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DEVELOPMENT OF FINITE GROUND COPLANAR (FGC) WAVEGUIDE 90 DEGREE CROSSOVER JUNCTIONS WITH LOW COUPLING

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ABSTRACT

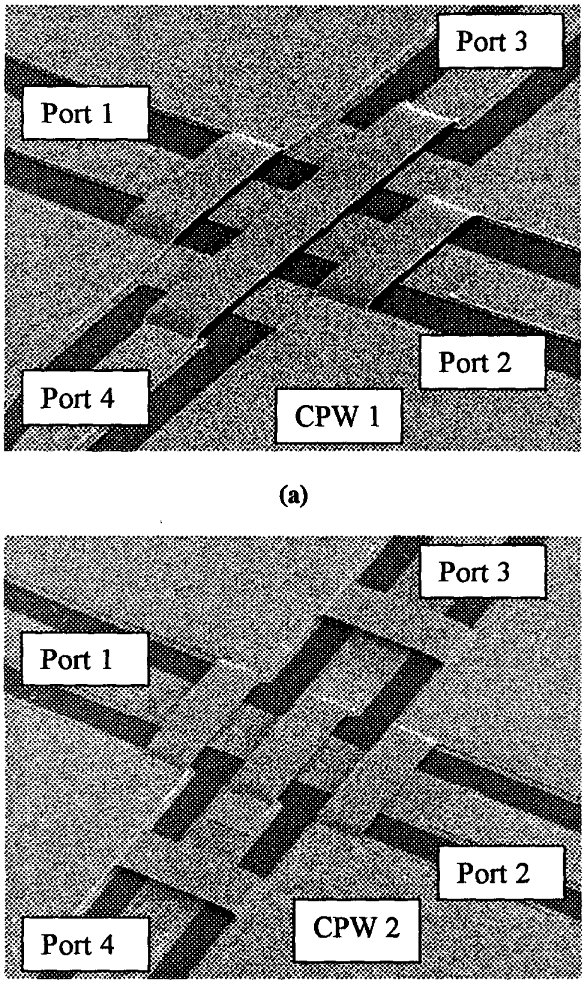
Microwave and millimeter-wave integrated circuits and RF distribution networks often require two transmission lines to cross over each other. In this paper, experimental measurements and 3D-Finite Difference Time Domain (FDTD) analysis are used to characterize Coplanar Waveguide (CPW) and Finite Ground Coplanar (FGC) waveguide crossover junctions for the first time. It is shown that FGC crossover junctions have approximately 15 dB lower coupling than CPW crossover junctions with no degradation in return and insertion loss.

INTRODUCTION

Monolithic Microwave and Millimeter-Wave Integrated Circuits (MMICs), microwave MultiChip Modules (MCMs), and antenna distribution networks often require two transmission lines to cross over each other. For microstrip transmission line based circuits, these crossover junctions are straight forward and only require an airbridge, but circuit designers often prefer coplanar waveguide (CPW) transmission lines because it is a planar transmission line, which enables easy series and shunt element connections without metal filled via holes [1]. This simplifies the fabrication process, eliminates backside processing, and lowers fabrication cost by approximately 30 percent. Recently, an improved version of CPW has been developed called Finite Ground Coplanar (FGC) waveguide. FGC has electrically narrow ground planes, which have been shown to reduce parasitic resonances caused by parallel plate modes, enable novel uses of the ground planes to integrate lumped elements, reduce circuit size, and reduce coupling between parallel transmission lines [2-5]. However, CPW and FGC crossover junctions have not been characterized. In this paper, experimental measurements and a Three Dimensional-Finite Difference Time Domain (3D-FDTD) analysis are used to characterize CPW and FGC crossover junctions to determine the scattering parameters of the 4-port junction.

CIRCUIT DESCRIPTION

Both CPW and FGC crossover junctions require the center strip of one line to cross over the second line; however, the ground plane connections are different. For CPW discontinuities, it is known that the ground planes must be tied together by airbridges at each discontinuity to short out the parasitic slotline mode that is easily excited. Furthermore, since the ground planes are very wide, it is impossible to fabricate an airbridge that would enable the ground planes of one CPW line to completely cross over the second CPW line as the center strip does. Thus, at the CPW crossover junction, the two lines necessarily share their ground planes. There are two CPW crossover junction layouts. The first is shown in Figure 1a, CPW1, and it uses underpasses to connect two of the four ground planes. Because the center strips are now further apart, the airbridge connecting them is long as seen in Figure 1a. The second layout, CPW2, is shown in Figure 1b. It uses airbridges to connect all of the ground planes together.



(a)

(b)

Figure 1: SEM micrograph of Coplanar Waveguide (CPW) crossover junction. (a) CPW 1 has ground planes connected by underpasses and (b) CPW 2 has all ground planes connected by airbridges.

On the other hand, the ground planes of FGC are both electrically and physically narrow, which enables airbridges to be used for the ground planes as well as the center strip as shown in Figure 2. Therefore, FGC lines may cross over each other without sharing any metal structures between them.

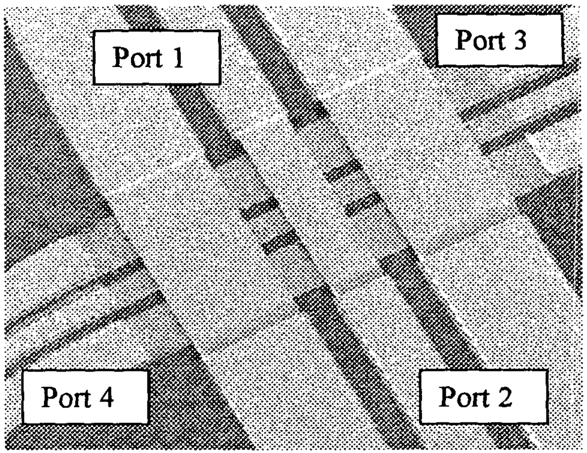


Figure 2:' SEM micrograph of Finite Ground Coplanar Waveguide crossover junction. Both lines have the same dimensions.

EXPERIMENTAL PROCEDURE

Circuits are fabricated on Si wafers with a resistivity of 2500 Ω-cm, ε_r=11.7, and a thickness of 410 μm. Prior to fabrication, the wafer is thoroughly cleaned, including an HF acid dip to remove the native oxide. The first level metal is defined by a liftoff process and consists of 0.02 μm of Ti and 0.6 μm of Au. A 1.0 μm Au plating process is then used to build the center strip, the ground planes, and the airbridges, which results in the center conductors and ground planes having a total thickness of 1.6 μm and the airbridges having a total Au thickness of 1.0 μm. The airbridge height above the substrate is approximately 3 μm. No insulators, SiO_2 or Si_3N_4, are grown on the wafers either before or after metallization for passivation.

The CPW lines have a center strip width, S, and slot width, W, of 30 and 22 μm respectively. The CPW ground plane is 150 μm wide, which, at five times the center strip width, is equivalent to an infinite width ground plane [2]. S and W of the FGC lines are 32 and

19 μm respectively, and the ground plane width is 64 μm. These lines are designed to have similar S+2W and a nominal characteristic impedance of 50 Ω so that their characteristics can be compared. Besides the airbridges at the crossover junction, an airbridge is located immediately after the probe pads to short the parasitic slotline mode that is often excited at CPW junctions.

A Thru-Reflect-Line (TRL) calibration is implemented through the MULTICAL software [6] routine, with the calibration standards fabricated on the same wafer as the test circuits. Thus, the reference plane is accurately placed at the crossover junction. To measure the 4-port scattering parameters, a HP vector network analyzer, GGB Industries picoprobes, and a quartz wafer between the Si wafer and the metal wafer chuck is used. Since the network analyzer only measures two port circuits, two of the four ports are terminated by specially designed GGB picoprobes with built in 50 Ω terminations.

THEORETICAL MODELING (FDTD)

Theoretical characterization of the coupling between the lines at the crossover junctions is obtained through the FDTD method [2,7]. It is implemented with: interleaved positioning of the electric and magnetic field components to provide a second-order accuracy of the algorithm; grids of 54 by 200 by 80 cells terminated with 4 Perfectly Matched Layers (PML) cells in each direction provide accurate results for a time-step $\Delta t = 0.9\Delta t_{max}$; and the superposition of the excitation on the FDTD calculated field value of all cells of the excitation region for each time-step guarantees the elimination of spurious retroreflective effects (total field formulation). A Gaussian pulse with $f_{max} = 40$ GHz and odd horizontal spatial distribution is used to excite only the CPW mode in the circuit; however, the CPW mode and all parasitic modes that are generated by the junctions are modeled. To achieve a faster convergence (less than 15,000 time-steps) the Gaussian pulse is multiplied by a correction spatial factor that accounts for the edge effects of the ground and signal conductors. Two probes placed symmetrically on either side of the center conductor in the slot regions are used for the decomposition of the field into CPW and slotline modes. Finally, the frequency-domain results are derived from the time-domain values through the application of FFT algorithm.

RESULTS

The measured and calculated coupling, $|S_{14}|$, between CPW and FGC lines that cross over each other is shown in Figure 3. First, it is seen that the measured and calculated coupling for each line is in good agreement, which indicates a high level of accuracy in the characterization methods. More importantly, Figure 3 shows that the FGC crossover junction has lower coupling than either CPW crossover junction does across the entire frequency band, and the reduction in coupling is approximately 15 dB.

Besides lower coupling, FGC crossover junctions have lower insertion loss as shown in Figure 4. It must be noted that while the measured results include conductor, dielectric, and radiation loss, the FDTD analysis only includes radiation loss. Therefore, since the measured and theoretical insertion loss agrees so well, we can assume that radiation loss dominates. The return loss for the crossover junctions is shown in Figure 5. $|S_{11}|$ of the CPW crossover junction increases from approximately -40 dB at 2 GHz to -18 dB at 40 GHz, while the return loss for the FGC crossover junction increases from -35 dB at 2 GHz to -12 dB at 40 GHz.

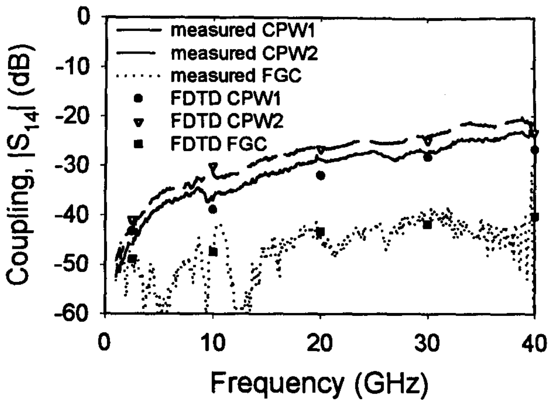


Figure 3: Measured and calculated coupling between CPW and FGC crossover junctions.

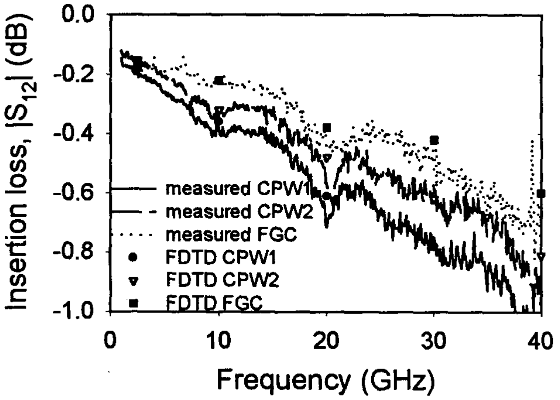


Figure 4: Measured and calculated insertion loss of CPW and FGC crossover junctions.

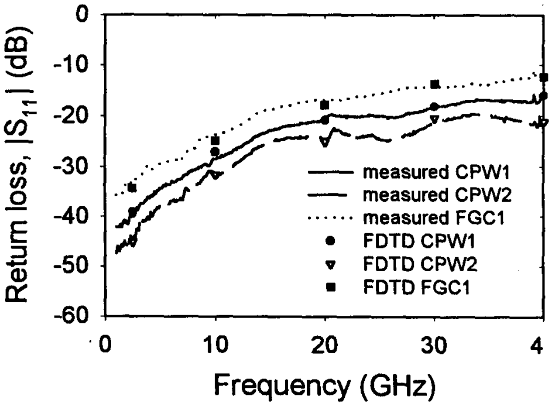


Figure 5: Measured and calculated return loss for CPW and FGC crossover junctions.

CONCLUSIONS

CPW and FGC crossover junctions are analyzed through experimental measurements and 3D-FDTD method for the first time. The measured and theoretical results are in good agreement and both show that FGC crossover junctions are superior with 15 dB lower coupling, lower insertion loss, and acceptable return loss of less than 15 dB through 40 GHz.

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