

## Introduction

Recent advances in transistor and superconductivity technologies have driven researchers to develop custom cryogenic on-wafer probing systems. Examples include systems at both the University of Hawaii and Sandia National Laboratories.\* Both use closed-cycle liquid helium cooling systems and are capable of performing broadband S-parameter measurements (45 MHz to 50 GHz) over a wide temperature range (18°K to 300°K).

This technical brief identifies key issues related to cryogenic measurements and demonstrates that with Cascade Microtech probes and Impedance Standard Substrates (ISS), the accuracy and repeatability of cryogenic calibrations can be comparable to room temperature calibrations.

## Calibration and Measurement Considerations

Probing at cryogenic temperatures requires the use of a vacuum environment to avoid condensation and/or freezing of water (<273°K) and even “air” at the lower temperatures (i.e. nitrogen <77°K). The most important factors in achieving repeatable and accurate on-wafer cryogenic measurements are the temperature stability of the sample, probes, and microwave cables.

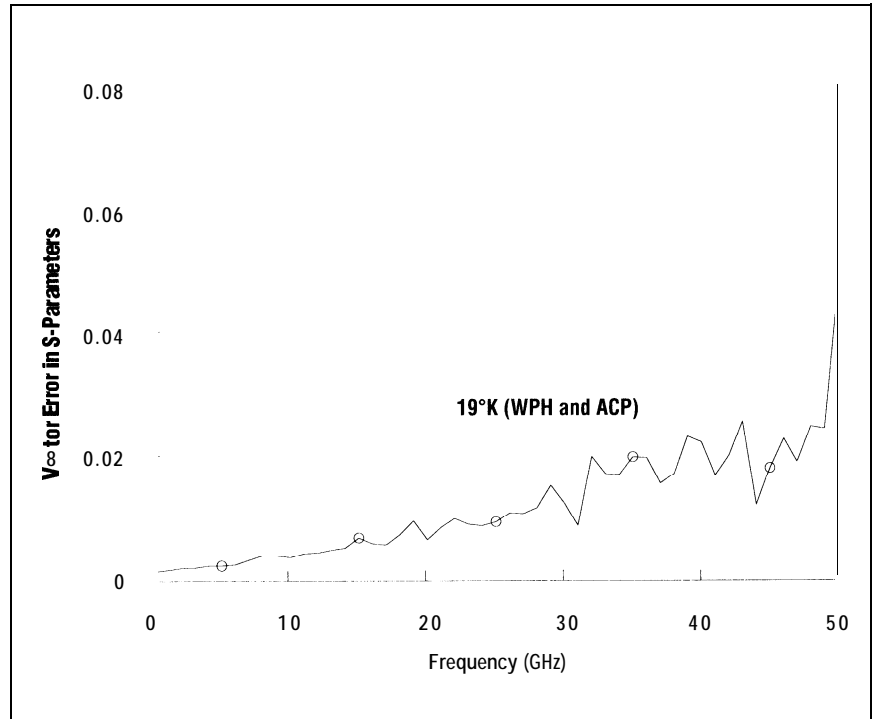


Figure 1. Plot of vector error function between LRM calibrations at 19°K with WPH- and ACP-series probes.

Temperature stability of the sample is best achieved with closed-cycle liquid helium cooling systems. Temperature stability of the probes is achieved by thermally anchoring the Cascade probes to the refrigeration unit using copper braiding. Finally, temperature stability of the microwave cables is achieved by thermally anchoring the cable ends in a vacuum environment.

Another key issue is the selection of the proper probe heads. Both Cascade WPH-series and ACP-series probes have been successfully used. The WPH probes are recommended for applications above 40 GHz, while the newer ACP-series probes are recommended for applications below 40 GHz. The ACP-series probes provide superior mechanical contact (less

sensitive to microphonics from the closed-cycle system) and equivalent electrical performance (up to 40 GHz) when compared to the WPH-series, as shown in Figure 1.

## Repeatability and Accuracy

The University of Hawaii recently studied the repeatability and accuracy of LRM calibrations with respect to NIST's multi-line TRL calibration. They found that calibration at cryogenic temperatures is as repeatable as calibration at room temperatures.

A similar technique was used to study the effect of temperature variation on an LRM calibration. The vector error function between a calibration at 24°K and calibrations at other temperatures increases significantly with increasing

temperature. For applications at cryogenic temperatures, results indicate the importance of temperature stability, which is best achieved in a high-vacuum environment.

## VNA Calibration

Understanding the temperature dependencies of calibration standards is important when selecting the best calibration techniques for cryogenic measurements. In particular, the temperature dependence of the load resistor must be characterized. Studies at Sandia National Laboratories indicate that this temperature dependence is easily characterized and quite manageable. Consequently, the LRRM method with load inductance compensation is considered to be the calibration technique of choice for cryogenic measurements.

Measurements were performed using a Hewlett Packard HP 8510C network analyzer with an HP 8517A testset. LRM and LRRM calibrations were performed with Cascade's VNA Calibration Software using a Cascade ISS. All LRRM calibrations used load inductance compensation. To learn more about these calibration techniques, refer to Cascade's application note, **Achieving Greater On-Wafer S-Parameter Accuracy with the LRM Calibration Technique**, and technical brief, **Technique Verifies LRRM Calibrations for GaAs Measurements**.

In order to utilize any calibration technique requiring a load, the load temperature dependence must be understood. Figure 2 shows the measured temperature dependence of Cascade's resistor materials. Both NiCr and TaN resistor materials were tested. This data was measured point by point by placing a microwave probe on

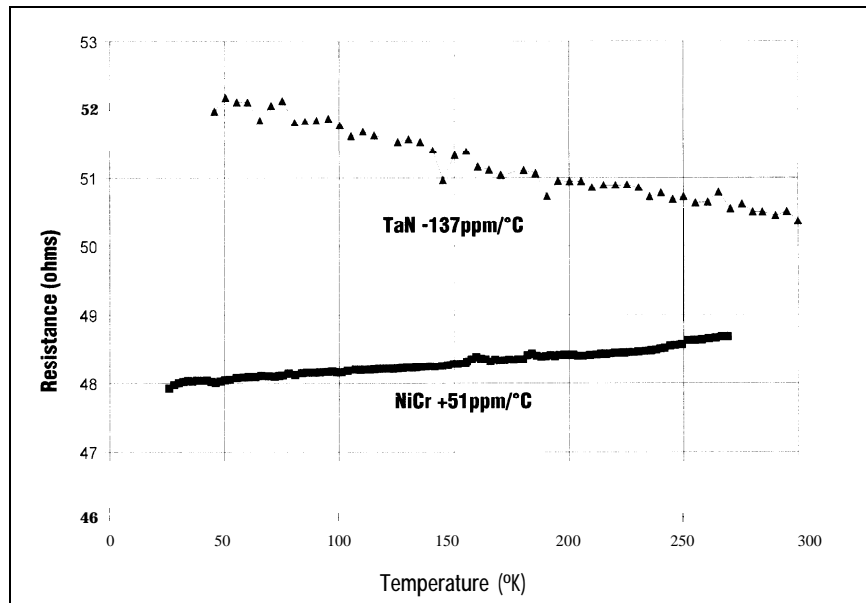


Figure 2. Measured temperature dependence of Cascade's resistor materials.

the resistor at each temperature. The background resistance (i.e. cables and probes) is compensated for in Figure 2 by subtracting the measured resistance with the probes shorted at each temperature. The resulting data indicates an approximately linear temperature dependence over the entire measurement range of 45°K to 300°K. For these particular resistors, randomly selected for this test, the room temperature ( $T \cong 300^{\circ}\text{K}$ ) values slightly deviate from 50  $\Omega$ , but normalized temperature dependence is still valid. The temperature-dependent deviation from 50  $\Omega$  is small and can be easily accounted for in a calibration.

## Conclusion

Important points to consider when making cryogenic measurements are:

- Temperature stability of the sample, probes, and microwave cables
- Proper selection of probe type
- Proper selection of the calibration technique for VNA
- Characterization of the temperature dependence of the calibration standards

- Repeatability compared to room temperature calibrations

Good temperature control, cooling of the probe heads, and low-vacuum pressure all contribute to good system stability. In addition, waiting for system thermal equilibrium enhances measurement accuracy. As with room temperature measurements, probe placement is important at cryogenic temperatures for accurate and reproducible calibrations. Due to the complexity of probe contact in a cryogenic vacuum environment, the LRRM method with load inductance compensation is currently considered the calibration technique of choice.

**\*For more information about cryogenic on-wafer measurements, contact Dr. Joy Laskar at the Georgia Institute of Technology or Dr. Vincent Hietala at Sandia National Laboratories**



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