NOVEL CONCEPT FOR A DUAL ON WAFER PROBE TIP AND CORRESPONDING CALIBRATION TECHNIQUES

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Abstract
The paper discusses a revolutionary design concept for a dual RFIC wafer probe and corresponding calibration substrates (CSR) which demonstrate perfect symmetrical behavior. The probe makes it possible to achieve the same behavior standard as a single transmission line design. This paper explains the novel design approach and illustrates the quality of the design up to 40 GHz.

I. Introduction

RF wafer probes are typically designed with a single transmission line in either a GS (ground-signal) or GSG (ground-signal-ground) configuration. The most popular probe configuration is GSG, because they show lower radiation loss.

Special calibration substrates made from AL_2O_3 with CPW (coplanar waveguide) – SHORT, OPEN, LOAD, THRU standards complete such setups. The calibration standards on these substrates have delays and/or capacitive or inductive behavior. This behavior is described and removed in the calibration process via correction values. These correction values in the calibration are imperative for wafer level measurements. The wafer probe and calibration structure need to be well designed to minimize mode conversion by avoiding symmetry deviations.

The increase in demand for wireless and digital devices has pushed the development of the differential signal design which saves power and causes less interference. These new designs have in turn increased the demands placed on characterization of differential and mixed–mode RFICs. These have been met by the development of multiport VNAs, but testing at wafer level requires the design of different RF probes.

Therefore, two transmission lines are required in each RF wafer probe. The configuration with the best performance at the highest frequencies is a ground-signal-ground-signal-ground (GSGSG) configuration.

The dual channels are virtually independent and will work when separately triggered. Single ended configurations demonstrate unsatisfactory performance when operated by single-source analyzers.

This paper shows the optimization of the probe itself as well as SHORT; OPEN; LOAD and THRU calibration standards for GSGSG probing.

II. Challenges for the dual probe design

A CPW is constructed for GSGSG probes. Two modes can be transmitted in the CPW structure (1), an even-mode and an odd-mode. The even-mode is an unwanted mode, and must be avoided. The source for an even-mode could be asymmetrical CPW cross section or a length difference of its two sides. This asymmetry will lead to mode conversion and, if the line is long enough with respect to frequency, resonant behavior may be observed. Studies discussed in [5] have theorized that the length of the gaps or the probe fingers will never be perfectly matched. This we can prove is not true.

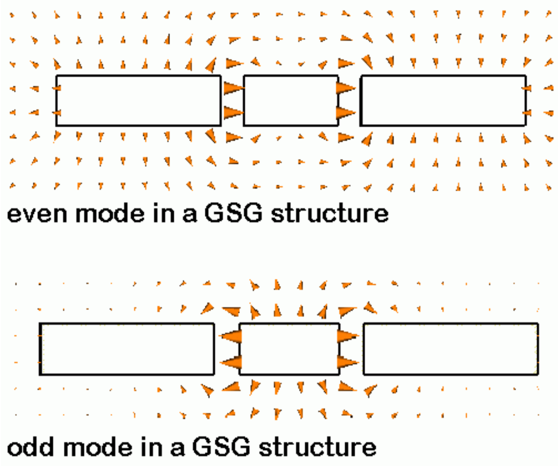

***Fig. 1**: Even- and Odd-Mode in a CPW Structure*

To avoid such length differences the CPW structure of this particular design has been placed in a semi-circle with the DUT in the middle (2). Additionally, for differential measurements an equal delay time between signal 1 and signal 2 is very important. Both are achieved by this circular arrangement of the planar transitions, combined with high precision connectors of exactly the same electrical length.

***Fig. 2:** CPW Contact Structure of a Dual IZI Probe 40 K3N GSGSG 150*

An extremely accurate CPW structure is manufactured using MEMS micromachining technology, thus very long contacts with a spring like action can be made. The gaps between the contact fingers form the 50 ohm transmission CPW structure. The main challenge in most RF probing solutions is to control the impedance in this transfer line between planar DUT and the standard outside transmission lines. The chosen solution is often that the contacts are kept very short, but this impairs contact quality and lifetime.

The **IZI**-Probe's metal structure has a thickness of 100 µm. This is much more than other similar designs have. The structures shown in [5] have only a quarter of that thickness, so their gaps are wider to achieve 50 Ohm impedance. A narrow gap guided to a high density RF-field inside the CPW structure. This is done with the **IZI**-Probe design. With other words the thickness of the structure is 2 times more than the gap width and for GS structures 4 times more. Figure (3) show an electron microscope view of a GSG type **IZI**-Probe. The independent contact springs of the GSGSG probe have a length of 2200µm while maximum allowed deviation from its contact point line is only 15 microns. The gap width is controlled to less than 5 microns. The typical SWR is better than 1.2 up to 40 GHz.

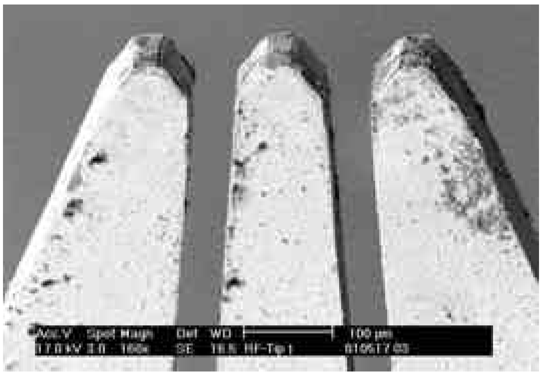

***Fig. 3** (source GFD Ulm): View of a GSG IZI Probe tip*

This CPW accuracy guarantees high precision 50 Ohm lines with very low radiation loss and crosstalk. The transmission path continues from the CPW into the coaxial 2.92 RF precision connector via an internal air line. The 2.2 mm long, hard nickel springs provide superior contact quality, DC resistance < 0.1 Ohm and unique probe tip flexibility that increases the already extremely long probe lifetime.

In a real-life application, two different modes of operation have to be considered.
Of course, proper operation in differential mode is desired, which is mainly a challenge for network analyzers and cabling. Providing a differential signal at the probe itself requires two signal sources with adjustable phase shift, which have to be calibrated to true 180 degrees phase difference at the probe over the whole frequency range. If so, a GSSG configuration will show good performance as well.

However, currently most analyzers will perform four port single signal measurements and then compute a common and differential mode response from it. This does not only assume a linear behavior of the DUT, but requires the probe to work without radiation when driven by such a signal. As low radiation means low losses, the insertion loss for single path operation is a good indication (Fig. 4), while the final proofs are good quality of planar calibration and low sensitivity to surroundings.

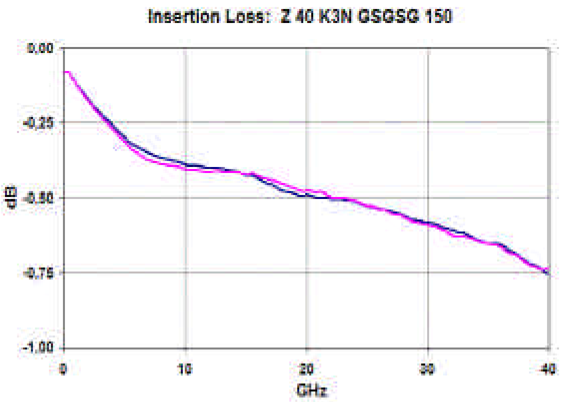

Fig. 4: *Single Signal Insertion Loss of a Dual* I***Z***I*-Probe*

Another important characteristic is coupling or crosstalk between both signal paths at the probe itself. Fig. 5 shows, that isolation is better than 30 dB over the full frequency range even if the probe is terminated by reflective standards. Such a low level allows the use of a probe for two channel / single signal operation as well; in contrast the performance of a GSSG probe will not be satisfactory at higher frequencies. The reason therefore is the higher coupling along the both signal contacts, which are not separated by a ground.

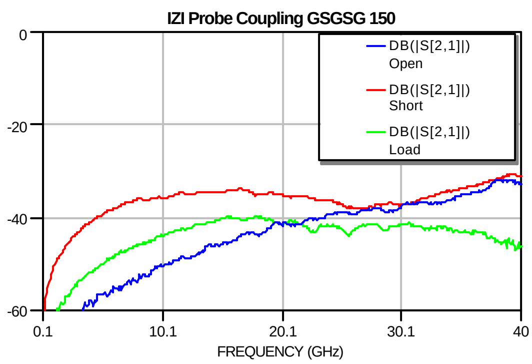

Fig. 5*: Dual* I***Z***I *Probe: Isolation between Both Channels*

III. Challenges for the calibration substrate design

Traditional wafer level RF probe setups include a wafer probe together with a specially designed calibration substrate. The advantage of such a calibration substrate is the high accuracy of the standards, especially laser trimmed 50 Ohm LOADs. Another point in their favor is that the standards are well known, simulated and data supplied by the manufacturer. Such calibration standards are characterized by electrical models (6) and it's important to use these values in the calibration method. Otherwise the parasitic will cause a systematic error in all measurements. Most VNAs accept the values but don't use the complete model for all calibrations, especially if LRM is chosen. The values for the LOAD standard are not used in any VNA -LRM method. An improvement with that respect is the LRM+ method, which is available in special calibration software [6].

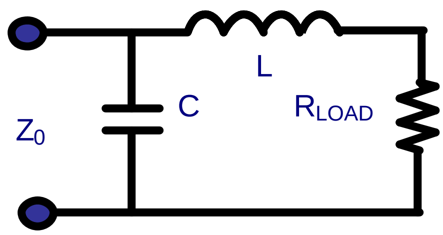

Figure 6: *Example of Electrical Model (planar LOAD standard)*

It will be shown, what is the existing standard for GSG and how can it continue to a GSGSG setup with the same performance.
The corresponding calibration substrates for |Z|-Probes GSG with 100…250 µm contain OPEN, SHORT, LOAD, THRU and different LINE standards. It's important for proper calibration that all standards have the same environment. The OPEN standard should therefore not be substituted by simply lifting the probe, because contact planarization is only guaranteed on the substrate surface and the stray capacitance should always be the same as on the other standards. A difference up to 0.2 dB at 40 GHz is typical for different probe types, between OPEN and AIR. If the dielectric on the wafer is different to the substrate, the difference stays always the same and causes only an offset. Figure (7) shows such an OPEN standard for GSG. The

marks above are in 100 µm distance and below in 150 µm for 5 contacts. It's easily seen that a pitch range from 100 to 250 can't be covered by one standard. For example, the 100 µm signal contact would meet the gap for 150 µm contact.

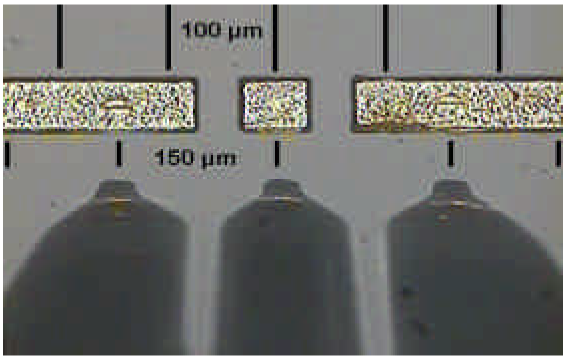

Figure 7: *OPEN Standard and 150 µm GSG Probe*

Reducing the pitch range can solve this, but the signal pins would then always land sideways on its pads causing asymmetry and radiation as mentioned above. For transmission line structures the problem can be evaded by centering each side of a dual probe on a single signal line, however this requires moving at least one probe. A true solution is only providing a special substrate for each pitch as with the CSR substrate series (8).

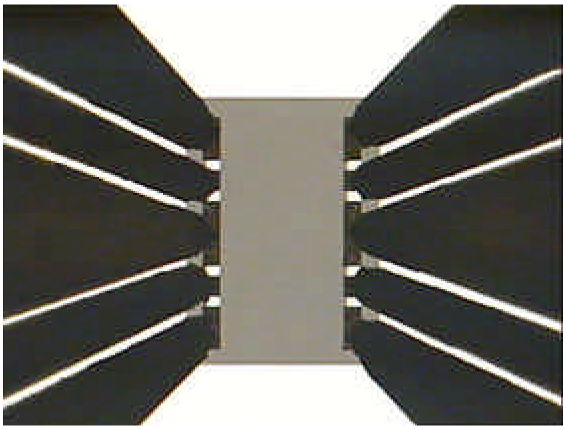

Fig. 8: *LOAD standard on CSR 31, GSGSG 150 µm Pitch*

The THRU standards are always designed for the same probe distance, so each port can be connected to all other ports without any probe movement. This enables automatic calibration with manual x-y manipulators. For smaller pitches, "I"- and "U"-THRUs are designed with the same electrical length, while a Z-THRU inevitably has to be longer (9). If the calibration method requires equal LINE length the "I"-THRU can be used as mentioned before.

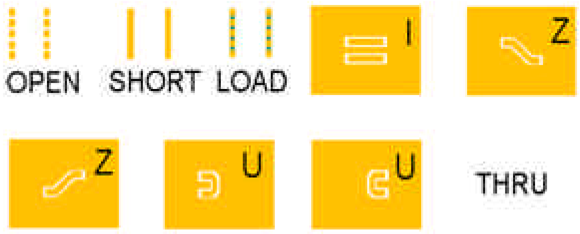

Fig. 9: *Complete Set of Dual Calibration Standards*

The CPW transmission THRUs on the dual substrate family have ground connected around the end in a "ring" structure. This is already employed on GSG substrates to avoid mode conversion by asymmetry.

IV. Summary

The new dual IZI Probe with the CSR 30ff calibration substrate family opens new possibilities for on wafer test of balanced and differential RFICs.

Design and manufacturing focus was set on achieving the highest symmetry and contact quality in a wide pitch range.

The new dual RF IZI Probes' electrical performance is shown together with the corresponding CSR substrate. The setup provides the same accuracy and contact quality as single transmission line probing and allows excellent multi-port VNA calibration and measurement up to 40GHz.

REFERENCES

[1] M. Wollitzer, B. Rosenberger, Novel Concept for a modular millimeter wave probe tip, RF conference Atlanta 2000

[2] Adamian, V, Cole B., VNA-Based System Tests Differential Components, MICROWAVES & RF March 2000, Article

[3] Heuermann, H., Schaltungstheorie und -synthese mit Gleich- und Gegentaktgrößen, Umdruckversion 1, 28.Juli 2003, FH Aachen

[4] S.Schott, S. Thies, M. Wollitzer, An impedancecontrolled high precision wafer probe tip for applications up to 40 GHz, Microwave Journal, October 2001

[5] Lesher,T., Hayden, L., Strid, E., Optimized Impedance Standard Substrate Designs for Dual and Differential Applications, ARFTG conference December 2003

[6] Suss MicroTec Test Systems GmbH, High Frequency Probing, brochure 01/2004