Design and On-Wafer Measurement of a W-Band Via-Less CPW RF Probe Pad to Microstrip Transition

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Abstract **— A very wide band via-less coplanar waveguide RF probe pad to microstrip transition is presented. The simulation with Agilent's Momentum (MOM) shows that a 3 dB bandwidth of 173% can be achieved from 10GHz to 110GHz with an average loss of 0.4dB, and 0.2dB at 70GHz. The fabrication was done on 100μm thick high resistivity silicon wafer, and two measurement methods were used to obtain the s-parameters of the transition. Measured results show that the insertion loss has an average value of 0.4dB from 40GHz to 100GHz, with the return loss better than 13dB.**

I. INTRODUCTION

As the demand for high density and high performance microwave and millimeter wave circuits increases, RF devices become smaller and more highly integrated. One of the most commonly used transmission lines in RF circuit design is the microstrip due to its compact size, ease of fabrication and low cost. However, not all the circuits or devices are fabricated with microstrip, thus their integration may involve different types of transmission lines. In order to achieve the highest possible integration, while maintaining each circuit's effective performance, transitions are needed to reduce the mismatch and coupling between different circuit elements. One important class of transition is the coplanar waveguide (CPW) to microstrip transition. Coplanar waveguide lines are widely used because of their ease of fabrication and the fact that all the conductors lie on the same layer or plane [1-6]. In [2,4] via-less transitions based on radial stubs and sections of coupled lines were developed with 3 dB bandwidth of 25%. These transitions typically require an extensive design process and are not compact for frequencies below 30 GHz. Transitions with via holes have also been developed [5-6].

The CPW RF probe pad to microstrip transition design rules were established in [1] by studying multiple transitions centered at 20GHz on a 400 μm high resistivity ($\rho > 5000\ \Omega$-cm) silicon substrate. This paper presents a via-less CPW to microstrip transition that demonstrates the effectiveness of these design rules at W-band along with a more robust measurement technique. As compared with [2-6], the transition is simpler, more compact and more broadband (covering from 20GHz to 100GHz).

The transition was designed and fabricated on a 100 μm high resistivity ($\rho > 5000\ \Omega$-cm) silicon substrate with a center frequency of 70 GHz. The Method of Moments (MoM) was used to both verify the experimental results and optimize the design.

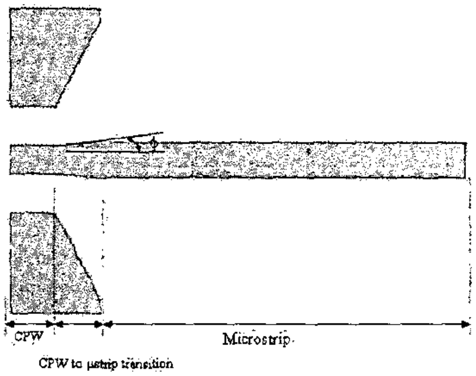

Figure 1 Top view of the CPW to microstrip transition structure requiring no vias (Bottom ground plane everywhere).

II. DESIGN AND FABRICATION

Figure 1 shows the schematic of the coplanar waveguide (CPW) to microstrip transition. The complete structure consists of a CPW section, a CPW-to-microstrip transition section, and a microstrip section. In the intermediate transition section, the width of the CPW signal strip is gradually increased to match the width of the microstrip. The " ϕ " in Figure 1 shows the angle between the CPW signal line and the microstrip line. At the same time, the gap between the ground planes and the signal line is widened to retain a 50 Ω characteristic impedance in order to match that of the microstrip line, and minimize reflections and parasitic effects.

The circuit is designed with a center frequency at 70 GHz and built on 100 μm thick high resistivity silicon substrate (εr = 11.7). The metallization layer is 3 μm of electro-plated gold that provides sufficient conductor thickness at both lower (X-band) and higher (W-band) frequencies. The back side of the wafer is metallized to provide the ground plane for the microstrip line.

The dimensions of the transition [1] are as follows: for the CPW section, the signal line width is 90 μm and the gap is 110 μm. These two values give the CPW line a 50 Ω impedance. The length of the CPW section and the transition section is 100 μm. The width of the transition is gradually changed from 90 μm (CPW line width) to 110 μm (microstrip line width), the corresponding angle of "ϕ" is 5.7^0. The fabricated circuit and wafer are shown in Figures 2 and 3.

Figure 2 SEM picture of two CPW to microstrip transition with back-to-back configuration.

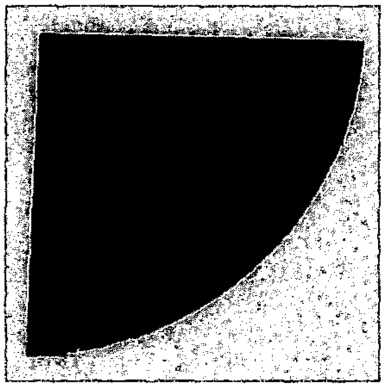

Figure 3 Picture of fabricated CPW to microstrip transition with TRL, conductor backed CPW and microstrip stub standards.

III. DEEMBEDDING AND MEASUREMENT

Two measurement methods were chosen to accurately determine the S-parameters of the transition: an unterminating technique similar to that in [7] and a two-tier deembedding technique using NIST's Multical Software [8]. For calibration purposes a CPW calibration and a microstrip calibration set were fabricated containing 6 delay lines to cover 20-110 GHz. Measurements were performed using an Agilent 8510XF and GGB 110H Picoprobes.

The procedure for the unterminating technique uses measurements made at the input of an unknown 2-port network (the embedding network, in this case the transition), with different 1-port load terminations (in this case microstrip stubs of differing length) at its output as shown in Figure 4.

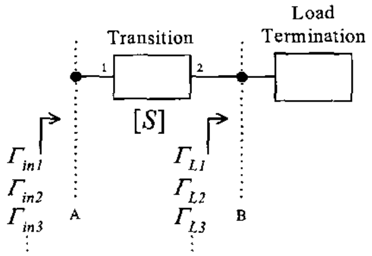

Figure 4 Measurement configuration for unterminating an on-wafer transition.

The known load terminations are connected at the output port (port 2) of the transition whose characteristics are desired. This connection point is labeled in Figure 4 as plane B, and is the plane at which the characteristics of the terminations are known, specifically their reflection coefficients Γ_L at each measurement frequency. The measured reflection coefficients at plane A, Γ_{in}, are related to the known reflection coefficients produced by the *i*th termination at plane B by the scattering matrix that defines the unknown passive transition network:

$$\Gamma_{in_i} = S_{11} + \frac{S_{12}S_{21}\Gamma_{L_i}}{1 - S_{22}\Gamma_{L_i}}.$$

This technique requires a minimum set of three measurement pairs to solve for S_{11}, S_{22}, and the product $S_{12}S_{21}$. However, to reduce measurement related errors, redundant terminations can be used in order to obtain an average over the solutions of the calculated S-parameters. If reciprocity can be assumed for the unknown network, then the transmission coefficients S_{21} and S_{12} are equal and can be obtained from the product $S_{12}S_{21}$. There is an ambiguity, however, on the sign of S_{21}, which can simply be resolved by making a delay measurement of the network.

For the unterminating technique six identical transitions were used with microstrip open stubs (load termination) of differing lengths attached to the end of the transition (see Figure 4). In order to ensure proper calibration NIST's Multical [8] was used, establishing the CPW reference plane at the probe tips (reference plane A, Figure 4) and the microstrip reference plane after the transition (reference plane B, see Figure 4) to characterize each microstrip stub. The six terminations (stubs) were characterized using the microstrip calibration. Subsequently the input reflection coefficient was measured for each transition and termination pair using the CPW calibration. Using all six measurement pairs, taken three at a time, twenty solutions for the S-parameters of the transition were obtained at each frequency. The S-parameters of the transition were then obtained by averaging over all of the measurements.

The two tier deembedding technique utilizes the same calibrations sets (CPW and microstrip) as in the unterminating technique. The result gives the S-parameters of the transition used in the microstrip calibration set. A comparison of the two techniques is shown in Figures 5 and 6.

The results show very good agreement between the techniques. As shown in Figures 5 and 6, the 1-port unterminating method is more prone to measurement and probing errors than is the two-port two-tier method. Additional measurements can increase the accuracy and reduce the residual error present in the results.

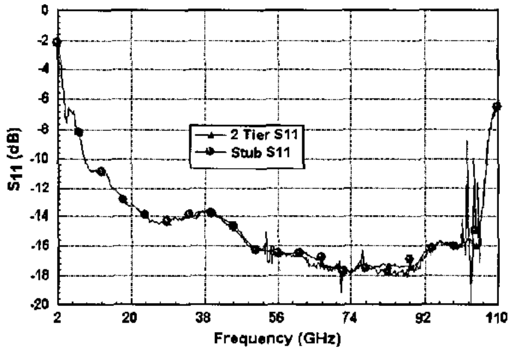

Figure 5. S11 comparison of the CPW to Microstrip transition using the 2 tier deembedding and unterminating technique

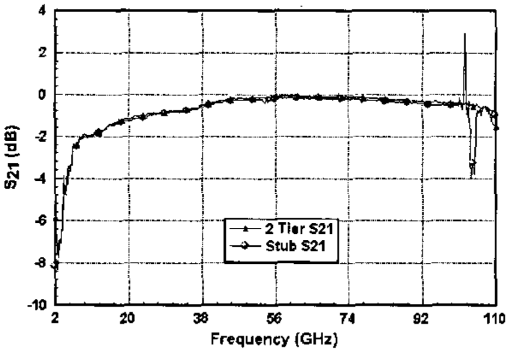

Figure 6. S21 comparison of the CPW to Microstrip transition using the 2 tier deembedding and unterminating technique

The measured results are compared with the simulated results (Agilent's Momentum) in Figure 7.

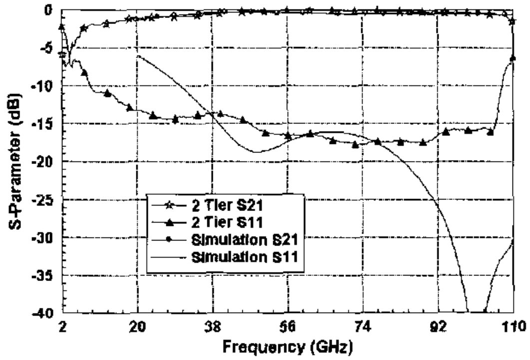

Figure 7. Measured and simulated results versus frequency.

Figure 7 shows that the measured and simulated insertion loss agrees very well from 20GHz to 100GHz, with an average loss is about 0.4dB, while from 50GHz to 80 GHz, the insertion loss is less than 0.2dB.

IV. CONCLUSION

In this paper, a wideband CPW to microstrip transition was presented for the W-Band frequency range. This transition does not require any connection (vias) between the CPW ground planes and the microstrip backside ground plane; therefore it simplifies the fabrication and lowers significantly the production cost. Two measurement methods showed that a loss of 0.4 dB is achieved from 40 GHz to 100GHz. To the authors' knowledge, this is the smallest reported loss with the widest 3 dB bandwidth (~173%) for such a compact and via-less transition. This transition can be used in a variety of RF/mm wave system design due to its broad bandwidth and low loss.

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REFERENCES

[1] G. Zheng, J. Papapolymerou and M. Tentzeris , "Wideband coplanar waveguide RF probe pad to microstrip transition without via holes" Submitted to *Microwave and Wireless Components Letters, Jan. 2003*

[2] G. Gauthier, L. P. Katehi, G. M. Rebeiz, "W-band finite ground coplanar waveguide (FGCPW) to microstrip line transition," *Proc. 1998 IEEE Symposium on Microwave Theory and Techniques*, pp. 107-109.

[3] G. Strauss, P. Ehret, W. Menzel, "On-wafer measurement of microstrip-based MMICs without via holes," *Proc. 1996 IEEE Symposium on Microwave Theory and Techniques*, pp. 1399-1402.

[4] D. F. Williams and T. H. Miers, "A coplanar probe to microstrip transition," *IEEE Trans. on Microwave Theory and Techniques*, vol. 36, no. 7, pp. 1219-1223, July 1988.

[5] A. M. E. Safwat, K. A. Zaki, W. Johnson, C.H. Lee, "Novel design for coplanar waveguide to microstrip transition," *Proc. 2001 IEEE Symposium on Microwave Theory and Techniques*, pp. 607-610.

[6] A. M. E. Safwat, K. A. Zaki, W. Johnson, C.H. Lee, "Novel transition between different configurations of planar transmission lines," *IEEE Microwave and Wireless Components Letters*, Vol. 12, No. 4, pp. 128-130.

[7] R. F. Bauer and P Penfield, Jr., "De-Embedding and Unterminating," IEEE Trans. Microwave Theory Tech., vol. MTT-22, pp. 282-288, Mar. 1974.

[8] R. Marks, "A multiline method of network analyzer calibration," IEEE Microwave Theory and Techniques, vol. 39, no. 7, pp. 1205-1215, July 1991.