# Calibration and Measurement Characteristics of Differential Broadband Single-Sweep 70 kHz-220 GHz System

## WHY THIS WORK MATTERS

The need for broadband, traceable S-parameter measurements in differential and multiport device contexts is rapidly growing, especially as mmWave ICs bandwidth push beyond 110 GHz into the D-band and G-band ranges. While two-port calibration workflows are relatively well established, few measurement systems exist today that can reliably provide true differential, wafer-level characterization beyond 110 GHz, particularly with single-sweep capability.

This technical brief discusses the method and results recently published in [1]. This work introduced a differential wafer-level measurement system that combines the Anritsu ME7838G4 4-port broadband vector network analyzer, a manual TS200 probe station from MPI Corporation, and TITAN™ Dual T220MS-GSGSG probes together with a dedicated calibration substrate, also from MPI Corporation. The system enables continuous single-sweep measurements from 70 kHz to 220 GHz and supports both single-ended and true differential characterization without the need for baluns, de-embedding structures, or segmented frequency coverage. Beyond presenting the hardware platform, this work proposed a practical method for assessing calibration and measurement accuracy in differential broadband systems. Using a manual probe station, it delivers quantified results for measurement repeatability and calibration uncertainty across the full frequency range. These results serve as a reference for evaluating system performance and can support inter-laboratory comparisons, instrument benchmarking, and long-term monitoring of system stability in advanced mmWave measurement environments.

  

## TECHNICAL SUMMARY

The measurement system presented in work[1] enables broadband 4-port differential on-wafer measurements from 70 kHz to 220 GHz in a single sweep. It integrates the Anritsu ME7838G4 vector network analyzer with four remote heads, a manual TS200 probe station, and TITAN™ Dual T220MS-GSGSG probes with MEMS-based RF tips (Fig. 1). The differential probes are directly mounted to the VNA heads. The TITAN™ Dual Probes feature a GSGSG coplanar tip structure fabricated using high-precision MEMS technology. The probe tip geometry is optimized not only for efficient signal transition to the device contact pads but also for precise visual alignment and highly repeatable contact. The aforementioned TITAN™ Dual Probe design characteristics are essential for achieving calibration and measurement repeatability and reproducibility at mmWave frequencies.

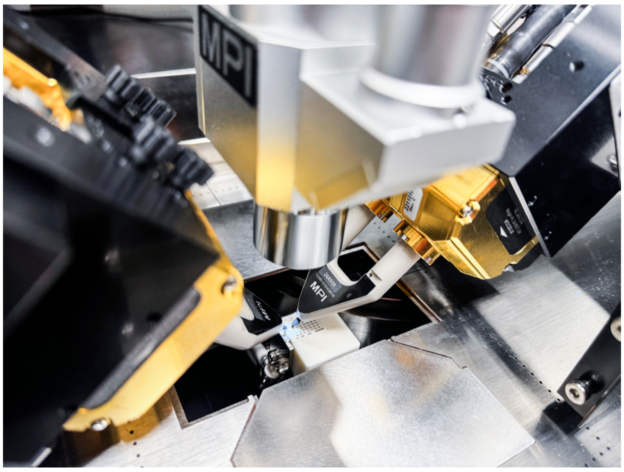

Fig.1: TITAN™ Dual T220MS-GSGSG0050 Probes measuring calibration standards on the dedicated TCS-GSGSG-0050-0050 Calibration Substrate.

Calibration was performed using a differential TCS-GSGSG-0050-0050 calibration substrate from MPI Corporation, which includes broadband short, open, load, straight, and loopback thru standards, as well as multiple transmission line elements[2]. The differential calibration structures incorporate pair-terminated standards, a pioneering approach that minimizes parasitic coupling between adjacent elements and significantly enhances calibration accuracy at mmWave frequencies[3].

A 4-port LRM calibration method was applied, requiring only four thru connections, and was executed manually across multiple calibration cycles. System performance was evaluated by analyzing standard deviation and reproducibility metrics across a variety of S-parameter combinations, including both single-ended and mixed-mode representations.

Because a complete, traceable calibration framework for differential wafer-level measurements is not yet established, engineers and metrology professionals require practical references to estimate typical calibration and measurement uncertainties. Such references are particularly important for validating system performance, supporting data quality control, and enabling meaningful comparisons across different setups. In the absence of conventional uncertainty estimation and propagation models, quantified repeatability and reproducibility results can serve as a benchmark for data reproducibility, inter-laboratory comparisons and long-term system monitoring.

To address this need, we applied a statistical method to evaluate the system's reproducibility based on repeated measurements and calibration cycles. Confidence intervals were calculated from the standard deviation of repeated S-parameter measurements. The evaluation followed a model in which the reproducibility limit R is defined as the confidence interval between independent measurements at the 95% confidence level. It is computed using the relation:

$$R(S_{i,j})=1.96 * \sqrt{2} * s(S_{i,j})$$

where $s(S_{i,j})$ is the standard deviation of the S-parameter $S_{i,j}$. This approach enables a rigorous assessment of calibration performance across the full 4×4 S-matrix and is applicable to both single-ended and differential representations.

The results demonstrate that differential measurements exhibit repeatability characteristics comparable to single-ended systems, with confidence intervals remaining bounded across the full frequency range. In some cases, differential parameters showed lower variability due to possible correlated error propagation.

## TYPICAL APPLICATION SCENARIO

In this work, we evaluated calibration and measurement reproducibility under typical laboratory conditions, using a manual probe system operated by an engineer with average skill level. The results provide a realistic estimate of measurement performance that can be expected in standard laboratory environments. Laboratories equipped with automated probe systems, motorized positioners, or advanced environmental control are expected to achieve even greater repeatability and lower uncertainty.

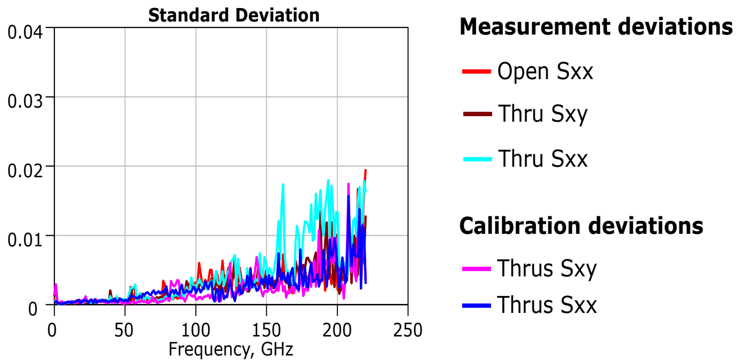


Fig. 2: Maximal Measurement and Calibration Standard. s($S_{i,j}$), linear scale.

Reproducibility limits were determined across a wide range of measurement conditions, including deep match, high reflection, and high transmission. This makes the results applicable to nearly all types of on-wafer devices. The reported maximum standard deviation errors remain below 0.02 in the upper frequency band from 160 GHz to 220 GHz, and below 0.008 in the lower frequency range (Fig. 2). These values offer a simple and practical reference for evaluating measurement differences and can serve as a clear criterion for assessing consistency across measurement sessions or between different systems.

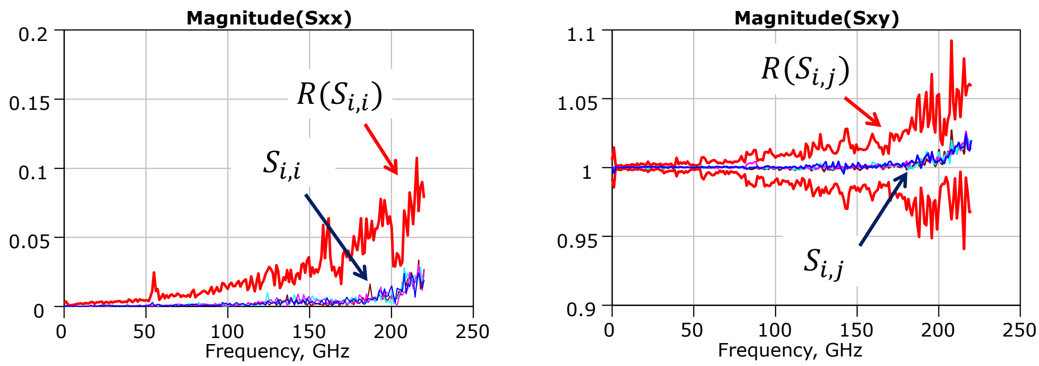


Fig. 3: Application of the Reproducibility Limits R (linear scale) to the measured S-parameters of dual short transmission line corrected by the LRM calibration

Since these values are based on repeated calibration and measurement cycles, engineers do not need to repeat time-consuming statistical evaluations. We recommend using the reported reproducibility limits as a practical benchmark (Fig. 3). However, if measured differences exceed these limits, or if more precise performance is expected (for example, when using automated equipment), we suggest repeating the reproducibility assessment under the specific conditions of the application.

## REFERENCES

[1] A. Rumiantsev, J. Martens, and S. Reyes, „A Differential Broadband Single-Sweep 70 kHz-220 GHz Wafer-Level System: First Calibration and Measurement Characteristics," in 2023 100th ARFTG Microwave Measurement Conference (ARFTG), 22-25 Jan. 2023 2023, pp. 1-4, doi: 10.1109/ARFTG56062.2023.10148890.

[2] „TCS-GSGSG-0050-0050 Calibration Substrate," in Manual, ed: MPI Corporation, 2024, p. 9.

[3] H. C. Fu and K. Jung, „Improve RF Dual Probe Calibration Accuracy with Peer- Terminated Standards," in 2024 IEEE/MTT-S International Microwave Symposium - IMS 2024, 16-21 June 2024 2024, pp. 780-783, doi: 10.1109/IMS40175.2024.10600404. [Online]. Available: https://ieeexplore.ieee.org/document/10600404

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