S-PARAMETERS MEASUREMENT OF CHIP GaAs FETs up TO 22 GHz USING THE TRL CALIBRATION TECHNIQUE

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ABSTRACT

In this paper, the design of a Microstrip Test Fixture for TRL calibration is described. Experimental results for S-parameters measurement of a GaAs FET chip in the 3-22 GHz frequency range are presented. Repeatability of connections and measurements is discussed and experimental results are also presented.

INTRODUCTION

Accurate, repeatable S-parameters measurement of chip GaAs FET and HEMT transistors is often required when designing microwave and mm-wave hybrid amplifiers. The TRL (Thru-Reflect-Line [1]) calibration method offers two main advantages in a microstrip environment. First, the calibration standards are more simple and less critical [2], than those in other methods like OSL (Open-Short-Load). Second, a careful modelling of connectors and transitions is not necessary. A number of Microstrip Test Fixtures for frequencies up to 46 GHz have been reported in the literature [3],[4],[5], but experimental results using the TRL technique above 20 GHz are not still available. Repeatability measurements have also been reported [6], but the factors limiting the repeatability of TRL measurements have not been studied.

DESIGN OF A MICROSTRIP TEST FIXTURE FOR TRL CALIBRATION

The key factors in the design were the repeatability of the microstrip-to-coaxial transitions in the Test Fixture, the similitude of the two highly reflective loads (REFLECTS), and the length matching of the corresponding microstrip transmission lines in the standards and the chip carrier.

The selected method for assuring a good repeatability and low parasitics was to implement a Test Fixture composed by three separate pieces [3], the input connector wall, the central support (which allows for the allocation of the three calibration standards and the chip carrier, one at a time), and the output connector wall. The structure is mounted each time that a calibration or measurement step is performed. Figure 1 shows an exploded view of the designed Test Fixture.

The electrical contact (see figure 2) is achieved by vertical pressure. All the standards and the chip carrier have a specially-designed ground shelf (at both sides) which contacts to the corresponding inverted ground shelf at the connector walls. Thus, the microwave ground path is kept to a minimum. The pin contact to the microstrip line is achieved simultaneously.

All the mechanical components were made in gold-plated brass. The connectors are SMA-type, usable up to 22 GHz. The selected substrate was Cu-Clad 217 ($\epsilon_r=2.17$, $h=0.254$ mm). The 'THRU' and 'LINE' lengths (10 and

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14.5 mm respectively), permit the calibration and the measurements to be performed in the 3 to 22 GHz band. The 'REFLECTS' are short-circuits made at the end of two microstrip lines, 5 mm length each. All the lines in the standards and chip carrier are mounted in a 3.5 mm width, 3 mm height channel, which forms a rectangular waveguide below cut-off at the operating frequencies. Thus, a mode-free operation of the transmission lines is ensured. All the mechanical dimensions have been carefully tested.

S-PARAMETERS MEASUREMENT USING THE TEST FIXTURE

The selected GaAs FET chip transistor to perform the measurements was the FSX02X from Fujitsu. First, the transistor was mounted on the carrier and thermocompression-bonded to the microstrip lines and the ground support. The bonding wires length was that recommended by the manufacturer (0.3 mm for Gate and Drain). Then, using the implemented standards, a TRL calibration was performed. An HP 8510B A.N.A. (which includes the TRL calibration software) was used in the calibration and measurement process. Figure 3 shows the measured S-parameters of the chip, including the bonding wires and all the associated parasitic capacitances. These capacitances are due to the open-end effect of the microstrip lines at the plane of the bonding wires connection to the chip, and to the coupling effect between the lines (figure 4). They were obtained from an S-parameters measurement of the chip with the Gate and Drain bonding wires disconnected [7]. Then, the chip parameters were deembedded, showing very small differences with respect to the chip's, including the parasitics (2° in phase and 0.1 dB in magnitude, maximum).

A comparison of the measured chip S-parameters with the manufacturer's data (figure 3) shows a small magnitude deviation. Phase deviation is significant only for S12 (54° maximum at 20 GHz). The causes of these deviations can be attributed to differences of the test set-up (substrate, source wires length, shielding conditions) with respect to the manufacturer's.

REPEATABILITY MEASUREMENTS

Repeatability for connectors, adapters and transitions can be defined [6] as the absolute magnitude of the vector difference between repeated reflection coefficient measurements. In our case, only the microstrip lines are 'changed' (disconnected and reconnected) during the calibration and measurement process. Connectors are not changed. As a result, only the microstrip-to-coaxial transitions are 'changed'. By 'transition' we mean the physical contact between the connector 'pin' and the microstrip lines, and the ground contacts between the shelves.

The repeatability has been measured in the following way. First, a coaxial Open-Short-Load (OSL) calibration was performed at the plane of connectors. Then, repeated S11 (or S22) measurements for each standard were compared. The measured repeatability of a single 'pin' disconnection/reconnection on the same microstrip line is shown in figure 5. The worst value is -30 dB. Time domain measurements were also made (a change in the frequency span to 0.13-26.5 GHz was necessary) and a suitable time gate was used to isolate the response of the pin contact point. Then, this response was converted to frequency domain, showing (figure 5) a smooth characteristic with a worst value of -44 dB. However, the accuracy of the whole calibration process is limited by the transition repeatability under more restrictive conditions, for example, the change of standard. The measured worst value (using time gating) was -37 dB in this case (see figure 6).

Another factor that affects the calibration accuracy in a less obvious way

is the non-equality between the two short-circuits used as 'reflects'. The measured differences (using time gating to isolate the shorts) show a worst value of -18 dB (see figure 7).

The S-parameters measurement repeatability under the same TRL calibration can also be defined as $|S_{ij} - S'_{ij}|$ (absolute error), where S'_{ij} is the measured parameter after one disconnection/reconnection cycle. The worst value was -30 dB (without time gating). Defining the relative error for this case as $|S_{ij} - S'_{ij}|/|S_{ij}|$, the dispersion percentage of a measurements series, as a function of frequency, can be computed. A worst value of 5.5 % was obtained, corresponding to the S21 parameter (figure 8). In a similar way, the repeatability of the measured S-parameters for two different TRL calibrations can also be defined. The measured values (figure 9) are better than -25 dB (absolute error) except for the S21 parameter.

CONCLUSIONS

A specially designed Microstrip Test Fixture for TRL calibration has been presented, allowing the S-parameters measurement of GaAs FET chip transistors in the 3-22 GHz band. Experimental results show small deviations with respect to the manufacturer's data (except for the phase of S12). The open end parasitic capacitances have also been measured, showing a very small effect in the measured chip S-parameters.

The coaxial-to-microstrip transition repeatability has been studied. Experimental results (using time domain gating) show that the change of standard in the calibration process is the main limiting factor, yielding a worst value of -37 dB. This factor also limits the accuracy of the S-parameter measurements.

The non-equality between the two short-circuits used as 'Reflects' has been measured yielding a worst value of -18 dB.

The repeatability for an S-parameter measurement series (under the same TRL calibration) has been defined. Experimental results show that the disconnection/reconnection cycle is the limiting factor in this case, yielding a worst value of -30 dB (without time gating), which represents a dispersion percentage of 5.5 %. If two different TRL calibrations are compared, the measured S-parameters repeatability is -25 dB.

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Figure 1
 Test Fixture

Figure 2
 Electrical contacts between
 connector walls and support

Figure 5
 Coaxial-to-Microstrip transition Repeatability
 (Single 'pin' disconnection/reconnection)

- 1 - Transition 1
- 2 - Transition 2
- 3 - Transition 1 (time gating)
- 4 - Transition 2 (time gating)

Figure 4
 Parasitic Capacitances

Z
 START 3.00000000 GHz
 STOP 22.00000000 GHz
 REF 1.0 Units
 280.0 mUnits/
 148.78 Ω -148.75 Ω
 hp

MARKER 1
 3.0 GHz

S₁₁
 REF 5.0 Units
 1.0 Units/
 -2.6489 U. 1.97 U.
 hp

MARKER 1
 3.0 GHz

S₁₂
 REF 125.0 mUnits
 25.0 mUnits/
 27.626 mU. 52.202 mU.
 hp

MARKER 1
 3.0 GHz

Figure 3
 Measured S-Parameters.
 Transistor FSX02X.
 Solid : Measured (3-22 GHz)
 Dashed : Manufacturer (3-20 GHz)

S₁₁-M1 log MAG
 REF 0.0 dB
 1 15.0 dB/
 -39.811 dB
 hp

MARKER 1
 18.062189052 GHz

START 0.131040716 GHz
 STOP 26.409999996 GHz

Figure 6
 Coaxial-to-Microstrip
 transition Repeatability
 (Change of standard).
 Time gating
 1 - Transition 1
 2 - Transition 2

Figure 7
Repeatability between
REFLECTS.
Time gating

Figure 8
Dispersion percentage of
an S-parameter measurement
series under the same TRL
calibration

Figure 9
S-parameter measurement
repeatability. Two different
TRL calibrations are
compared