# ANALYSIS AND DESIGN OF A VERTICAL CPW TRANSITION BETWEEN MICROSTRIP PLANES

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**Abstract**

Different types of vertical connections between microstrip lines on parallel planes have been investigated. A coplanar waveguide (CPW) is used as a vertical connection between the planes. A number of transitions between the horizontal and vertical parts of the connection as well as the influence of the solder are numerically investigated. The most promising transitions have been manufactured and measured with excellent results.

**Introduction**

The interest to use multi-layer structures for applications in microwave integrated circuits and active antenna arrays has grown significantly in the recent years. An important difference between the multi-layer assembling technique and previous design architectures is the need of interlayer connections. Various approaches for transitions between microstrip lines on separate layers have been introduced such as galvanic connections by via lines [1] and electromagnetic coupling through apertures in a common ground plane [2]. Furthermore transitions from conductor-backed CPW to stripline using three-wire lines have been studied [3].

In this contribution a new solution is proposed, where a coplanar waveguide is used to connect microstrip lines on separate planes. It can be used with advantage in those cases, where the distance between the microstrip planes is not negligible or where the microstrip layers do not have a common ground plane. The properties of the microstrip-CPW-microstrip (MS-CPW-MS) transition have been studied using electromagnetic simulation methods and the results have been verified by experiments.

**General aspects**

The microstrip technique is common in planar design. For microstrip technology used in multi-layer structures there is a problem of making vertical connections between the layers. The use of 90° microstrip to microstrip (MS-MS) transitions in layered structures has been reported, [4]. A major problem with this configuration is the connection between the ground planes of the microstrip lines. As shown in Fig. 1, the horizontal substrate has to pass through the vertical substrate to connect the ground planes.

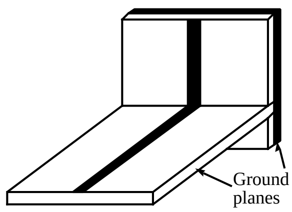


Fig. 1. 90° microstrip to microstrip transition.

The connection of the vertical microstrip in Fig. 1 to an upper horizontal microstrip plane is even more troublesome. A cut-out in the upper horizontal microstrip substrate, where the vertical microstrip can pass, has to be made. After the vertical microstrip has passed the horizontal plane it must be bent 180° to connect to the upper horizontal microstrip. This is shown in Fig. 2.

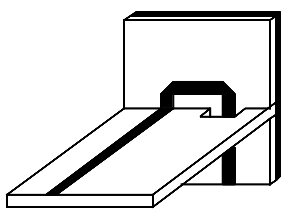

Fig. 2. Upper 90° microstrip to microstrip transition.

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The ground plane connection is easier to achieve if the ground plane and the conducting strip are on the same side of the vertical substrate. The coplanar waveguide is such a transmission line. It is therefore an interesting candidate to use as a vertical connection between microstrip planes. Fig. 3 shows the principle of the vertical MS-CPW-MS connection.

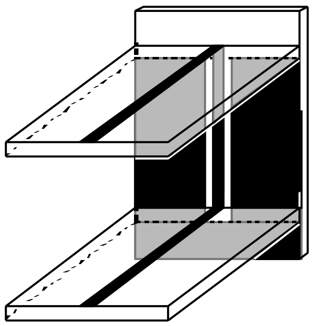

Fig. 3. Entire vertical connection, MS-CPW-MS.

This type of connection is easiest to apply at the edge of the structure. However, it is also possible to apply it inside the structure but the assembling can be troublesome.

## Simulations

The MS-CPW-MS connection has been simulated in Hewlett Packard's 3D simulator, HFSS. The connection was divided into one lower and one upper transition and these were simulated separately. The lower and upper transitions are shown in Figs. 4 and 5 respectively.

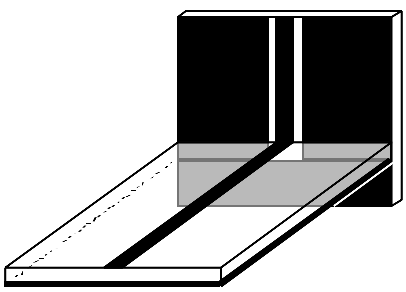

Fig. 4. The lower transition, microstrip to CPW.

The simulations were first performed at 9 GHz to find promising structures. For structures with good performance at that frequency the properties were then simulated over the frequency range of 2-16 GHz with 1 GHz step size.

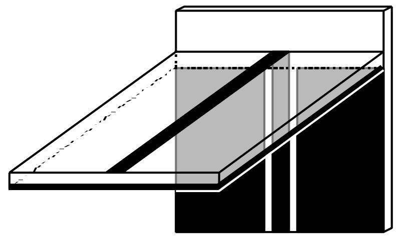

Fig. 5. The upper transition, CPW to microstrip.

In order to obtain dimensions suitable for etching, we decided to use the substrate RT/duroid 6006 with thickness 0.63 mm.

For the first simulations of the lower transition, the width of the strip was kept constant through the structure. The microstrip width was chosen to obtain 50 Ω characteristic impedance with the substrate above. For the CPW, with center strip width equal to the microstrip width, the slot was chosen to obtain 50 Ω characteristic impedance. This lower untapered transition, which was manufactured and measured, is shown in Fig. 6, where also the etched dimensions are shown.

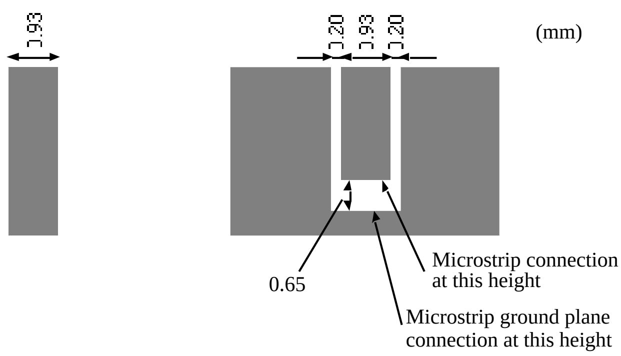


Fig. 6. The lower untapered transition. MS part to the left and CPW part to the right.

In order to improve the characteristics the lower transition was simulated with different tapers in the transition. Decreasing the width of the MS transmission line increases the inductance per unit length and compensates for additional capacitance in the transition. The tapers were, for simplicity, made geometrically linear. The lower tapered transition, which later on was manufactured, is shown in Fig. 7. Both MS and CPW tapers end at the same characteristic impedance, 60 Ω.

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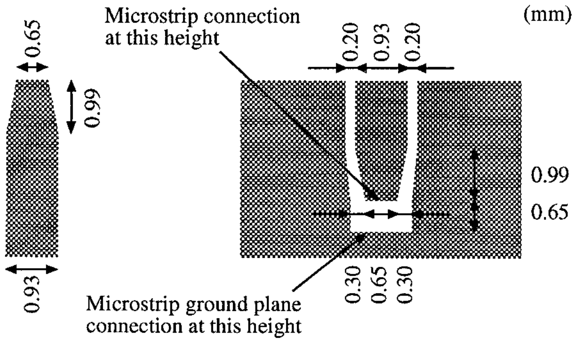


Fig. 7. The lower tapered transition. MS part to the left and CPW part to the right.

For the upper transition, a cut-out has to be made in the MS ground plane. Otherwise the CPW will be shorted. Different types of cut-outs were simulated. These were rectangular, circle arc and elliptical arc cut-outs. The rectangular cut-out showed the best characteristics among the simulated ones. The width of the cut-out was fixed, equal to the distance between the CPW ground planes, and the cut-out depth was varied to find good characteristics. The simulations also showed that it is important to end the CPW ground planes at a height corresponding to the upper MS ground plane. This is not critical for the lower transition. No taper that improved the upper transition characteristics at the center frequency was found. The manufactured upper transition is shown in Fig. 8.

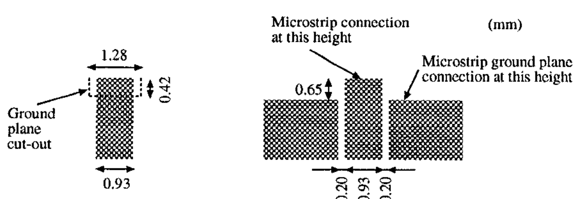


Fig. 8. The upper transition. MS part to the left and CPW part to the right.

## Measurements

The measurements were performed with an HP 8510C Vector Network Analyzer (VNA) in the frequency range 2-16 GHz. An 'Adapter Removal' calibration procedure, available on the HP 8510C, was used with TRL calibrations. This calibration procedure makes it possible to measure the 90° MS-CPW transitions separately.

To measure the entire MS-CPW-MS connection a MS TRL calibration was performed.

The DUT's were measured with 10 mm connecting transmission line on each side of the transition. The results from the measurements for the lower untapered and tapered transitions are shown in Figs. 9 and 10 respectively. Fig. 11 shows the results for the upper transition. After measuring the 90° MS-CPW transitions separately they were assembled to form the entire MS-CPW-MS connection, which was also measured. The results for the lower tapered transition assembled with the upper transition are shown in Fig. 12. The plots show the measured magnitude of $S_{11}$ (squares) and $S_{21}$ (triangles). The simulated reflection is plotted with solid lines. Simulated transmission is not plotted since losses and radiation were not included in the simulation.

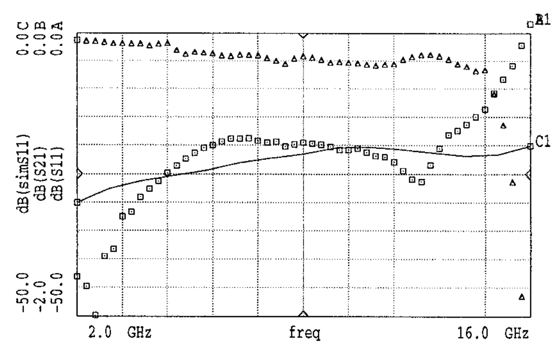


Fig. 9. Measured and simulated results for the lower untapered 90° MS-CPW transition.

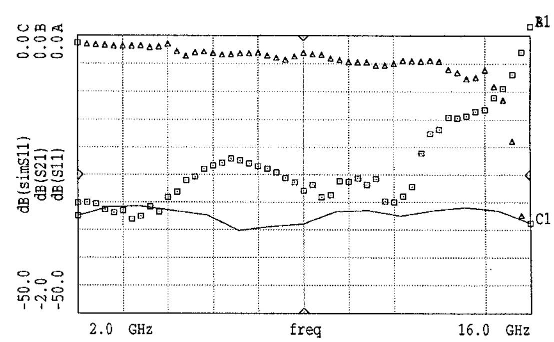


Fig. 10. Measured and simulated results for the lower tapered 90° MS-CPW transition.

The influence of the size of the solder ball at the lower transition is shown in Fig. 13. The solder ball was simulated as a cube cut across the diagonal.

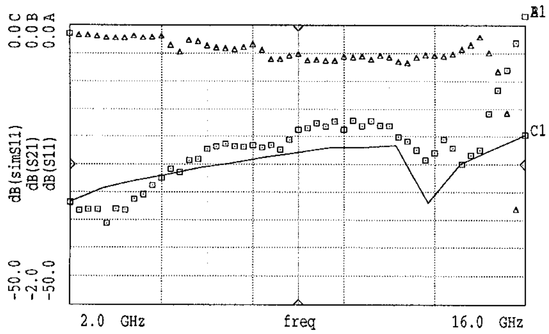


Fig. 11. Measured and simulated results for the upper 90° MS-CPW transition.

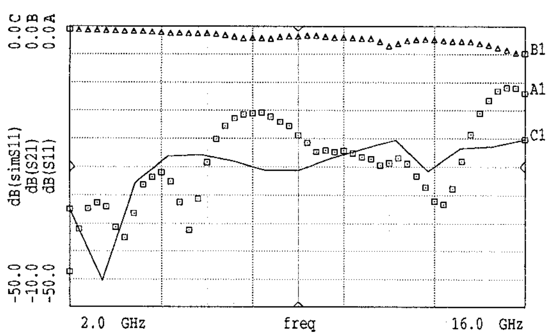


Fig. 12. Measured and simulated results for the entire MS-CPW-MS connection (lower tapered and upper transition together).

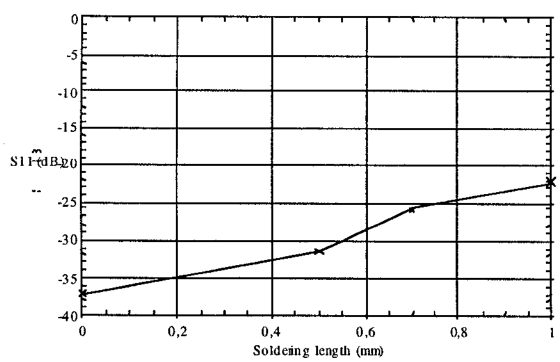


Fig. 13. The influence of the size of the solder ball on the lower transtion.

## Results and conclusions

The measurements show that the MS-CPW-MS connection has good characteristics and is very useful in the design of layered structures.

Of the two lower transitions, the tapered transition was found to be the better one. For the lower tapered transition the measured reflection was -28 dB at the center frequency, 9 GHz, and -15 dB at 14 GHz. In the frequency range 2-14 GHz the measured reflection was lower than -15 dB and the transmission loss lower than 0.2 dB. The taper improves the lower transition.

For the upper transition the measured reflection was -19 dB at the center frequency and -22 dB at 14 GHz. In the frequency range 2-14 GHz the measured reflection was lower than -17 dB and the transmission loss lower than 0.3 dB. The MS ground plane cut-out is important for the characteristics of the upper transition. It is also important to end the CPW ground planes at a height corresponding to the upper MS ground plane.

For the entire MS-CPW-MS connection the measured reflection was -19 dB at the center frequency and - 25 dB at 14 GHz. In the frequency range 2-14 GHz the measured reflection was lower than -15 dB and the transmission loss lower than 1.0 dB.

## Acknowledgment

The authors would like to thank the Defence Research Establishment (FOA) in Linköping, Sweden and NUTEK's program for Smart Skin Antennas for financial support.
We thank the staff in the machine shop for etching the circuits and machining the fixtures.

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