Solve complexity issues in 4-port RF designs

By Larry Dangremond
Senior Product Manager
Probes and Signals
Cascade Microtech Inc.

There is an increasing need for engineers to characterize high-speed IC devices that use new differential or 4-port RF design architecture. Such architecture is prevalent in today's high-speed wireless products.

For RF measurements on 4-port designs, engineers need to validate and calibrate their RF test system on four ports instead of two. But the addition of two more ports is not just the sum of 2+2. Complexity and problems expand exponentially. Until now, advanced "probing-tolerant" 4-port calibrations did not exist.

This article shows how to solve complexity issues arising from the measurement of 4-port devices and to ensure that RF test system calibration is accurate, reliable and repeatable.

Moving from 2- to 4-port measurements presents several challenges. For example, one might ask, "Can a 2-port VNA calibration be directly applied to 4-port designs?" The answer, clearly, is no. Other issues may also arise that are related to dual-signal wafer probes and impedance standards used for 4-port calibration.

Problems unique to 4-port device measurements include:

- Uncorrected probe-position-related measurement variation;
- Incomplete electrical knowledge of calibration elements;
- VNAs that lack advanced calibrations for 4-port;
- Sensitivity to non-ideal 4-port calibration structures;
- High crosstalk dual-signal probes.

Error-prone areas

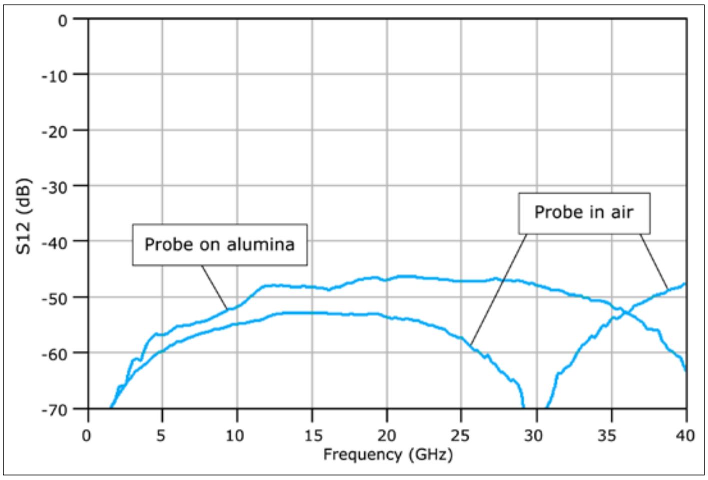
Probe-based 4-port device measurements have some unique challenges. Variation in probe location on a calibration standard may cause electrical behavior to vary from the defined standard parameters. When probes move relative to each other, there is yet another opportunity to introduce a calibration error. Often, electrical definitions for standards are not available. As the number of ports goes up (as with 4-port), more standards are measured. In a worst-case scenario, this can be proportional to N2.

A complete solution for successful 4-port RF measurements includes a wafer probe with a digital imaging system for enhanced navigation, low-crosstalk dual-signal probes, dual-impedance standard substrate (ISS), phase-stable cables and special calibration and measurement software with advanced calibration algorithms optimized for 4-port. This approach features:

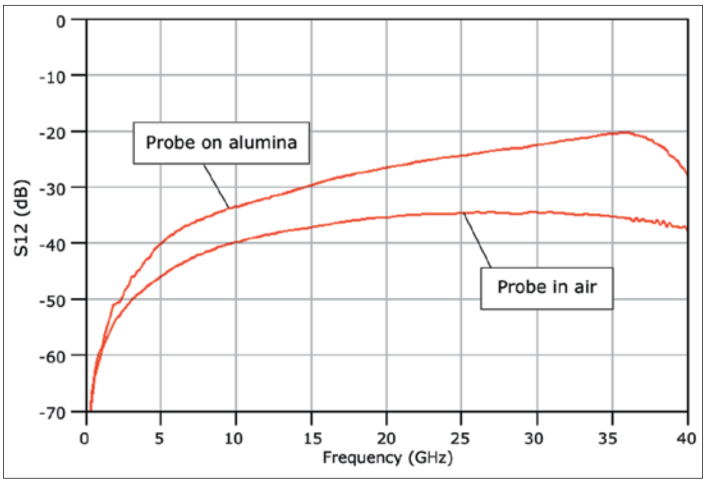
- Fixed probe positioning with automated stage moves;
- Low sensitivity to probe variation on standards;
- Minimal required standards and definitions;
- Tolerance of non-ideal standards;
- Low-crosstalk RF dual-signal probes;
- Advanced 4-port calibration methods.

The first challenge in 4-port measurement is proper system setup to ensure accurate and repeatable calibration and validation results. When building a 4-port test system, each of the components should be considered individually.

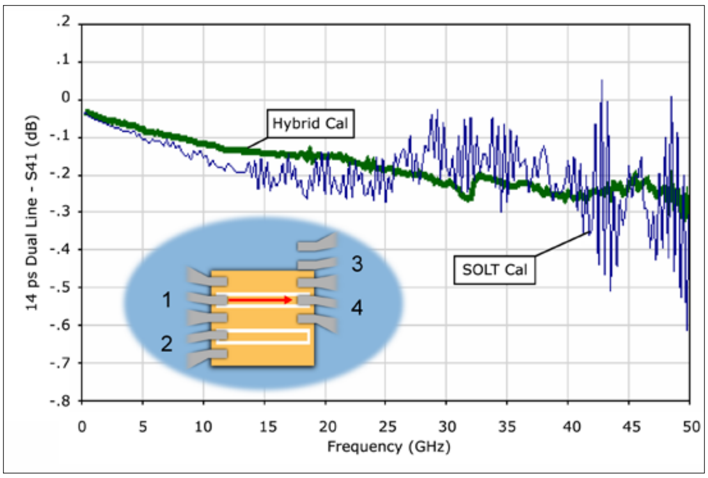
For mixed-mode or differential measurement, today's 4-port VNAs use multiple 2-port calibrations (short-open-load at each



Cross-transmission line comparison of insertion loss of a hybrid calibration vs. a SOLT calibration. The SOLT calibration shows significant error; the hybrid calibration is clean.



A conventional metal-fingered probe has crosstalk and limited performance in applications above 15GHz (plot A). The dual-signal Infinity probe offers isolation >40dB up to 40GHz (plot B).



A complete system for 4-port calibration leverages the strengths of existing 2-port calibration methods.

port). This requires a single-port-at-a-time excitation. VNAs convert single-mode data to mixed-mode mathematically. A key constraint here is that the DUT must be linear for accurate computation of mixed-mode terms.

For 4-port work, dual or differential probes are required. Although dual probes are not new, it is only now that multiport analyzers and calibration techniques are available to really put them to the test. For precision differential measurement, probes with low signal-to-signal crosstalk are needed.

GSGSG vs. GSSG probes

For 4-port designs, the ground-signal-ground-signal-ground probe is suitable and available for frequencies up to 67GHz. The ground connection separates the signals and is always better than ground-signal-signal-ground (GSSG). In a perfect world, there should be no crosstalk; conventional probes create crosstalk that cannot be corrected.

Conversely, the disadvantages of GSSG are higher signal-to-signal coupling, limited frequency specification. Many probes are limited by the long metal fingers of the tips. Further, the higher the pitch, the worse the case will be.

With conventional probes, the side-by-side mechanical fingers (coplanar waveguide) create a fringing field effect between the fingers. Field patterns are hard to control, which in turn causes coupling and limits the bandwidth.

To get meaningful device data, the instrument must be calibrated so that the calibration reference plane is at the probe tip.

The dual-signal Infinity probe from Cascade Microtech uses microstrip lines with a coplanar transition at the probe needles. These microstrip lines confine fringing fields more tightly than conventional probes that reduce coupling to nearby devices or other probes for higher accuracy. The microstrip minimizes crosstalk, making it possible to configure dense, fine-pitch multi-tip probes that can handle more test points at higher frequencies.

To get meaningful device data, the instrument must be calibrated so that the calibration reference plane is at the probe tip. That way, only the device is measured and not the probe and cable. To perform this calibration, a set of known standards are used at the probe tip. There are several algorithms that can be used for calculating the error coefficients for correcting the raw data. Some methods are less useful for on-wafer measurements and even less accurate and repeatable at higher frequencies.

For example, it is known that the short-open-load-through calibration accuracy is affected by probe placement variation on standards and definitions of seven standards. While calibration definitions are supplied by probe manufacturers, some values depend on the correct amount of skate on the standards. With excessive or insufficient skate, the entered standard values become invalid and lead to errors.

Less errors

The line-reflect-reflect-match (LRRM) calibration technique uses automatic compensation to provide the actual value of standard inductance rather than the assumed value supplied with the probe, thus reducing the errors caused by probe placement variations.

Furthermore, the LRRM calibration does not rely on standards with imprecisely known electrical characteristics. In this calibration, the straight through provides the most information. This structure is nearly ideal, since loss or impedance deviation impact is minimized due to its short length. For dual-probes and 4-port, loopback throughs are needed but do not have to be ideal.

The new LRRM-SOLR hybrid calibration for 4-port designs is available in Cascade Microtech's WinCal XE calibration software. This calibration method takes advantage of the strengths of two calibration methods to provide quality 4-port performance.