

# Measurement of Active and Passive Millimetre Wave Devices using Microstrip to Coplanar Line Transitions

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## Abstract

At millimetre wave frequencies the use of coaxial based test fixtures does not provide an accurate characterisation of planar passive or active devices. Tests using coplanar probes produce more reliable and repeatable device measurements. A suitable method to perform device characterisation is through broadband coplanar to microstrip transitions. A test bench for obtaining S-parameters up to 50 GHz is described. Calibration method and test results of passive and active circuits and devices are presented. The obtained experimental S-parameters have been used for circuit design and further integration of millimetre wave receiver systems.

**Keywords:** millimetre-wave measurements, coplanar to microstrip transition, device characterisation.

## 1. INTRODUCTION

The most common characterisation of microwave active and passive devices is the Scattering parameters matrix (S-parameters). The Vectorial Network Analyzer is the key test instrument to perform such measurements. Test ports are usually coaxial connectors to achieve broadband performance. Test of microstrip circuits, or semiconductor devices to be assembled in microstrip lines, needs an appropriate transition from coaxial to microstrip. There are several types of commercially available coaxial to microstrip “Test Fixtures”, with an appropriate set of standards to correct the systematic errors introduced by the transitions. Unfortunately at millimetre wave frequencies the quality and repeatability of such transitions is poor. When this happens there are still residual systematic errors in the S-parameters tests. These errors can hide the actual device behaviour.

In the development of passive and active circuits up to 50 GHz, to be applied in broadband receivers, several inconsistencies were found in the S-parameters testing of microstrip band pass filters and low noise PHEMT devices. The problem came from poor and non repeatable coaxial to microstrip transitions used in the test setup. A better alternative was the use of broadband coplanar to microstrip transitions, combined with a calibration and test process using a coplanar probe station [1]. Very stable test coaxial cables against temperature and bending were needed to achieve good quality tests. This method allows a highly repeatable and consistent S-parameter measurement test bench up to 50 GHz.

## 2. TEST BENCH DESCRIPTION

The implemented test bench is composed of: a Vector Network Analyzer (Agilent E8364A), phase stable 2.4 mm connector coaxial cables (Gore-Tex), coplanar probe station (Cascade Microtech), coplanar probes (67A-GSG-150-P Picoprobe) and coplanar to microstrip transitions (ProbePoint 1003 from J-Micro in Alumina substrate). Frequency limitation up to 50 GHz is due to the available generator and 2.4 mm coaxial connectors. The calibration is performed at coplanar probes planes using the TRL technique with a calibration substrate (ProbePoint CM12). The first key element in the measurement system is the coaxial cable. Each cable has a length of 70 inches (1.78 meter). This is needed by connectivity reasons between the Analyzer and the coplanar probe station. At 50 GHz it means a relatively high attenuation (about 7.5 dB each cable) and more than 300 wavelengths. A very stable phase and amplitude response against temperature changes or bending is needed. The second key element is the transition to microstrip. The advantage of a coplanar probe over a coplanar to microstrip transition is their very good repeatability and resonance free broadband behaviour from DC up to more than 50 GHz.

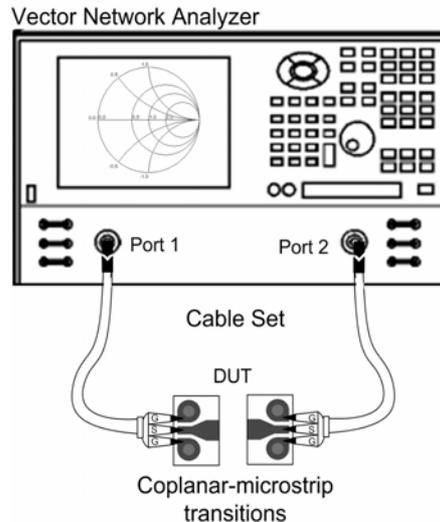


Fig. 1. Test bench composed of the Vector Network Analyzer, coaxial cables, coplanar probes and coplanar to microstrip transitions

### 3. MICROSTRIP TO COPLANAR TRANSITION

A well designed coplanar to microstrip transition should have a tapered shape to avoid an abrupt electromagnetic field discontinuity [2]. The used transition has a linear taper and via holes connecting the coplanar ground pads to the bottom ground. A view of a transition is shown in Fig. 2 (a).

The microstrip to coplanar line transition has been simulated using an electromagnetic simulator. The simulation showed a resonance free transition. The results from 20 GHz up to 60 GHz are shown in Fig. 2 (a). The losses are lower than 0.1 dB and the matching better than 15 dB in all frequency range.

### 4. CALIBRATION

The quality of the calibration in a test system is due to the calibration method and calibration standards, not to the test system imperfections which have to be corrected. The residual error in a calibrated measurement is directly related to the quality of the calibration method or standards. In a stable measurement environment the systematic effects are repeatable and can be measured by the Vector Network Analyzer [3]. This process is called calibration. During calibration a series of known devices (standards) are connected. The systematic effects are determined as the difference between the measured and known responses of the standards. Under ideal conditions, systematic effects would be completely characterized and removed. A figure of merit for a calibrated system is the magnitude of the residual systematic effects. These are the portion of the uncorrected systematic error that remains because of imperfections in the calibration standards or method.

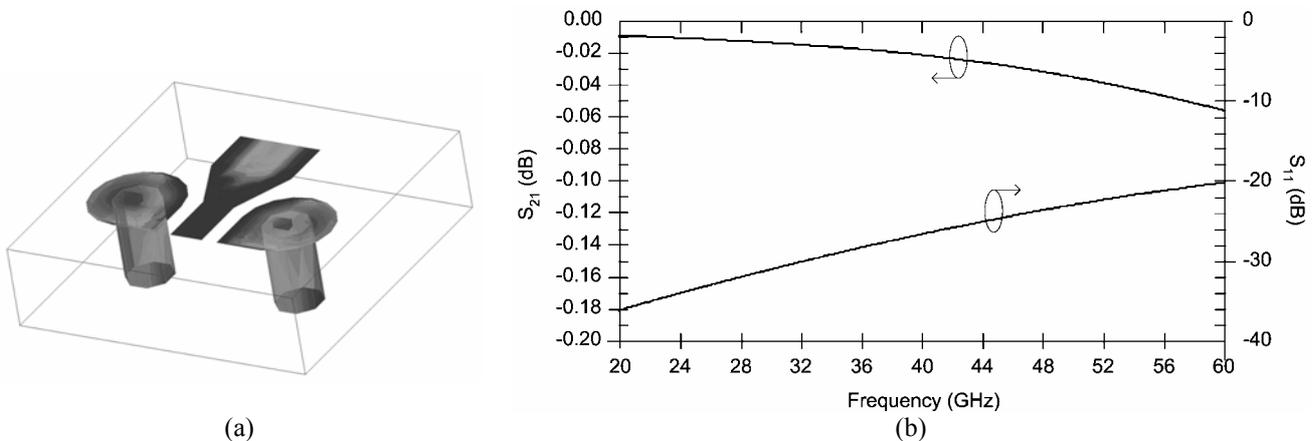


Fig. 2. (a) View of the microstrip to coplanar line transition (b) S-parameters of one transition

The S-parameter tests can be done using different types of calibration methods. The more accurate type is a vector calibration, correcting for both magnitude and phase. The most popular calibration method is the classic SOLT (Short, Open, Load, Thru), but this method has disadvantages, being the principle the accuracy of the standards. The better the standards are known, the better the calibration. An accurate characterisation of the SOLT standards is difficult at millimetre-wave frequencies. A better method is the TRL (Thru, Reflect, Line) because it is based on a transmission line standard [4]. The one precision standard is the line. Its characteristic impedance sets the reference impedance for the whole test system. The Reflect does not have to be a perfect open or short. The Line standard can cover an 8:1 frequency range. For wider bandwidths more than a Line standard is required. The TRL calibration method has been used for the test described below because its simplicity and quality and the good standards availability.

The calibration substrate (Alumina 10 mil thickness) contains microstrip lines, precision 50 Ohm loads, short and open circuit structures. All the structures are compatible with a wide variety of coplanar probes. It allows various calibration methods (SOLT, TRL, LRM, LRL).

The TRL calibration was performed from 20 GHz up to 50 GHz, using the multiline method. The calibration elements consist of a 0 psec line (Thru), one short (Reflect) and one additional 5.2 psec line (Line). After the calibration the residual systematic errors are small as Fig. 3 depicts in the case of the Thru standard.

## 5. DEVICE MEASUREMENTS

The S-parameter test method has been used to test millimeter wave devices: low noise PHEMT transistors, PIN diodes, microstrip band pass filters, microstrip switches and thin-film broadband attenuators up to 50 GHz. Test results have been very useful for further integration of these devices in more complex receiver systems.

### 5.1. Passive devices

A broadband band pass filter in the Q band was designed [5]. This circuit was initially tested using a test fixture and the presence of several poles in the in-band response of the filter and the high insertion loss, caused by the double coaxial-to-microstrip transition, were observed. The first thing to do was to eliminate all the inaccuracies of the test method which can mask the actual behaviour of the circuit, and to obtain an accurate measurement up to 50 GHz. A coplanar to microstrip transition connected to a coplanar probe station was used. The circuit is shown in Fig. 4 (a) and its behaviour in Fig. 4 (b). Using the coplanar to microstrip transition to test the filter, the tested results were quite close to the simulations.

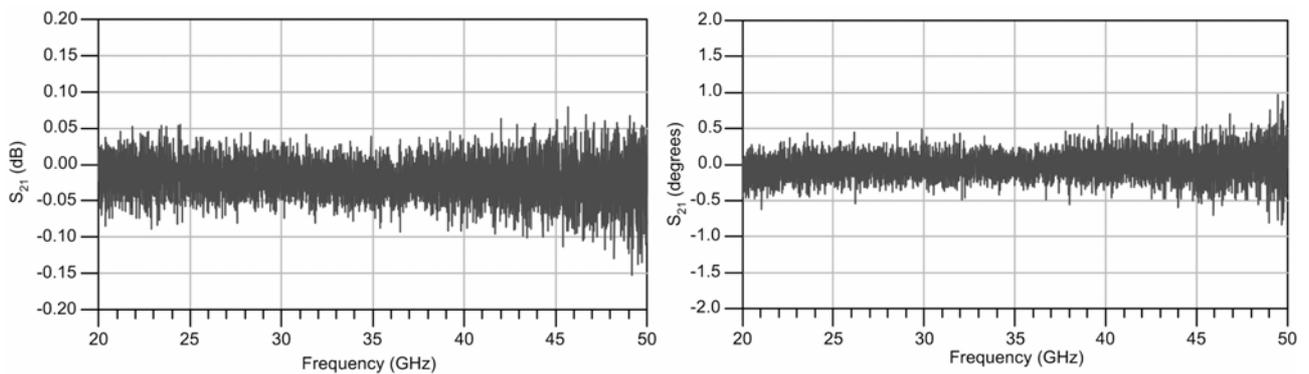
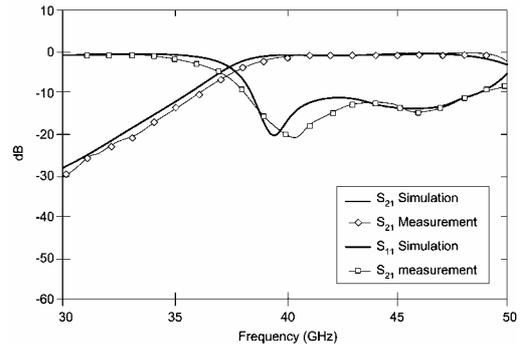


Fig. 3. Magnitude and phase of the Thru measurement after correction with a TRL calibration



(a)



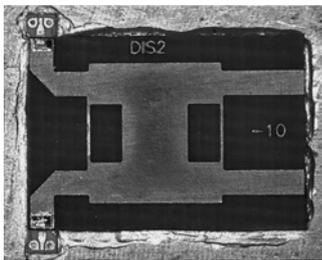
(b)

Fig. 4. (a) Three resonator band pass filter, (a) Insertion loss and return loss of the band pass filter

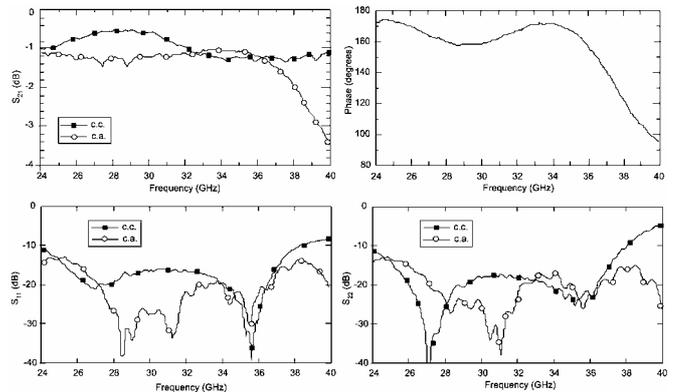
A broadband 3dB branch coupler in the Ka band was tested as a two port network using coplanar to microstrip transitions as Fig. 5 (a) shows. The coupler was tested twice, one with coupled branches open-ended and other connected to ground. The S-parameters obtained, which are depicted in Fig. 5 (a), showed a good agreement in magnitude and phase.

A PIN diode HPND-4005 was tested up to 50 GHz in order to be used to design a broadband phase switch. The diode was tested in Off and On states for several currents as Fig. 6 shows.

Several microstrip broadband attenuators have been designed. The attenuator has been developed with a topology that provides constant attenuation over broad bandwidth with good input and output matching, which requires a reliable test fixture. The use of coplanar transitions has provided accurate measurements. One attenuator of 3 dB is shown in Fig. 7 (a) and the attenuation and matching tested are depicted in Fig. 7 (b).

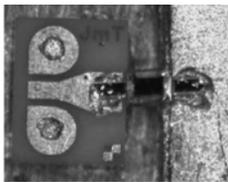


(a)

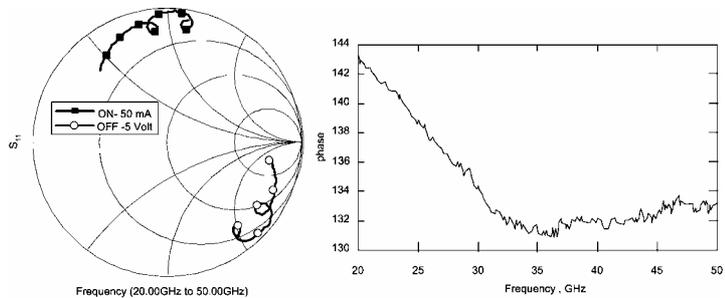


(b)

Fig. 5. (a) Broadband 3 dB branch coupler, (b) S-parameters and  $S_{21}$  differential phase results (cc: short, ca: open)

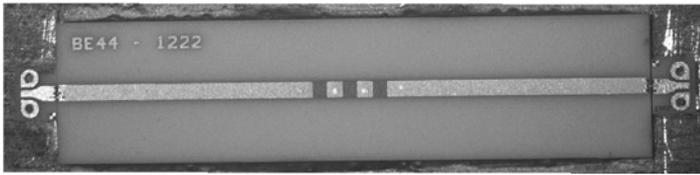


(a)

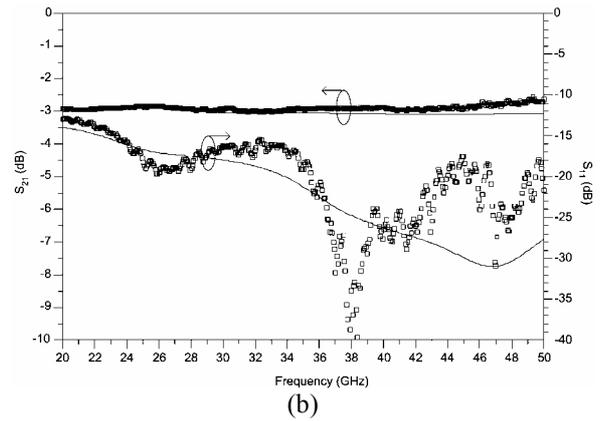


(b)

Fig. 6. (a) PIN diode HPND-4005, (b) Reflection coefficients of the PIN diode for Off (-5 Volt.) and On (50 mA) states. Phase plot is the  $S_{11}$  differential phase in degrees between Off and On states.



(a)



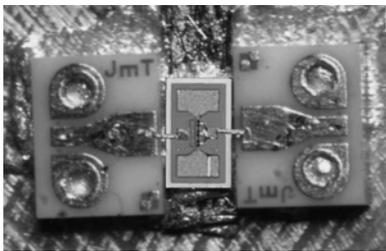
(b)

Fig. 7. (a) Microstrip attenuator, (b)  $S_{21}$  and  $S_{11}$  test results (dots) compared with simulated performance (solid lines)

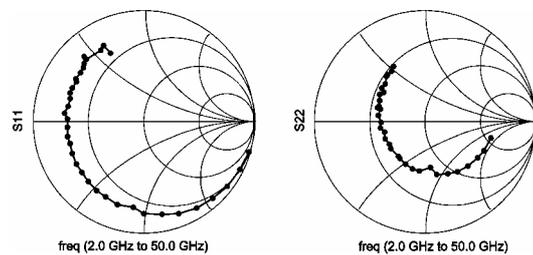
## 5.2. Active devices

For the design of circuits it is very important to have an accurate model or characterization of the active device. Before designing some amplifiers in the Q band, the EC2612 GaAs PHEMT transistor from UMS was tested using the coplanar to microstrip transitions as Fig. 8 (a) shows. The chip has internal via holes for the source connections to ground. The drain and gate were bonded with  $17.5 \mu\text{m}$  gold wires and length  $200 \mu\text{m}$ . The reflection S-parameters of the transistor for  $-10 \text{ dBm}$  input power, drain voltage 2 Volt and a drain-to-source current 10 mA, are shown in Fig. 8 (b).

The measurements of the transistor and the designed matching networks were used to obtain accurate models of all the elements needed to design a one stage amplifier shown in Fig. 9 (a). This was assembled with transitions and tested using coplanar probes. The bonding wires to connect the transistor were as similar as possible to those used to test the transistor alone. S-parameters in Fig. 9 (b) are for 2 Volt drain voltage and 10 mA. This figure includes simulated and tested results, which show very good agreement.



(a)

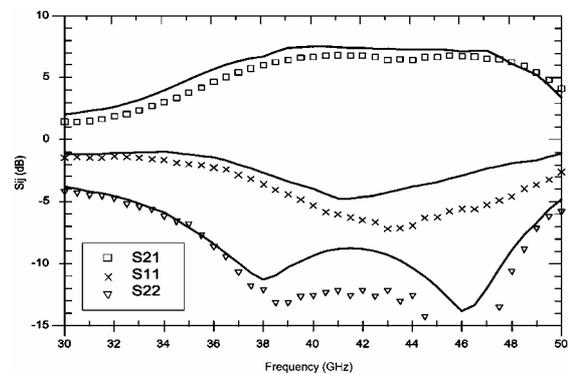


(b)

Fig. 8. (a) Photograph of a EC2612 transistor assembled with coplanar transitions, (b) Reflection S-parameters



(a)



(b)

Fig. 9. (a) Photograph of one stage amplifier assembled with coplanar transitions, (b) S-parameters magnitude of one stage amplifier, solid lines are simulated results and symbols are tested results

The last circuit presented consists of a phase switch in the Ka band which is composed of the broadband branch coupler and the PIN diodes tested previously. A photograph of the circuit is shown in Fig. 10 (a) and its tested results are shown in Fig. 10 (b).

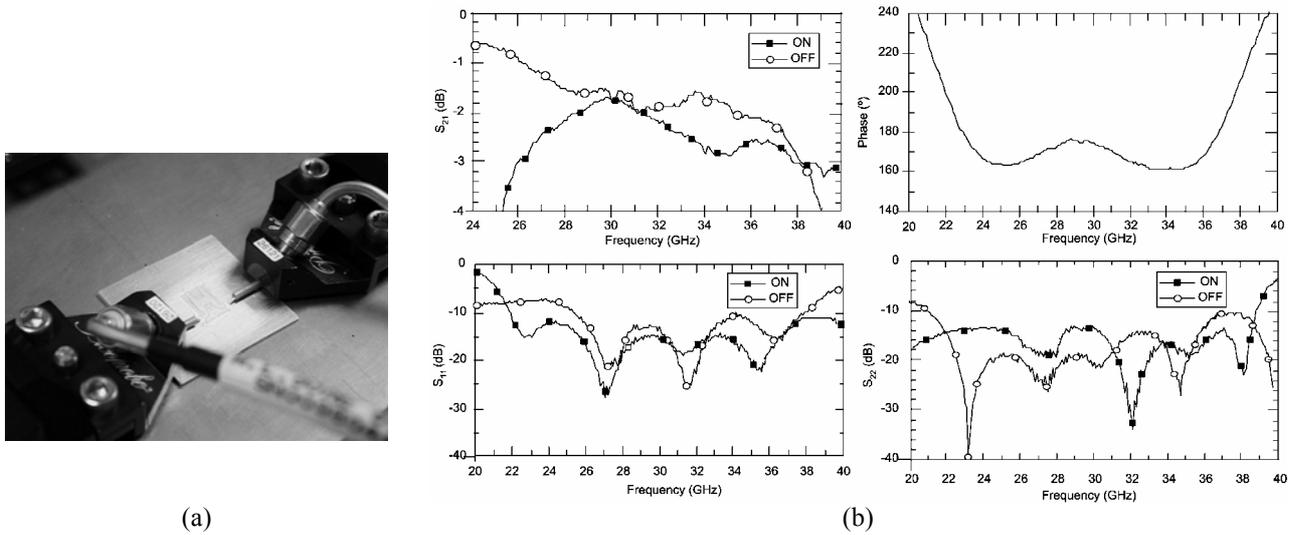


Fig. 10. (a) Coplanar probes testing of a PIN diodes phase switch at 30 GHz assembled with coplanar line transitions (b) S-parameters of the phase switch. Phase plot is the differential phase of the  $S_{21}$  from On to Off states of PIN diodes.

## 6. CONCLUSIONS

A test bench for S-parameters measurements up to 50 GHz has been presented. The use of broadband coplanar to microstrip transitions and coplanar probes has provided accurate characterisation of passive and active devices. This method of testing permitted to predict the behaviour of more complex circuits and systems using the obtained S-parameters in a commercial CAD software.

## 7. ACKNOWLEDGEMENTS

This work has been supported by the Ministerio de Educación y Ciencia, Plan Nacional de I+D+I, Programa Nacional de Espacio, grant reference ESP2004-07067-C03-02. The authors would like to thank Alexandrina Pana and Eva Cuerno for their careful assembly of the circuits.

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