Novel Transition Between Different Configurations of Planar Transmission Lines

Amr M. E. Safwat, *Member, IEEE*, Kawthar A. Zaki, *Fellow, IEEE*, William Johnson, *Member, IEEE*, and Chi H. Lee, *Fellow, IEEE*

***Abstract*—New designs of coplanar waveguide (CPW)-microstrip, CPW-stripline, conductor backed CPW (CBCPW)-microstrip, and CBCPW-stripline transitions are presented. Simulation using the high frequency structures simulator (HFSS) shows that the return loss of the CPW-microstrip transition is less than −25 dB up to 11 GHz. Similarly is the CPW-stripline transition. In the case of two back to back CBCPW-stripline transitions, the return loss is less than −22 dB up to 9 GHz. Experimentally, the S_{11} of two back to back CBCPW-microstrip transitions on Alumina substrate is less than −15 dB up to 25 GHz.**

***Index Terms*—Coplanar waveguide, microstrip, stripline, transition.**

I. Introduction

TRANSITIONS between different configurations of planar transmission lines have been subject to rigorous study since 1979 [1]–[6]. Recently, a transition between coplanar waveguide (CPW) and microstrip transmission lines in which the electric and magnetic fields change gradually from the CPW mode to the microstrip mode with constant characteristic impedance was proposed [6].

In this letter, the transition described in [6] is generalized to connect a CPW or a conductor backed coplanar waveguide (CBCPW) to a microstrip or a stripline.

II. Coplanar Waveguide to Microstrip Transition

CBCPW has four conductors over a substrate. Three conductors are on one surface forming the center line and two ground lines, and the fourth is a ground line at the bottom. $2w$ is the width of the center line, s is the separation between the center line and the ground lines on the surface, g is the ground line width on the surface, h is the substrate height, and ϵ_r is the relative dielectric constant of the substrate. The characteristic impedance of the CBCPW is the parallel combination of two characteristic impedances: The CPW mode ($Z_{\rm GW}$) and the microstrip mode ($Z_{\rm MS}$) [7].

The splitting of the characteristic impedance into the CPW and the microstrip is the basic idea of the proposed structure. The new transition consists of a CBCPW that connects the CPW to the microstrip. The width of the center conductor of the CBCPW changes linearly or according to any specific function between the width of the center conductor of the CPW and the width of the microstrip. For practical implementation, the transition is divided into n sections of CBCPW, as shown in Fig. 1. All sections are designed to have 50 Ω impedance. At the CPW side, the design parameters $(2w, s)$ are very small with respect to the substrate height (h). Along the transition to the microstrip line, the width of the central line increases gradually. To keep the characteristic impedance equals to 50 Ω, the separation (s) of each section is recalculated using the expressions in [8]. In the last section of the transition, the microstrip impedance of the CBCPW dominates.

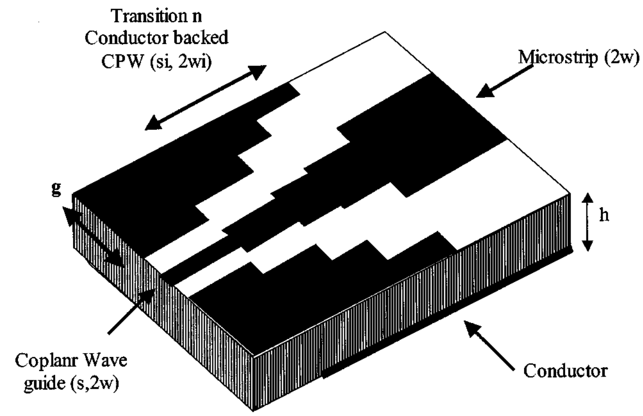

Fig. 1. Proposed transition; it consists of n sections of CBCPW. In the figure $n = 3$, one port is a CPW and the second port is a microstrip line.

The transition was studied using the high frequency structures simulator (HFSS), which is commercial software based on finite element method [9]. The substrate is InP that has $\epsilon_r = 12.4$ and $h = 350$ μm. Port 1 is a CPW that has $2w = 100$ μm, $s = 70$ μm, and 5 mm length. This is followed by a transition formed by 5 sections of equal length. The inner width increases with a step equals 30 μm and the total length of the transition equals 5 mm. Finally, port 2 is a microstrip having $2w = 260$ μm and 5 mm length. The s_{11} of this transition is less than −25 dB up to 11 GHz, as shown in Fig. 2. This is 10–20 dB better than [1]. Resonance occurs at $f = 12$ GHz and $f = 15$ GHz because of the finite length of the device. Fig. 2 also shows the effect of number of sections on the retrun loss. The length of the transition was kept equal to 5 mm and the number of section, n, was changed to 2, 10, and 20. When n equals 5 or higher s_{11} is less than −25 dB up to 11 GHz, but as n decreases to 2, s_{11} increases such that it is 10 dB larger.

Manuscript received November 1, 2001; revised January 8, 2002. The review of this letter was arranged by Associate Editor Dr. Arvind Sharma.

A. M. E. Safwat is with Cascade Microtech, Inc., Beaverton, OR 97006 USA (e-mail: asafwat@cmicro.com).

K. A. Zaki is with the Department of Electrical and Computer Engineering, University of Maryland, College Park, MD 20742 USA.

W. Johnson and C. H. Lee are with the Laboratory for Physical Sciences, College Park, MD 20740 USA.

Publisher Item Identifier S 1531-1309(02)03970-3.

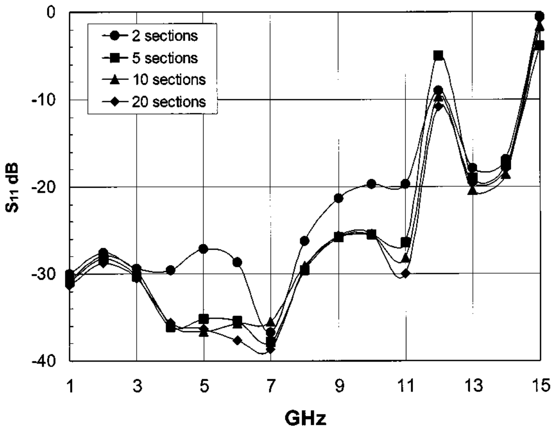

Fig. 2. Effect of the number of sections on s_{11}; total length of the transition is 5 mm. When $n = 5$, s_{11} is less than -25 dB up to 11 GHz.

III. Coplanar Waveguide to Stripline Transition

Stripline consists of a metal strip surrounded uniformly by a dielectric that is enclosed in a metallic shield. Connecting CBCPW or CPW directly to a stripline will lead to an abrupt transition of the electric and magnetic fields. To reduce the reflection the same techniques as in the CBCPW-microstrip transition can be used. At the second end, it is better to reduce the fields on the surface. In microstrip, the fields are confined in the substrate, therefore, adding a small section of microstrip will lead to a smoother transition at the stripline interface. This is correct as long as the field in the stripline is confined in the substrate. Consequently, the proposed transition is as shown in Fig. 3. It consists of n sections of CBCPW, then a microstrip, so that the CBCPW is connected to either a CPW or a CBCPW, and the microstrip is connected to the stripline.

Using the HFSS, the return loss of the CPW-stripline transition was calculated. All parameters are identical to the CPW-microstrip transition. The microstrip section in the transition has 1 mm length and 260 μm width. The output port is a stripline that has 168 μm width and 4 mm length. The stripline has a substrate height equals to the microtrip's and it is enclosed in a metallic shield that has 2 mm height and 3 mm width. Fig. 4 shows that using the characteristics of CBCPW, the return loss of CPW-stripline transition can be less than -25 dB up to 11 GHz as in the CPW-microstrip transition shown on the same figure.

Two back-to-back CBCPW-stripline transitions with different dimensions were also studied using HFSS. In this case, the following parameters were used: $\epsilon_r = 5.9$, $h = 360$ μm which is equal to the substrate height in the microstrip. Port 1 has 2 sections of CBCPW followed by a microstrip. The first CBCPW has $s = 95$ μm, $2w = 320$ μm and 5 mm length, the second has $s = 250$ μm, $2w = 400$ μm and 5 mm length. The microstrip has 490 μm width and 5 mm length. The stripline has 334 μm width and 10 mm length. The width of the metallic shield is 6096 μm and the height is 2800 μm. Identical microstrip and CBCPWs are connected at port 2. The resulting s_{11} of the fundamental mode, shown in Fig. 5, is less than -22 dB up to 9 GHz with much less value at low frequency. At higher frequency, higher order modes will be generated.

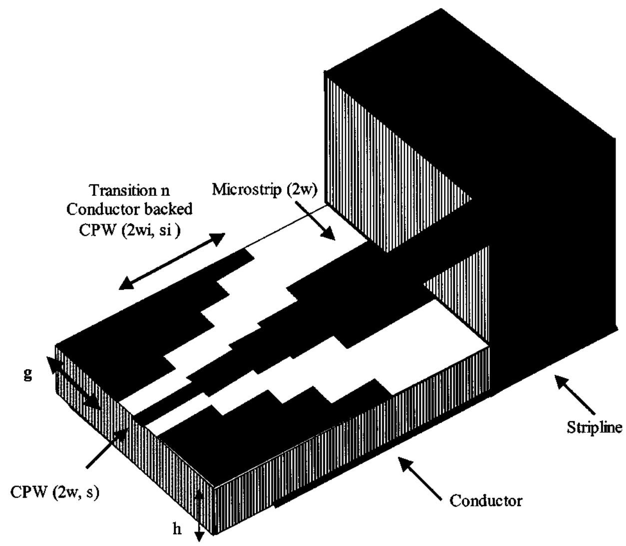

Fig. 3. Proposed CPW-stripline transition. It consists of n sections of CBCPW and a microstrip, in the figure $n = 3$; one port is a CPW and the second port is a stripline.

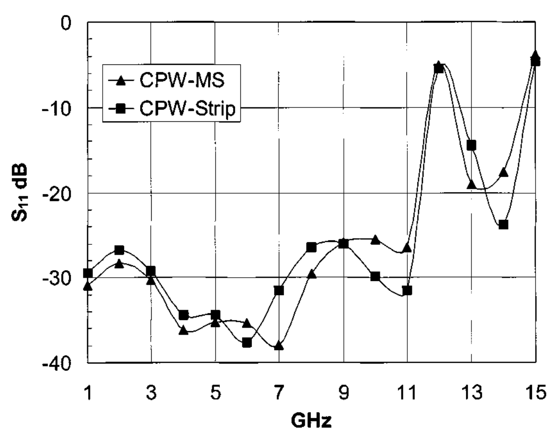

Fig. 4. Return loss of CPW-stripline (CPW-strip) compared to the CPW-microstrip (CPW-MS) transition. The CPW-stripline consists of five sections of CBCPW identical to the CPW-microstrip transition. 1 mm microstrip is inserted before the stripline. Port 1 is a CPW and port 2 is a stripline.

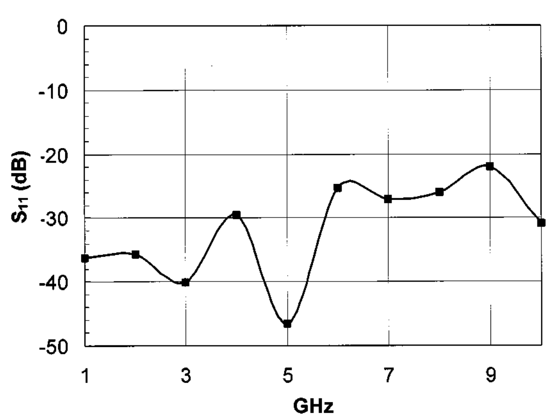

Fig. 5. s_{11} of two back to back CBCPW-stripline transitions. Each port has two CBCPWs and a microstrip. The last is connected to the stripline. s_{11} is less than -22 dB up to 9 GHz.

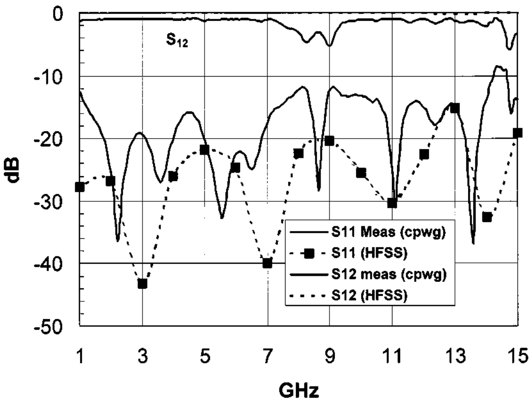

Fig. 6. Measured s_{11} for two back to back CBCPW-microstrip transitions on InP substrate. It consists of five sections of CBCPW, microstrip then five sections of CBCPW.

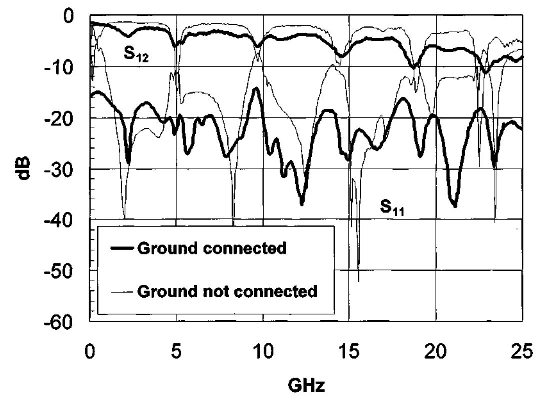

Fig. 7. Measured s_{11} for two back to back CBCPW-microstrip transitions on Alumina Substrate. It consists of an input CBCPW of length 5 mm, ten sections of CBCPW, microstrip, ten sections of CBCPW, then an output CBCPW of length 5 mm.

IV. Experimental Results

To verify the idea, two back to back transitions formed by 5 mm five sections CBCPW transition each of length 1 mm, 5 mm microstrip and 5 mm five sections CBCPW transition each of length 1 mm was fabricated on InP using conventional photolithography. $2w$ and s are as given in the simulation of the CPW-microstrip transition and $w + s + g = 3$ mm along the transition. The s parameters were measured using on wafer techniques and Agilent 8510 C. Measured s_{11}, shown in Fig. 6, is less than -12 dB between 1 GHz and 14 GHz. These results are better than those obtained in [1]. The simulated s_{11} of the fundamental mode, also shown on Fig. 6, shows the same behavior with a magnitude that is less than -15 dB to 15 GHz. The discrepancy between measurements and simulation can be explained by the fact that we had to simulate a very simplified version of the experimental structure. In the simulation, the excitations in terms of the RF probes were not included. Including them requires huge memory and time that may not be feasible. Also, in the simulation, the structure had to be shielded to have a single quasi TEM mode at the input (the CPW mode). If it is assumed open, more modes (microstrip and slot modes), which do not exist in the measurements, will be available and completely different interaction will occur. The last reason explains the resonance that occurs experimentally around 9 GHz, which is expected for open structures.

For practical application, the transition was fabricated on Alumina substrate that has 635 μm thickness. The fabricated device consists of 5 mm CBCPW, 5 mm ten sections transition each of length 0.5 mm, 5 mm microstrip, 5 mm ten sections transition, and 5 mm CBCPW. The input and output CBCPW have $2w = 100$ μm, $s = 44$ μm, the width of the microstrip is 642 μm and the width of each section in the transition increases with a step equals 50 μm. $w + s + g$ is kept equal to 3 mm. The measured return loss, shown in Fig. 7, is less than -15 dB up to 25 GHz. As in InP, resonance occurs at $f = 4.8$ GHz and its multiples. This increases the return loss to around -10 dB. Connecting the ground on the surface of the CBCPW to its ground at the bottom using silver paint to form an ideal CBCPW, resonance disappears and the return loss obtained is less than -15 dB from freq. $=$ 45 MHz up to 25 GHz. The presence of the silver paint reduces the s_{12} from -2 dB to -4 dB, as shown in Fig. 7.

V. Conclusion

Based on the propagation characteristics of the fundamental mode of the CBCPW, novel designs of CPW-microstrip, CBCPW-microstrip, CPW-stripline, and CBCPW-stripline transitions have been proposed. In these designs, the electric and magnetic fields are transformed smoothly from the CPW mode to the microstrip mode while keeping the characteristic impedance constant along the transition. Simulation using HFSS shows that the return loss of CPW-microstrip transition is less than -25 dB up to 11 GHz bandwidth. Similar results were obtained for the CPW-stripline transition. The return loss of the fundamental mode of two back to back CBCPW-strip transitions is less than -22 dB dB up to 9 GHz. Experimentally, two back-to-back transitions of CBCPW-microstrip on InP substrate have s_{11} less than -12 dB to 14 GHz. In the case of Alumina substrate, S_{11} is less than -15 dB up to 25 GHz.

References

[1] G. Strauss, P. Ehert, and W. Menzel, "On-wafer measurements of microstrip-based MMIC's without via holes," in *MTT-S Int. Microwave Symp. Dig.*, 1996, pp. 1399–1402.
[2] G. Gauthier, L. Katehi, and G. Rebeiz, "W-band finite ground waveguide to microstrip transition," in *MTT-S Int. Microwave Symp. Dig.*, 1998, pp. 107–109.
[3] J. Raskin, G. Gauthier, L. Katehi, and G. Rebeiz, "Mode conversion at GCPW-to-microstrip line transitions," *IEEE Trans. Microwave Theory Tech.*, vol. 48, pp. 158–161, Jan. 2000.
[4] M. Houdart and C. Aury, "Various excitations of coplanar waveguide," in *MTT-S Int. Microwave Symp. Digest*, 1979, pp. 116–118.
[5] D. Williams and T. Miers, "A coplanar probe to microstrip transition," *IEEE Trans. Microwave Theory Tech.*, vol. 36, pp. 1219–1223, July 1988.
[6] A. M. E. Safwat, K. Zaki, W. Johnson, and C. LEE, "Novel design of coplanar waveguide to microstrip transition," *MTT-S Dig.*, vol. 2, pp. 607–610, 2001.
[7] ——, "Mode-matching analysis of conductor backed coplanar waveguide with surface etching," *J. Electromagn. Waves Applicat.*, vol. 15, no. 5, pp. 627–641, 2001.
[8] K. C. Gupta, R. Garg, I. Bahl, and P. Bhartia, *Microstrip Lines and Slotlines*. Norwell, MA: Artech House, 1996.
[9] "High Frequency Structures Simulator (HFSS)," Agilant Co.