MILLIMETRE-WAVE DEVICE MODELLING DIFFERENCES IN MICROSTRIP AND COPLANAR WAVEGUIDE

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ABSTRACT

The measurement of an active device produces results which are dependent on the transmission medium in which the device is embedded. These differences, insofar as a particular device is concerned, are related solely to its extrinsic elements, the intrinsic device being the same in all cases. Results are presented for on-wafer measurement and 2D simulation of a specially designed active device and its associated transmission structure in both microstrip and coplanar waveguide. This dual approach has the advantage of enabling a model for the intrinsic device to be validated and the extrinsic model elements for both structures to be obtained.

INTRODUCTION

Choosing a circuit topology to represent the extrinsic behaviour of a millimetre-wave device is dependent on the method of application and characterization of the device itself. For instance, Figure 1 shows the different measured S-parameter results which are obtained for essentially the same device when measured in microstrip and coplanar waveguide. The purpose of this paper is to model correctly extrinsic device topologies in the millimetre-wave frequency range that correspond to carefully defined model and measurement reference planes, while the devices are measured in coplanar and microstrip test formats. The extrinsic models are validated by the resulting similar intrinsic model elements.

The measured and simulated results are obtained for pseudomorphic HEMTs with a 0.2 μm gate length arranged in a 6x15 μm configuration with typical extrinsic f_t's of 70 GHz. Well controlled gaussian process variations enabled the selection of a mean and ± one standard deviation device in microstrip and coplanar waveguide. State-of-the-art automatic probing facilities were used for all measurements.

EXTRINSIC MODELS AND THEIR EXTRACTION

Definition of the model reference plane, Figure 2, is of paramount importance in the millimetre-wave frequency range as it affects the level of higher-order modes. If the measurement and model reference planes are not at the same location then de-embedding is required to move the measurement reference plane to the model reference plane. This in itself is process sensitive, may be difficult to perform accurately in the millimetre-wave frequency range, and be inaccurate due to electromagnetic interaction and higher-order mode generation.

Significant differences in the extrinsic device models revolve around the differences between the coplanar ground located on the top of the wafer and the substrate ground located on the bottom of the wafer. There is some parasitic capacitive coupling to the substrate ground in both situations but the extrinsic parasitic capacitances are larger in the coplanar case. In the microstrip case there is a common ground between the source and parasitic capacitances, but there is a larger source inductance due to the via-holes. A simple inductor equivalent circuit for a via-hole is inadequate above 40 GHz and consequently distorts the values of the other extrinsic elements.

The equivalent circuits, Figure 3, are the simplest ones possible which correctly model the different parasitic values and topologies when measuring in microstrip or coplanar. To separate the extrinsic elements from the intrinsic elements modifications to the methods developed by Dambrine et al [1] were used. In the microstrip case the method is slightly modified to account for source pad capacitance (Cps) and to accommodate a more complex equivalent circuit for the via-holes. In the coplanar case the topology is different.

A series of passive device structures were tested which resulted in a validation of the extrinsic model elements by allowing a direct comparison with the 2D electromagnetic field simulation [2] (Figure 4), of the devices and surrounding coplanar and microstrip test structures.

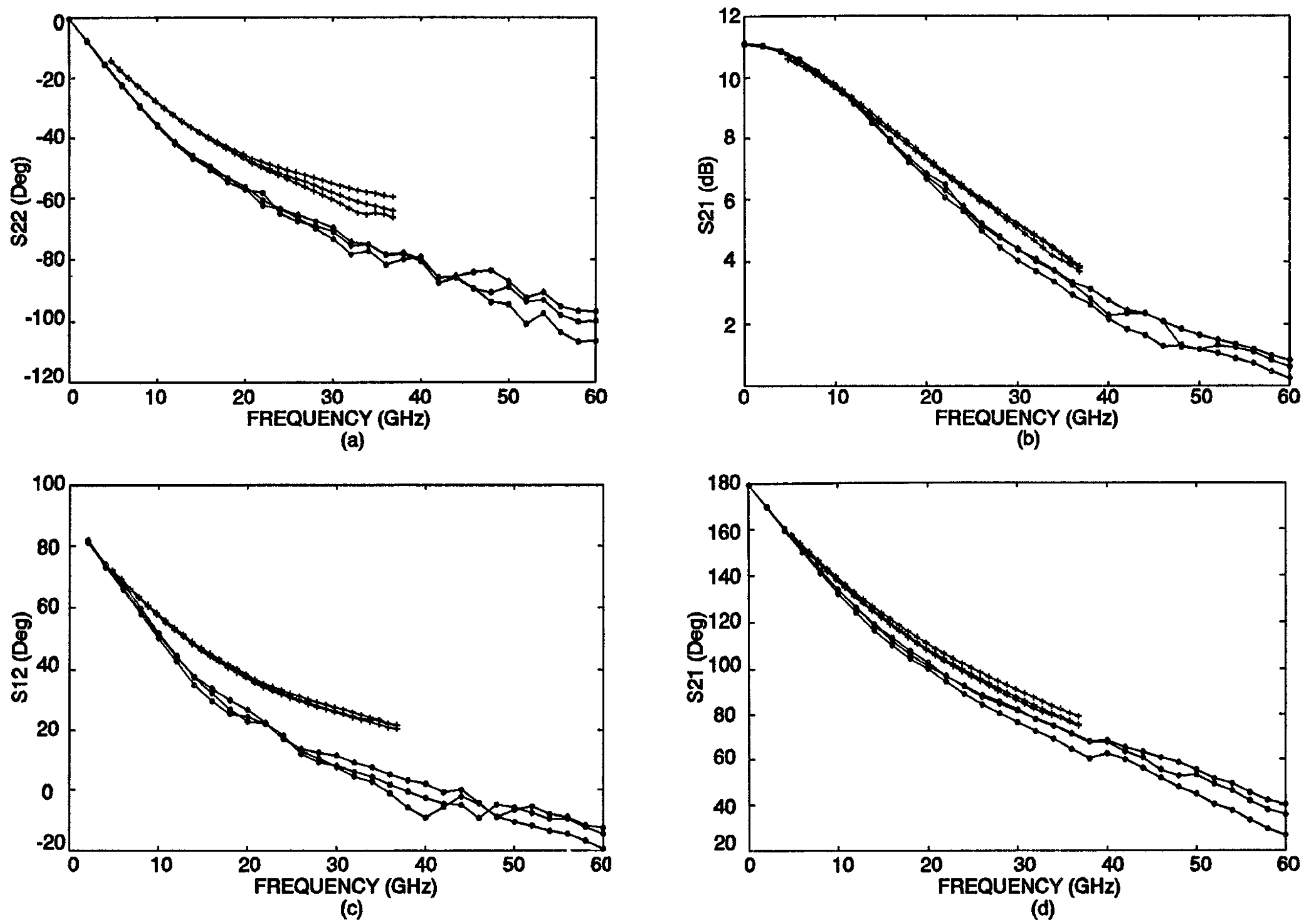
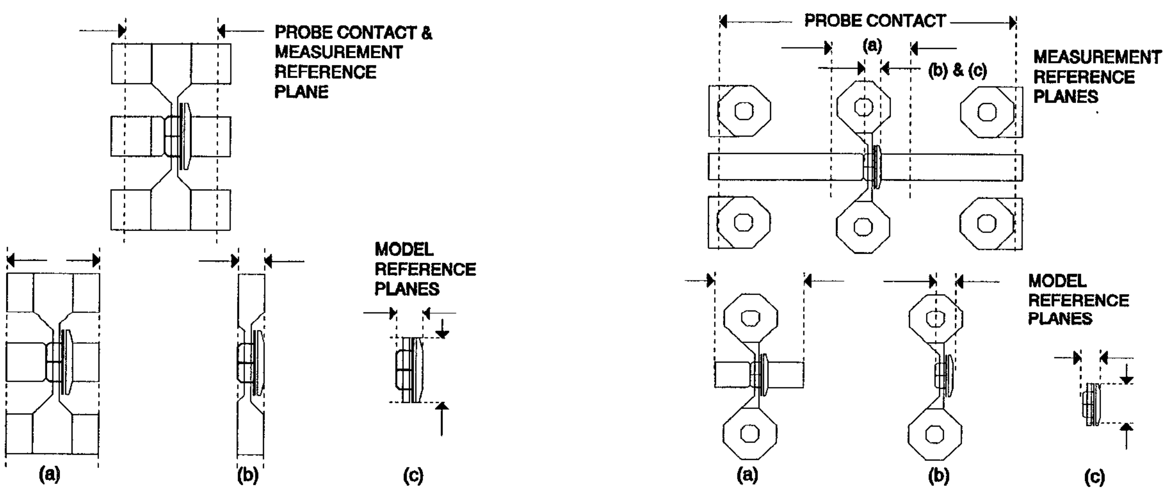


Figure 1 - Measured S-Parameter Data in Coplanar (o) & Microstrip (+) For Mean & ± Standard Deviations



Coplanar Reference Planes

Microstrip Reference Planes

Figure 2 - Model Reference Planes & Test Formats

EXPERIMENTAL RESULTS

Before performing S-parameter measurements it was necessary to select devices that were intrinsically similar. This was done by measuring the d.c. I-V characteristics, from a sample of 49 devices on the same wafer, and selecting 3 devices whose characteristics fell within the mean and ± one standard deviation in both test formats [3].

Coplanar model extraction as described above was performed on the measured data. The resulting intrinsic model elements [4] as a function of frequency are shown in Figure 5. Small-signal transconductance (gm) is not shown as it was constant and frequency independent for both the coplanar and microstrip extraction process. Also shown in Figure 5 is the resulting intrinsic extraction if microstrip measured data is used while using the same topology and extrinsic elements values as in the coplanar case, and after the correct microstrip topology and extrinsic element values are used.

Note that there is still some frequency dependence for Cds and Cgs especially in the coplanar case. This is due to the relatively simple extrinsic model topology that was chosen. However the flatter response achievable in the microstrip case indicates a simpler extrinsic model will produce a better or at least comparable fit. In all the model element responses the microstrip based measurement data is smoother.

CONCLUSIONS

Testing intrinsically similar devices in coplanar and microstrip has the unique advantage of helping to ensure physically correct extrinsic elements while yield two measurement perspectives on similar intrinsic model elements. For a similar number of extrinsic model elements in the microstrip and coplanar waveguide cases it was possible to achieve a flatter frequency independent intrinsic model element response in the microstrip case.

REFERENCES

[1] G. Dambrine, A. Cappy, F. Heliodore, E. Playez, "A new method for determining the FET small-signal equivalent circuit", *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-36, Jul. 1988, pp. 1151-1159.

[2] Sonnet Software

[3] P.C. Walters, R.D. Pollard, J.R. Richardson, P.M. Gamand, P.R. Suchet, "Coplanar versus microstrip measurements of millimetre-wave devices", *Proc. 40th IEEE Automatic RF Tech. Group (ARFTG)*, Orlando, Florida, Dec. 1992.

[4] M. Berroth, R. Bosch, "High frequency equivalent circuits of GaAs FET's for large-signal applications", *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-39, Feb. 1991, pp. 224-229.

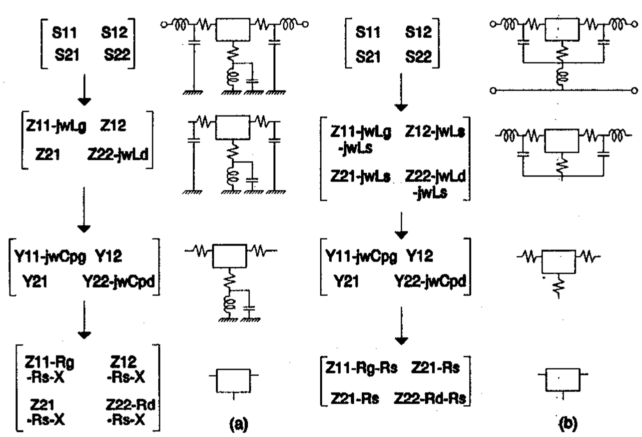


Figure 3 - Extrinsic Extraction For (a) Microstrip & (b) Coplanar Topologies

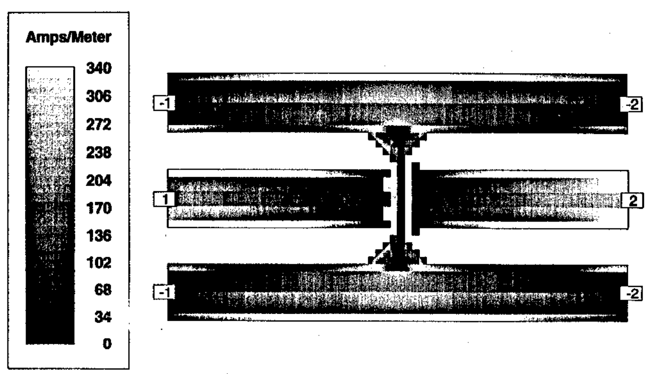


Figure 4 - Electromagnetic Simulation of the Coplanar Device Test Format at 60 GHz (Sonnet Software)

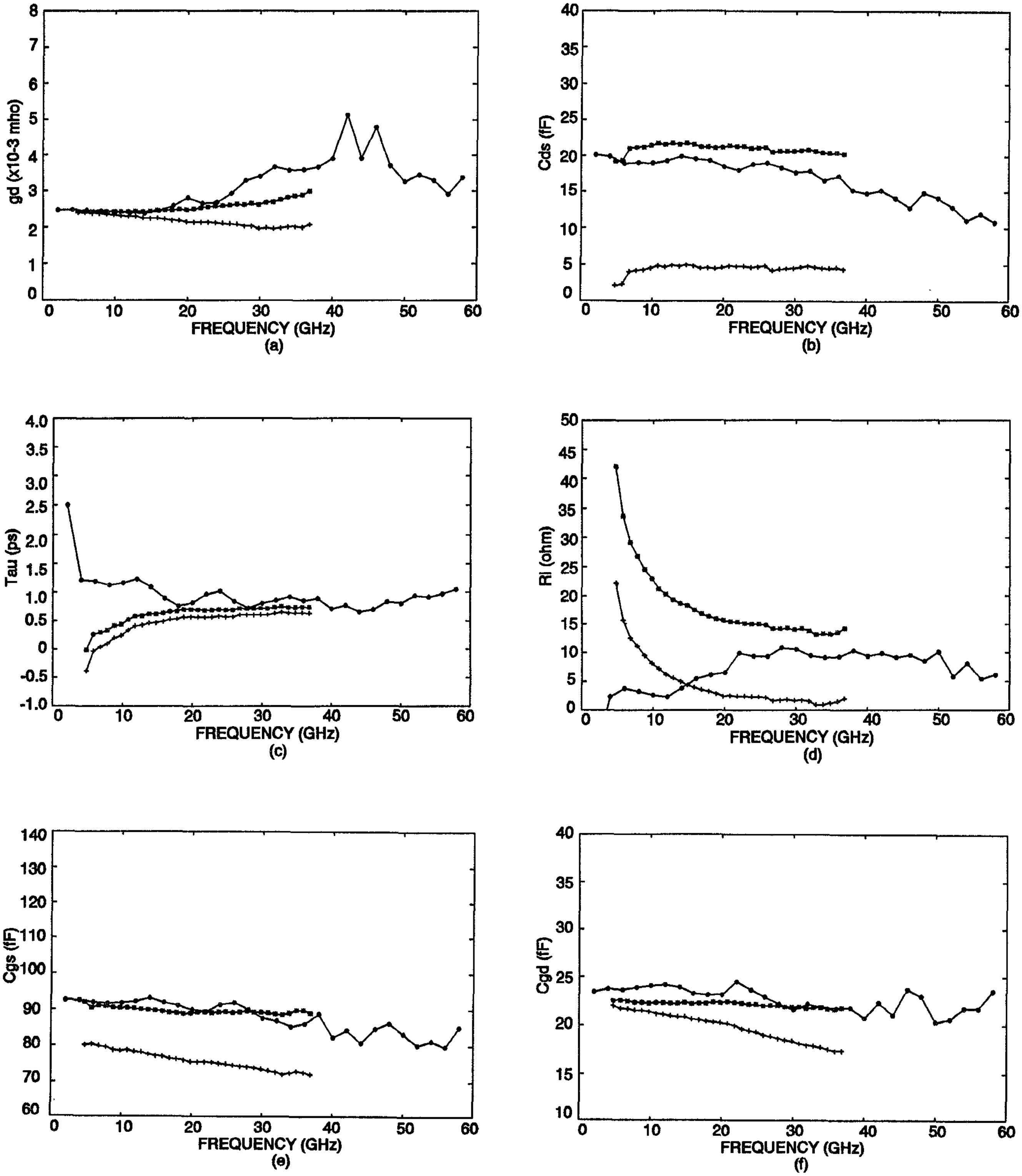


Figure 5 - Intrinsic Model Elements; After Coplanar Extraction (o); After Coplanar Extraction With Measured Microstrip Data (+); After Microstrip Extraction (*) With Correct Topology & Extrinsic Elements