HIGH PERFORMANCE TEST FIXTURE FOR 10-PORT MMIC's CHARACTERISATION

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ABSTRACT

High-performance measuring multi-port 3-level fixture for active device characterization in the Ku-band is described in this paper. It is a low-cost alternative of the expensive microwave "on-wafer" measurements with CPW probes. The method of modeling of the separate components of the each embedding RF-path of the fixture is used for de-embedding purposes. Testing of several phantom-type structures on the chip-carrier level confirms the ability of the considered fixture to give repeatable results for the extracted own MMIC's parameters: mainly for the insertion phase and the gain.

INTRODUCTION

There is a variety of measuring methods and de-embedding procedures for "in-fixture" characterization of non-coaxial SMT devices with 2-3 ports [1, 2]. Nevertheless of mathematical simplicity of the S-parameters extraction and utilization of improved calibration techniques [3] for VNA-based measurements, certain problems appear concerning the reproducibility, the phase uncertainty [4], etc. The difficulties increase with increasing of the number of ports and decreasing of the size of the device. Microwave probing [5] with coplanar waveguide (CPW) probes gives an opportunity for "on-wafer" measurement of packaged or "on-board" MMIC's, but it is restricted in respect to the port numbers.

We propose in this paper a simple and low-cost solution for test fixture used for S-parameter characterization of multi-port packaged MMIC's in the Ku-band. First of all, several methods for characterization of the measuring fixture are compared. Next, the parameters of several phantom-type structures are measured, which are incorporated in the fixture instead of the multi-port active device. Finally, the possibilities for 100-per-cent preliminary control of the transmitted S-parameters (magnitude and phase) of packaged 10-port MMIC's are discussed and statistical results from measurements of a lot of active devices in Ku-band are given to illustrate the test fixture abilities for characterization of their phase delay and gain.

II. MEASURING FIXTURE FOR 10-PORT PACKAGED DEVICES

The view of the measuring structure is given in *Fig. 1a, b*. It has three-level architecture – see *Fig. 2a*. The packaged MMIC (2nd and 3rd levels) lies on an array of RF- and GND- bumps, which are responsible to the galvanic contacts of the corresponding RF-signals, dc- and GND-potentials. These bumps are manufactured hard enough and they ensure repeatable contact, if small, but equal mechanical pressure is applied by the movable part of the support. This non-metal piston pushes upon the plastic lid covered the packaged MMIC and, therefore, does not practically disturb its RF-performances.

The 1st level of the test fixture contains the PCB plate with arranged 10 RF-signal paths, each including one SMA-microstrip (MSL) transition, curved (for the inputs) or straight (for the outputs) microstrip line and one MSL-GCPW (grounded coplanar waveguide) transition. The RF-contacting bump (semi-sphere, 0.6-mm in diameter) lies at the end of the short GCPW section – *Fig. 3* (pos. 3). The each PCB embedding path through small contact area and lateral via-castellation transition is connected to the corresponding embedding path on the chip carrier. Each of these 2nd level (CC) paths includes one via-castellation transition, "through" 50-Ohms GCPW sections with gold-wire bonds at the end, which is the 3rd level connection to the chip ports.

The generalized de-embedding scheme of the whole structure is shown in *Fig. 2b*. The corresponding S-matrixes denote: $\hat{\mathbf{S}}_{\mathbf{PCB}\Rightarrow}$, $\hat{\mathbf{S}}_{\mathbf{PCB}\Leftarrow}$ – forward and backward PCB-paths; $\hat{\mathbf{S}}_{\mathbf{CC}\Rightarrow}$, $\hat{\mathbf{S}}_{\mathbf{CC}\Leftarrow}$ – both CC-paths and $\hat{\mathbf{S}}_{\mathbf{MMIC}}$ – the unpacked MMIC. The contribution of the both contacting bumps in each RF-channel is added to the CC-paths; therefore, the compound S-parameters of the packaged MMIC include the bump influence.

III. EMBEDDING PATHS CHARACTERIZATION BY MMIC's PHANTOMS

The next step in our investigation is the characterization of the S-parameters of the each embedding path of the fixture (separately for the PCB-plate and for the chip carrier) by MMIC phantoms – *Fig. 4*. Several known calibration and de-embedding methods are used, which give close-enough results for the extracted S-parameters of one and the same simple "through"-GCPW's phantom *Ph0* (*Fig. 5*) used instead of the packaged chip. From this reason, we apply in the next de-embedding procedures only the method of modeling of the fixture elements with separate lumped-element schemes. There are no problems with RLC-modeling of the 1st level PCB-embedding path: SMA-MSL transition [1], microstrip (TRL'85 model) and MSL-GCPW transition (extraction of the S-parameters after measurement of the ½ -part of the "through" plate 2, *Fig. 3,* [6]). All these PCB-elements are well matched and their RF-behaviour does not disturb the characterization of the packaged MMIC's. The modeling of the other components (contacting bumps, via-castellations, "through" GCPW sections and bonds) at the 2nd CC-level is more difficult; therefore, the extraction of the S-parameters of the packaged MMIC (incl. chip carrier) is more accurate using the described procedure than for the pure MMIC. Nevertheless, some evaluation of the own RF-parameters of the bumps, via-castellations and wire bonds is possible by measurements of the next type of phantoms: phantom *Ph1* (*Fig. 5*) for the CC-components; *Ph2* for the wire bonds at the 3rd MMIC level.

As an illustration, the results for the de-embedded S-parameters of different CC-phantoms of type *Ph1* (*Fig. 6*) prove the sensitivity of the test fixture and accompanying de-embedding procedures to characterization of the different components (incl. MMIC itself). The isolation between the neighbouring ports of the fixture is high enough; so, the crosstalk influence between the different embedding paths can be neglected as a first approximation. The repeatability of the parameters of one and the same phantom measured over and over again is high enough; 20-times separate measurements of one *Ph2* phantom gives for the repeatability error values less than ±0.1 dB for the insertion losses and less than $\pm 1.0^0$ for the transmitted phase.

Finally, *Fig. 7* illustrates the de-embedded gain deviations and phase shifts in the frequency range 12 – 13 GHz for 20 MMIC's measured by the described test fixture. Data unambiguously show that the evaluated repeatability errors are smaller than the obtained standard deviations as for the gain, as well as for the phase delay of the measured MMIC's and, therefore, the both obtained values are statistically significant. That allows an efficient and low-cost 100-per-cent preliminary control of the important S-parameters of packaged 10-port MMIC's in the Ku-band. One improved variant of the test fixture gives also possibilities to apply all the eight RF-signal to the MMIC inputs with equal or with different phase shifts between them.

REFERENCES

[1] M. Knox, "Test Fixtures and SMT RF Device Characterization: An Overview", MW Product Digest, Aug2000, p.23

[2] R. Lane, "De-Embedding Device Scattering Parameters", Microwave J., August 1984, p. 149

[3] J.-J. Bouny, "Impedance Measurements for High Power RF Transistors Using the TRL Method", Microwave J., Oct. 1999, p. 118

[4] N. H. Zhu, "Phase Uncertainty in Calibrating Microwave Test Fixtures", IEEE Trans. Microwave Theory Tech., MTT-47, No.10, Oct. 1999, pp. 1917-1922

[5] S. Basu and L. Hayden, "An SOLR Calibration for Accurate Measurement of Orthogonal On-Wafer DUT's", IEEE Trans. Microwave Theory Tech., MTT-S, v. III, Dec. 1997, pp. 1335-1338

[6] A. R. Martin, "Measurement of Device Parameters Using a Symmetrical Fixture", Microwave J., May 1987, p. 299

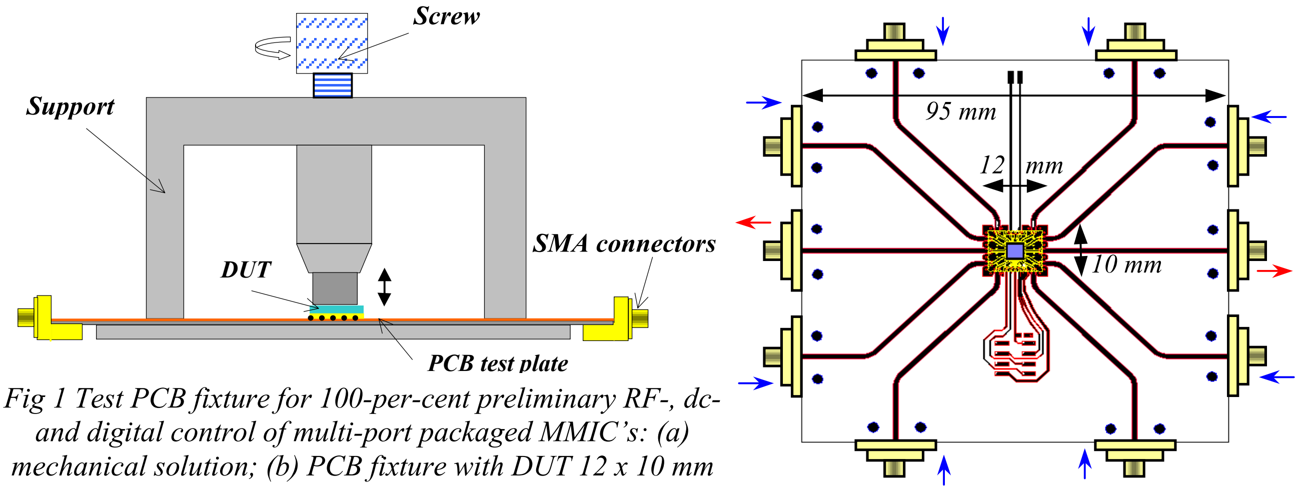


Fig 1 Test PCB fixture for 100-per-cent preliminary RF-, dc- and digital control of multi-port packaged MMIC's: (a) mechanical solution; (b) PCB fixture with DUT 12 x 10 mm

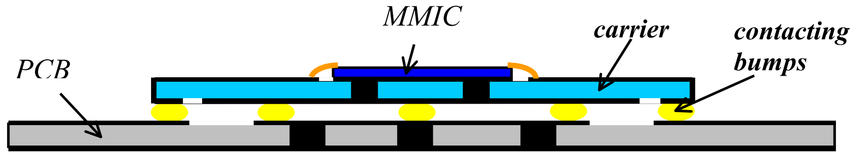


Fig. 2a. Vertical 3-level architecture of the measuring structure (not in scale);

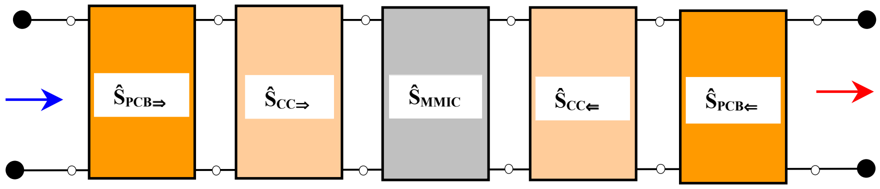


Fig. 2b. De-embedding S-matrix setup which includes: PCB-embedding path, chip-carrier (CC) embedding path and the unpacked MMIC, and the reverse path

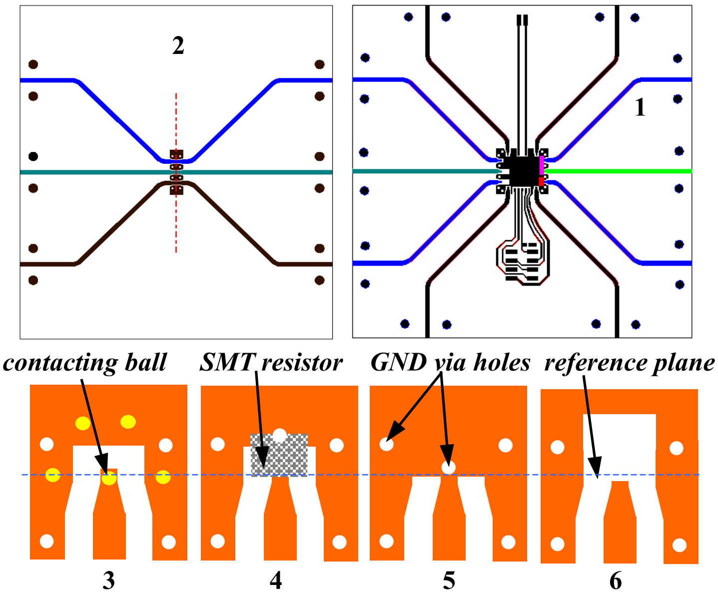
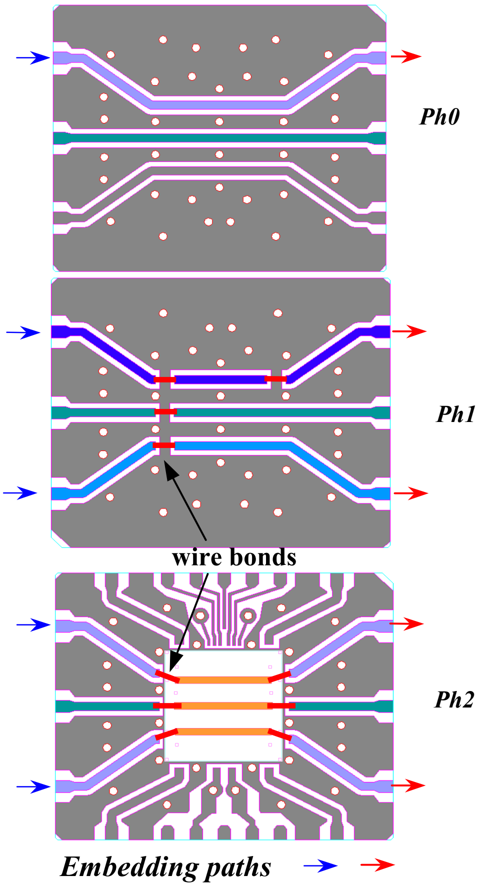


Fig. 3 (above) Calibration fixtures for the PCB-plate: 1- SOLT cal. plate 95 × 95 mm; 2- "microstrip-through" plate; 3- normal open end on PCB-plate; 4- SMT-load; 5- short; 6- open (RO4003 substrate: $\varepsilon_r = 3.52$, $tg\delta_\varepsilon = 0.0035$ @ 12.5 GHz, $h = 0.51$ mm)

Fig. 4 (right) Phantoms for chip-carrier characterization (TMM10i substrate: $\varepsilon_r = 9.8$, $tg\delta_\varepsilon = 0.002$, $h = 0.635$ mm): ***Ph0** – "GCPW-through" phantom;* ***Ph1** – CC-phantom with wire bonds;* ***Ph2** – CC-phantom with wire-bonded MMIC phantom on Alumina substrate containing three parallel microstrip lines*



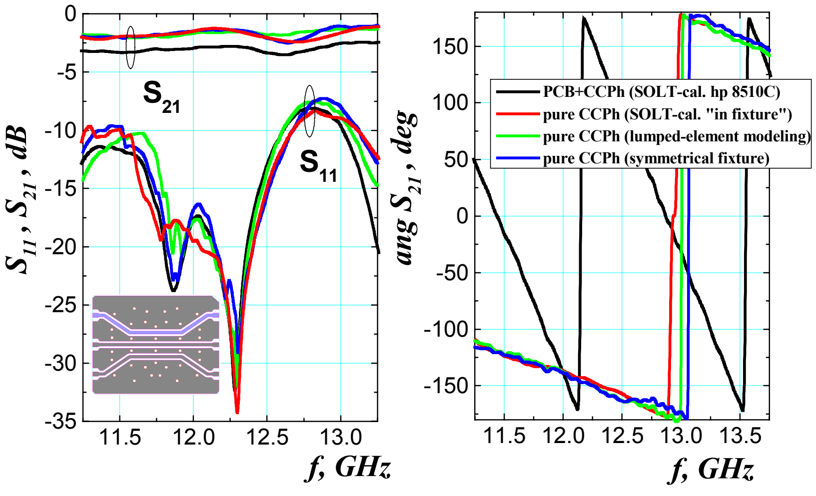
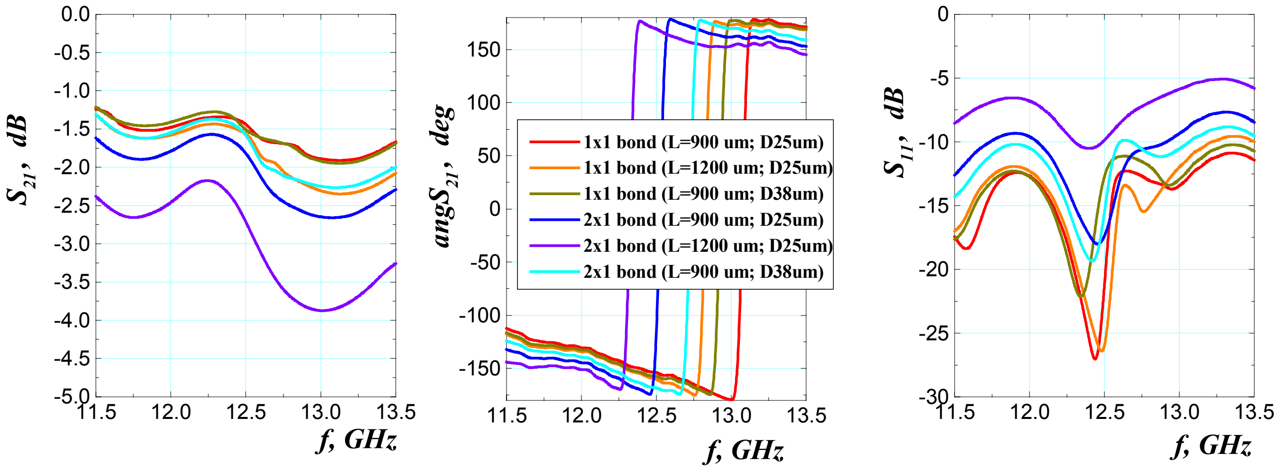


Fig 5 Data for the de-embedded S-parameters of the phantom structure ***Ph0*** *obtained by different methods:*

- *SOLT calibration "in fixture" with moving of the reference plane on the PCB-plate (Fig. 3, pos. 6);*
- *modeling with limped-element schemes of the connectors and the MSL's on the PCB-plate [1];*
- *using the approximation of fully symmetrical PCB test fixture [6]*



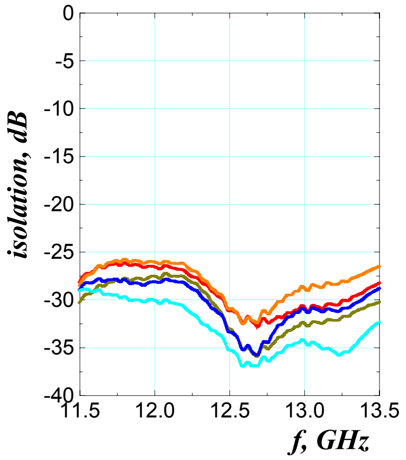


Fig 6 Data for de-embedded S-parameters of the phantom structure ***Ph1*** *obtained by modeling of the PCB. They illustrate the sensibility of the measuring structure to the number of the gold wire bonds, their length and diameter*

Fig 7 (bellow) Statistical data for the de-embedded S-parameters of 20 typical MMIC's:
(a) Gain deviation from the mean value; (b) Absolute transmitted phase for two states at 90^0 phase shift.

The results show that the standard deviations as for the gain, as well as for the phase are greater than the corresponding repeatability errors and therefore the obtained values are statistically significant