CHARACTERIZATION OF ACTIVE AND PASSIVE MILLIMETER-WAVE MONOLITHIC ELEMENTS BY ON-WAFER PROBING

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ABSTRACT:

A Technique for modeling active and passive monolithic elements in a microstrip environment at millimeter wave frequencies using on-wafer probing is developed. This procedure involves accurately characterizing the coplanar waveguide to microstrip transition used in making on-wafer measurements. Once the transition is characterized, the models for various elements can be determined.

INTRODUCTION:

Since the advent of on-wafer probing techniques at microwave frequencies (1)(2), the testing of MMIC's has been greatly simplified. On-wafer probing allows for non-destructive, rapid measurement of S-parameters if circuits and devices up to 50 Ghz. Several calibration and de-embedding techniques which are directly applicable to on wafer probing have been developed and implemented with good results (3-5). On-wafer probing opens doors to statistical characterization, adaptive processing and 100% screening of MMIC's. One problem with present techniques is that the embedding media is inherently coplanar waveguide. The vast majority of MMIC's for use under 50 Ghz are designed in microstrip. For coplanar techniques to be useful, a transition between the two media must be made. When using adaptive processing, the active devices can be measured before circuit metal is applied and the proper circuit pattern can be chosen to complete the wafer. For this to work, a relationship between coplanar measurements of FETs on thick substrates without via holes and microstrip FETs on thinned substrates with via holes must be developed. The technique described in this paper can be used to develop this relationship.

TRANSITION CHARACTERIZATION:

In order to assure highly accurate microstrip based measurements a good transition from the wafer probe to the microstrip must be made. Figure 1 show the layout of the coplanar waveguide to microstrip transition used in the measurements make throughout this work. The transition is configured of Cascade G-S-G type probes usable to 50 Ghz with good performance (2). Via holes are used on the ground pads to connect the coplanar ground to the microstrip ground.

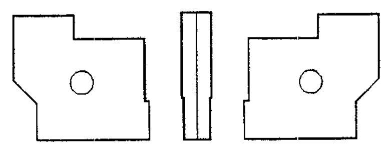

FIGURE #1

In order to obtain the two-port S-parameters of the transition, various lengths (from 26mils to 120mils) of microstrip line were placed between two transitions and the S-parameters were measured form 1.5 Ghz to 40 Ghz using a Wiltron 360 ANA and a Cascade probe station. The standard SOLT calibration on a sapphire ISS was used. The signal flow graph for the experimental set up is show in figure 2. Modifying the equations shown in figure 2 from (6) to include microstrip losses and dispersion, a computer program to de-embed the S-matrix of the transition from the measurement of two different lengths of microstrip line was written. The program assumes the magnitudes of S11 and S22 of the transition are << 1. This assumption is valid for this transition since the measured S11 and S22 of the experimental test sets range from .078 to .101 at 40 Ghz and the residual source and load matches are greater than 22 dB from 1.5 to 40 Ghz.

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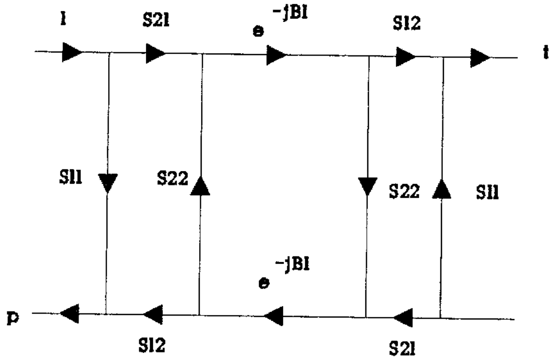
FIGURE 2 - SIGNAL FLOW GRAPH



$$(1)\ S11 = \frac{p1e^{-2jB12} - p2e^{-2jB11}}{e^{-2jB12} - e^{-2jB12}}$$

$$(3)\ s12s21 = te^{jB11}$$

$$(2)\ s22 = \frac{p2-p1}{s12s21\left(e^{-2jB12} - e^{-2jB11}\right)}$$

Figure 3(a) shows the calculated S-parameters for a transition on the Smith Chart. The transmission angle is about equivalent to the phase shift from a similar lent of coplanar transmission line. The transmission loss is less the .3 dB up to 40 Ghz. The match is better than 20 dB over the entire frequency range indicating a very good transition. Figure 3(b) shows a comparison of a measurement of a 120 mil line between two transitions and a simulation of the same using the derived S-matrix of the transition and the Touchstone model of the 120 mil line. Excellent agreement is seen over the entire measurement.

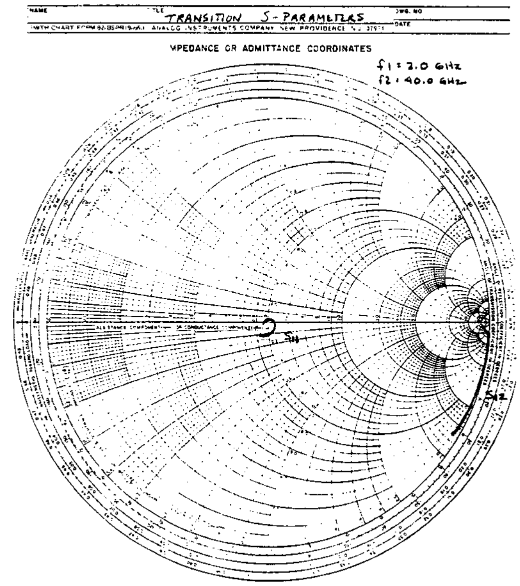


FIGURE #3(A)

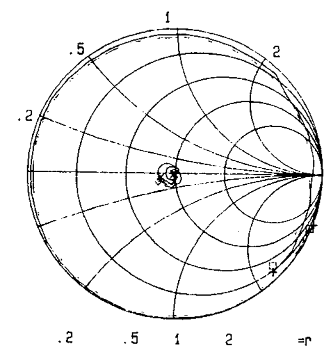


FIGURE #3(B)

COMPONENT CHARACTERIZATION:

The main difference between an FET embedded in a coplanar environment and one embedded in a microstrip environment is the effects of the source impedance due to via hole grounding (7). The source impedance (series R-L) tends to increase the input impedance of the FET and therefore lower the maximum available gain (MAG). In some case the increased feedback due to the common lead inductance will lower the Rollet k factor and increase the MAG. At millimeter frequencies however the source impedance usually lowers the MAG. Figure 4 compares the directly measured S21 and calculated MAG for a coplanar measured FET to that of a measured and de-embedded microstrip FET from the same reticle at the same bias. Some source impedance effect can be seen. Once the two-port S-parameter block is developed for the transition, the device S-parameters can be de-embedded from the measurement of an FET embedded in microstrip. A negation element in a CAD program can be used to peel away the embedding network and give device level S-parameters.

Another experiment was necessary to use this technique in adaptive processing. Before the test wafers were thinned to their final thickness of 100 microns, the S-parameters of several FETs were measured in the coplanar environment. After the wafers were thinned, the same FETs were measured again. Figure 5 compares these two sets of S-parameters. The difference between the two is well within the measurement and bias point repeatability. Therefore, if adaptive processing techniques are to be implemented, the thick coplanar measurements can be taken and modified to account for the microstrip environment and then the correct circuit pattern can be chosen.

The characterization technique is also applicable to passive components, lumped elements and microstrip discontinuities. Figure 6 shows a test array used for developing models of passive components and discontinuities.

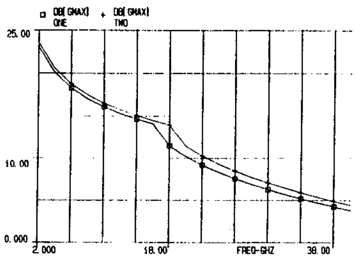


FIGURE #4

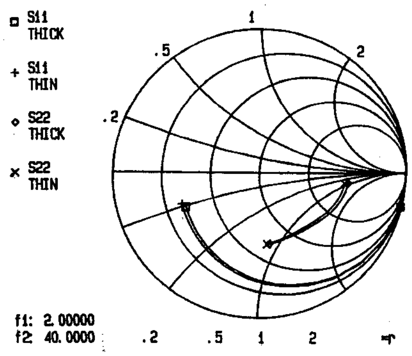


FIGURE #5

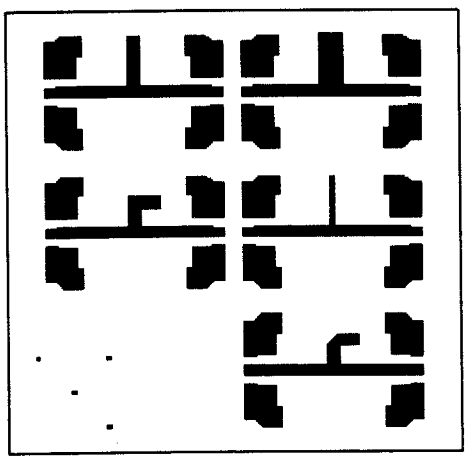


FIGURE #6

CONCLUSIONS:

A technique for accurately characterizing monolithic components at millimeter frequencies using on-wafer probing was reported. This method which is based on characterizing the coplanar waveguide to microstrip transition is extremely useful for developing CAD models and enhancing monolithic circuit yields through adaptive processing. This technique can be used in conjunction with any probe calibration technique such as TRL or MMAVERIC (8) as the calibration is independent of the characterization.

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