Comparison of Air Coplanar Microprobes for On-Wafer Measurements at W-band

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Abstract

We apply the on-wafer thru-reflect-line (TRL) [1] and thru-reflect-match [2] calibrations and measurements to evaluate and compare the performance of waveguide and coax fed microprobes at W-band. The results compare the repeatability, isolation, and performance of these probes.

Introduction

As commercial MMIC applications are moving into the millimeter-wave range, accurate on-wafer characterization becomes more critical for design and evaluation. In this paper, we investigate the performance of WR-10 waveguide and 1-mm connector input air coplanar microprobe technology. We demonstrate that TRL calibrations measure the standard quasi-TEM CPW mode and surface waves do not effect calibrations and measurements for both types of probes [3, 4]. We examine the measurement repeatability and compare with the worst case differences determined using the concept of two-tier calibration [5, 6]. We also study isolation as a function of probe tip separations.

Measurement Set-up

The measurement system is a vector network analyzer HP85109C whose W-band test-set has WR-10 waveguide output. WR-10 to 1-mm coaxial connector adapters are used to establish connections from the test-set to 1-mm coax fed probes. WR-10 input probes are connected directly to the W-band module using straight sections of WR-10 waveguides. Both probe configurations transition from air coplanar tips to a DUT. The 1-mm connector input probe consists of air coplanar tips attached to a 1-mm cable which is connected directly to a 1-mm female connector. The WR-10 input probe has an absorber between the waveguide input and the 1-mm cable where the probe tips are attached.

Calibration

Two-tier TRL calibrations [6] are performed on a W-band impedance standard substrate (ISS) for two types of probes, the 1-mm connector and WR-10 input probes respectively. The two CPW transmission lines used in the calibration are 89 μm wide center conductor separated from 270 μm wide ground planes by 26 μm gaps. The lengths of the two CPW lines are 200 μm and 448 μm. The ISS substrate is 635 μm thick and has a relative dielectric constant of 9.9. The quasi-static effective dielectric value ($\varepsilon_r + 1/2$ = 5.45) for the CPW mode corresponds closely to the effective dielectric constant measured by TRL calibration , see Figure 1. Two-tier calibrations also determine the characteristic impedance [7] of the CPW lines. Figure 2 shows that there is good correlation between measured and designed 50-ohm characteristic impedance of the CPW lines. The experimental data demonstrates that the TRL calibrations measure the quasi-TEM CPW mode for both types of probes. These results indicate

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that surface waves have not significantly impacted the calibrations. In addition, ε_{eff} and Z_o measured by both probe configurations are well correlated.

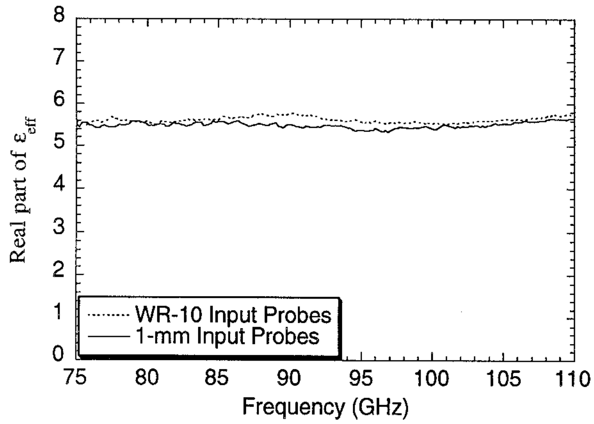

Figure 1. The real part of ε_{eff} measured by the multiline TRL calibration on W-band ISS substrate from Cascade Microtech

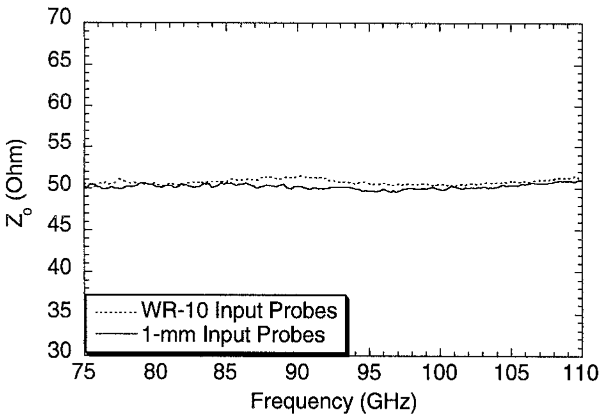

Figure 2. The real part of characteristic impedance measured by multiline TRL calibration

Repeatability

The repeatability tests are performed on two CPW transmission lines at two different days using TRL and LRM calibrations with both types of probes. The bound |Sij - S'ij| for ij ∈{11, 12, 21, 22} is the largest differences or worst case errors in measured S-parameters. This quantification is determined using two-tier calibrations. Using one calibration as the reference, the measurement of the standards for the other calibration is then calibrated. Residual error terms are computed from the calibrated standard measurements. Due to drift and random errors, the resulting error terms are used to quantify a worst case vector error in the S-parameters. Figures 3 and 4 show the differences in magnitude of two sets of measured S-parameters for 900 μm and 1800 μm long CPW lines using TRL calibration for the 1-mm connector input probes. In comparison, figures 5 and 6 show the repeatability of the WR-10 input probes. The maximum bounds in S-parameters for the WR-10 probes are superior than that of 1-mm connector input probes. However, the actual measured differences by both types of probes are similar and do not exceed the bounds. The actual differences are determined by subtracting two sets of measured S-parameters of the same DUT. Figures 7, 8, 9 , and 10 show similar experiments for LRM calibrations. The bounds |Sij - S'ij| determined by LRM calibrations are well correlated with the TRL case for both types of probes. In all cases, the actual measured differences do not exceed the maximum bounds. Both types of probes are highly repeatable for measurements at W-band. The differences measured by the 1-mm input probes can be attributed to the repeatability of the 1-mm coaxial cables.

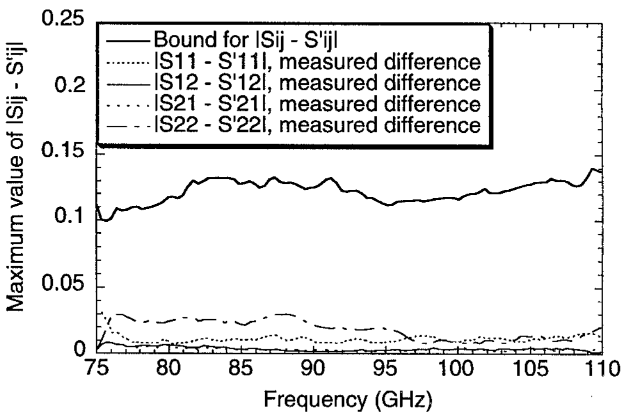

Figure 3. Worst case measurement differences of a 900 μm CPW line at two different times using TRL calibrations with 1-mm connector input probes

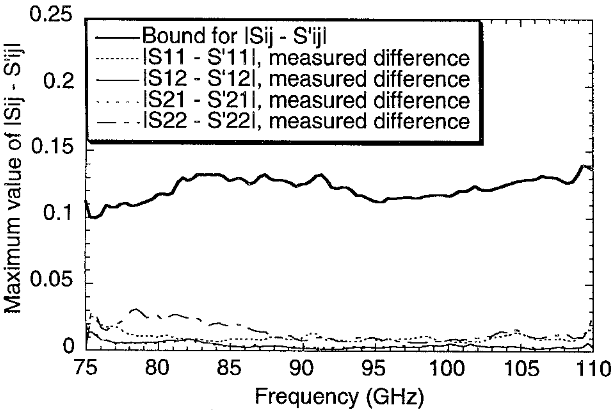

Figure 4. Worst case measurement differences of a 1800 μm CPW line at two different times using TRL calibrations with 1-mm connector input probes

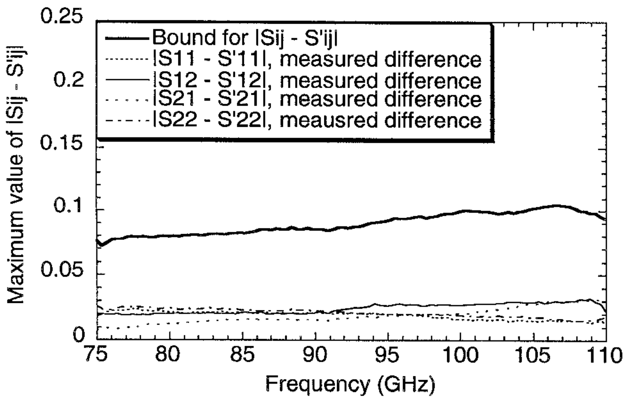

Figure 5. Worst case measurement differences of a 900 μm CPW line at two different times using TRL calibrations with WR-10 waveguide input probes

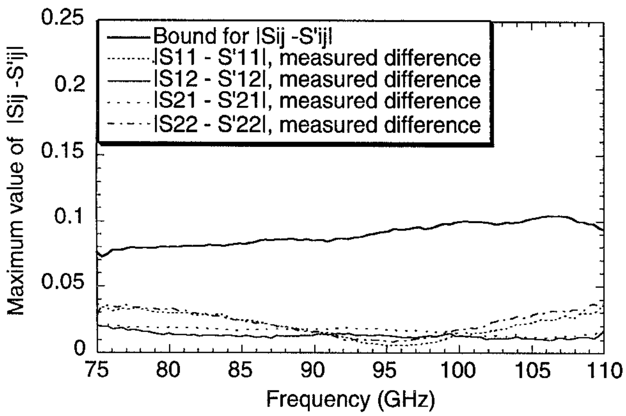

Figure 6. Worst case measurement differences of a 1800 μm CPW line at two different times using TRL calibrations with WR-10 input probes

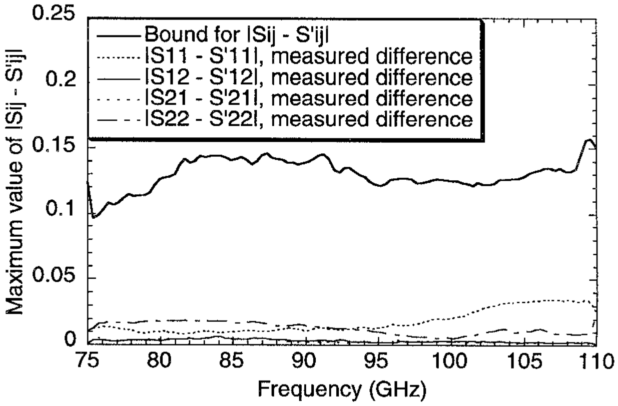

Figure 7. Worst case measurement differences of a 900μm CPW line at two different times using LRM calibrations with 1-mm connector input probes

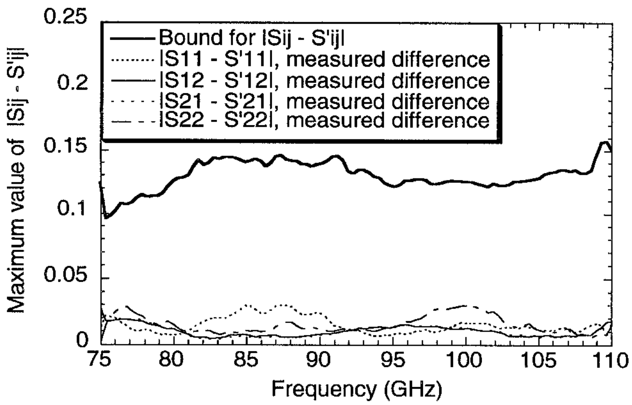

Figure 9. Worst case measurement differences of a 1800 μm CPW line at two different times using LRM calibrations with 1-mm connector input probes

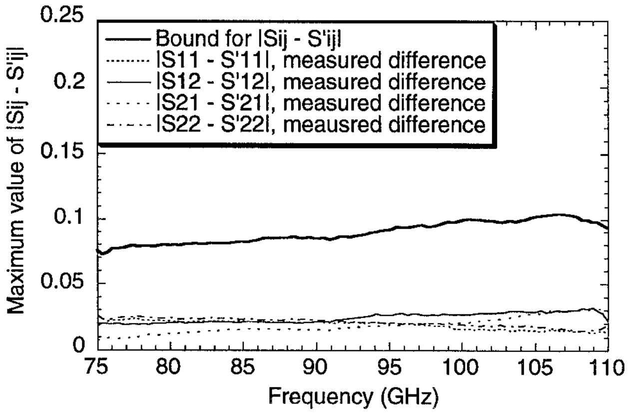

Figure 9. Worst case measurement differences of a 1800 μm CPW line at two different times using LRM calibrations with WR-10 input probes

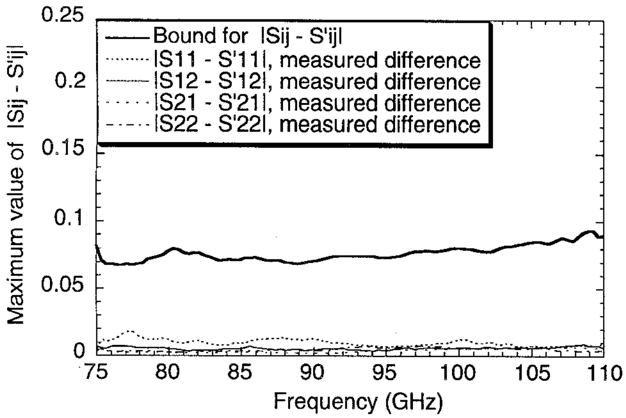

Figure 10. Worst case measurement differences of a 1800 μm CPW line at two different times using LRM calibrations with WR-10 waveguide input probes

An isolation study is conducted to examine the coupling between the probe tips as a function of separation distance. Two on-wafer 50-ohm resistors separated by 100 μm and 6 mm are measured with the two types of probes. For the separation of 100 μm, the isolation is in the range of 35dB for both probes. For 6mm separation, the isolation, for both types of probes exceeds 50 dB. Both types of probes have excellent isolation and are suitable for measurements of small devices at W-band.

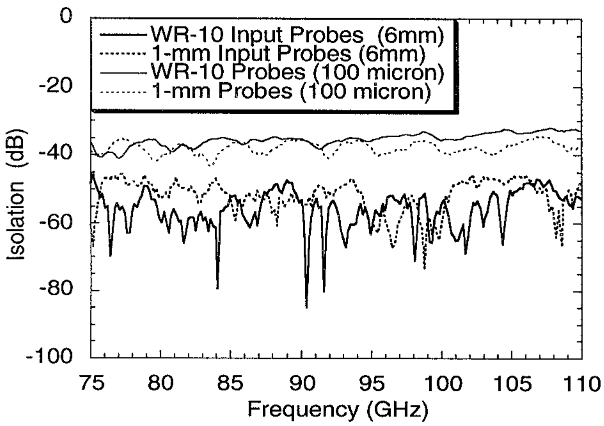

Figure 11. Isolations of both probes as a function of separation distance

Conclusion

We carry out detailed experiments to study the performance of two types of air coplanar waveguide probes at W-band. These calibrations demonstrate that the surface wave modes have negligible effects at W-band. We demonstrate a high degree of repeatability for both probe configurations. Finally, we demonstrate that both probe configurations provide ample isolation at W-band.

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