–130, 2005.
7. Vahidpour, M. and K. Sarabandi, "Ground coplanar waveguide to rectangular waveguide transition," *IEEE Antennas and Propagation Society International Symposium, 2009 APSURSI*, 1–5, 2009.
8. Aliakbarian, H., S. Radiom, V. Tavakol, P. Reynaert, B. Nauwelaers, G. A. E. Vandenbosch, and G. Gielen, "Fully micromachined W-band rectangular waveguide to grounded coplanar waveguide transition," *IET Microwaves, Antennas & Propagation*, Vol. 6, No. 5, 533–540, 2012.
9. Flammia, I., A. Stohr, C. C. Leonhardt, J. Honecker, and A. G. Steffan, "71–76 GHz grounded CPW to WR-12 transition for quasi-hermetic RoF wireless transmitter," *Electronics Letters*, Vol. 48, No. 9, 506–508, 2012.