OPTIMIZATION OF MM-WAVE DISTRIBUTION NETWORKS USING SILICON-BASED CPW

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ABSTRACT

This paper describes work relating to the optimization of silicon-based, coplanar waveguide (CPW) air-bridge and bend discontinuities. Experimental results shown here verify that the return loss is improved by introducing a step-compensation into the CPW center conductor. The technique is demonstrated in the design of an asymmetric coplanar-strip Wilkinson power divider at 45 GHz.

INTRODUCTION

Coplanar waveguide (CPW) is a uniplanar transmission line technology that provides excellent performance at mm-wave frequencies. However, circuit configurations such as power distribution networks are comprised of multiple bends, impedance steps and Tee-junctions, which require some form of compensation to mitigate the associated parasitic effects. This work addresses the use of a step-taper in the CPW center conductor to improve the response of air-bridge and right-angle bend discontinuities. The step-compensation method is also demonstrated in the design of an asymmetric coplanar strip (ACPS) Wilkinson power divider that is fed by CPW lines.

The experimental results presented in this paper were obtained from on-wafer measurements using a Wiltron 360B vector network analyzer. Instrument calibration was performed using the NIST Multical software [1]. All circuits were fabricated on a high-resistivity ($>$ 2000 Ω-cm) silicon wafer, and the gold traces were electro-plated to a thickness of 2.5 μm.

AIR-BRIDGES AND 90° BENDS

An air-bridge in coplanar waveguide introduces a shunt capacitance due to the parallel-plate structure formed by the CPW center conductor and the air-bridge span. For the line geometries studied in [2], the value of this capacitance was determined to be around 1.5 times the value found from the simple, parallel-plate approximation. Based on the numerical and experimental modeling done in relation to this work, the scaling factor is dependent upon the aspect ratio of the CPW line beneath the span. Scaling factors between 1.5 and 3 have been observed for aspect ratios between 0.45 and 0.15, respectively.

The required compensation for the air-bridge capacitance can be realized by reducing the width of the CPW line beneath the air-bridge (Figure 1). In [3], this technique was considered from the viewpoint of increasing the effective characteristic impedance of the line, in order to offset the decrease in Z_o affected by the air-bridge. A limitation of this perspective is that a localized narrowing of the center conductor may not provide enough compensation. An alternative approach taken here is to treat the air-bridge as a lumped capacitance, and then apply a transmission line model to derive the required length of high-Z_o line on either side of the air-bridge to achieve an impedance match in the desired frequency band. The resulting equation for the electrical line length on each side of the air-bridge (at the center frequency, ω_o) is as follows:

$$\theta = \frac{Z_o^2\, Z_h\, \omega_o C_{ab}}{2\,(Z_h^2 - Z_o^2)} \quad (1)$$

where Z_o is the nominal CPW impedance, Z_h is the impedance in the high-Z section, and C_{ab} is the air-bridge capacitance. A comparison of the measured return loss from a single air-bridge, with and without the step compensation, is shown in Figure 2. While the low frequency response is worsened by the taper length, the performance in the band of interest around 45 GHz improves by approximately 20 dB.

One way in which air-bridges are frequently used is to suppress the excitation of the coupled slot-line mode in laterally asymmetric geometries such as a right-angle bend. Without proper compensation, the combined discontinuities of the bend and the air-bridges can lead to poor return loss performance. One approach for chamfering a 90° bend was recently reported in [4]. This is referred to here as the triangular taper, as illustrated in Figure 3. Using a similar transmission line model as described above, a second technique utilizing step compensation is derived (right-hand side of Figure 3). A comparison between these two methods is shown in Figure 4, along with the response of a non-compensated bend. These data come from measurements of a single bend, which has the second port terminated in a matched load. The targeted center frequency around 45 GHz was not obtained for the step-design, however an improvement of approximately 10 dB was achieved near 55 GHz.

WILKINSON POWER DIVIDERS

The underlying objective of this research is to develop high-performance distribution networks at W-band, and the geometry selected for power division and combination was the Wilkinson coupler. Previous authors have reported on 110 GHz Wilkinson designs using a coplanar waveguide approach [5, 6]. In this work, CPW and asymmetric coplanar strip (ACPS) [7] geometries are being pursued in parallel, since the characteristic impedances obtainable with silicon-ACPS provide greater versatility in the distribution network layout.

As a preliminary step toward the W-band network, several 45 GHz Wilkinson couplers were developed to examine the effects of the step compensation approach. A typical ACPS design is illustrated in Figure 5. The measured S-parameters for a single coupler with no compensation are shown in Figure 6. The insertion loss is approximately 3.4 dB, however the minima in S_{11}[1] and S_{22} are displaced by 20 GHz; this can be ascribed to excess capacitance at the input and output ports, as verified with circuit-level modeling. The results given in Figure 7 pertain to a single coupler which incorporates the step compensation at all air-bridges. The return loss at each port noticeably improves, with no degradation in the insertion loss.

SUMMARY

This paper has described a step-compensation technique for improving the mm-wave performance of coplanar waveguide discontinuities such as air-bridges and bends. The approach was also demonstrated in the design of a silicon-based, 45 GHz ACPS Wilkinson power divider. Additional results for bend and Tee-junction geometries will be presented at the symposium, along with data on CPW and ACPS Wilkinson dividers at 45 and 90 GHz.

ACKNOWLEDGEMENTS

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References

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[1]For the Wilkinson coupler results, port 1 is the input port in the *divider* configuration.

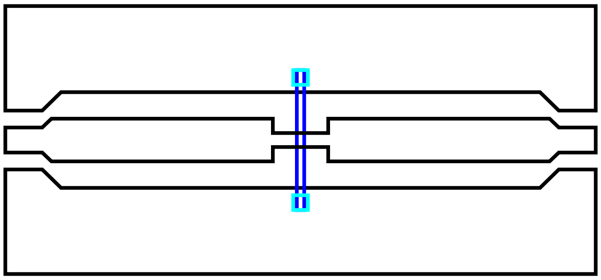

Figure 1: Illustration of CPW air-bridge (30 μm wide by 2.5 μm high) using step compensation. The center conductor width (S) is reduced from 58 to 20 μm in the tapered section, and the step length is 150 μm. The slot width (W) in the feedlines is 36 μm.

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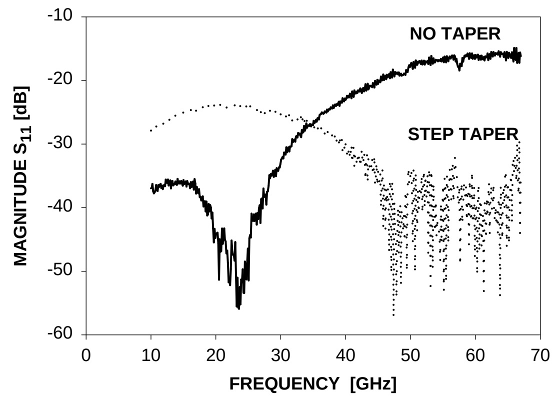

Figure 2: Measured return loss for an air-bridge across a CPW transmission line, with and without step compensation (see Figure 1).

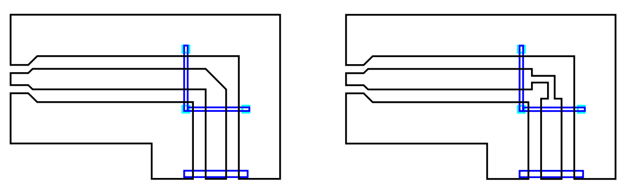

Figure 3: Illustration of CPW right-angle bends using a triangular taper after [4] (left) and a step-compensation taper (right).

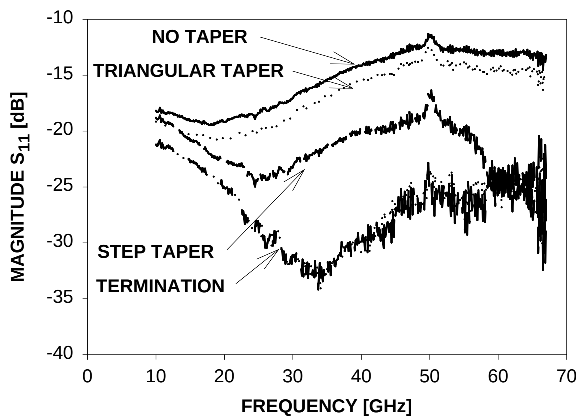

Figure 4: Measured return loss for CPW right-angle bends without tapering, using the triangular taper, and using the step taper. The air-bridge and CPW dimensions are the same as those given in Figure 1. The return loss for the output port termination is also shown.

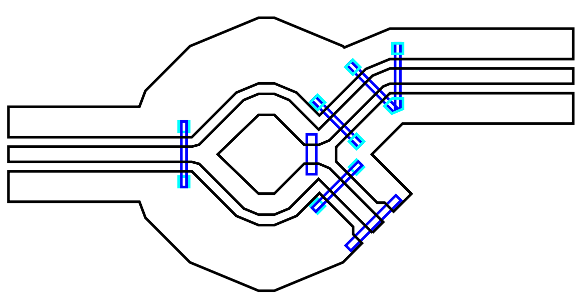

Figure 5: Illustration of an ACPS Wilkinson power divider, with CPW feedlines.

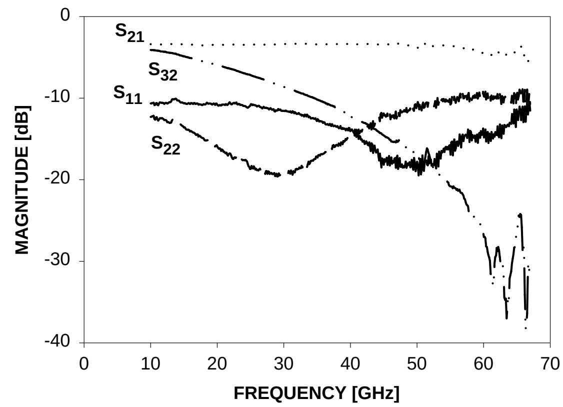

Figure 6: Measured S-parameters for a single ACPS Wilkinson power divider, using no air-bridge compensation.

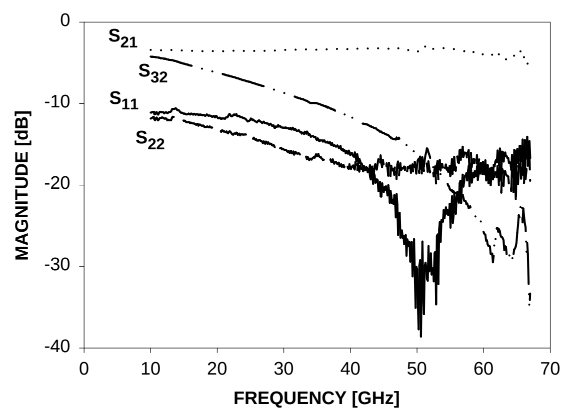

Figure 7: Measured S-parameters for a single ACPS Wilkinson power divider, using the step-compensation approach at each air-bridge.