A NON-CONTACTING PROBE FOR MEASUREMENTS ON HIGH-FREQUENCY PLANAR CIRCUITS

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ABSTRACT

A novel probe for internal measurements on high-frequency planar circuits has been designed and tested. It requires no electrical contact with the circuit and has little or no effect on the circuit under test. Amplitudes and phases of currents at arbitrary positions can be measured.

Using microfabrication techniques, working probes have been constructed for measurements in the 26.5-40 GHz band. Performance characteristics and typical measurements will be described. Direct measurements obtained with these probes provide new information on internal circuit operation. The technique can also be applied to rapid production testing.

INTRODUCTION

High-frequency planar circuits, especially those in monolithic form (MMICs), raise new problems in circuit design. In order to analyze the operation of these circuits, it should be helpful to make measurements of voltages and currents at internal points while the circuit is in operation. For this purpose, we have developed a non-contacting magnetic field probe, capable of measuring currents at arbitrary points of a microcircuit without disturbing the circuit under test.

The standard technique for connection to MMICs involves the use of contacting coplanar waveguide probes.(1) These are capable of making well-calibrated connections at the input and output points in circuits. However, they require special contact pads, and via holes or large bypass capacitors are required to make the ground connections for microstrip circuits. Such probes are unsuitable for measurements at interior points of the circuit not only because the contact pads are usually absent, but also because connecting the probe would produce a great disturbance of the circuit. An alternative approach is the electro-optic technique.(2,3) This approach is clever and promising, but has some disadvantages. The required apparatus is expensive and complicated; moreover the technique cannot be used directly on non-electro-optic substrates such as silicon or duroid.

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MAGNETIC FIELD PROBE DESCRIPTION

The technique described here uses a non-contacting magnetic field probe. It is an outgrowth of a 1-GHz probe invented in 1985.(4) Here we describe its first successful microfabrication in a form suitable for use at millimeter-wave frequencies. The probe consists of two loops and has the form of a magnetic quadrupole as shown in Figure 1. Its field configuration matches the fields of either microstrip or coplanar waveguide (CPW). In either case, the waveguide's magnetic field goes up through one loop and down through the other. Because of the loops' configuration, their contributions add. On the other hand, signals induced in the two loops by a nearly uniform field coming from a distant source, such as another waveguide in the microcircuit for example, tend to cancel as shown in Figure 2.

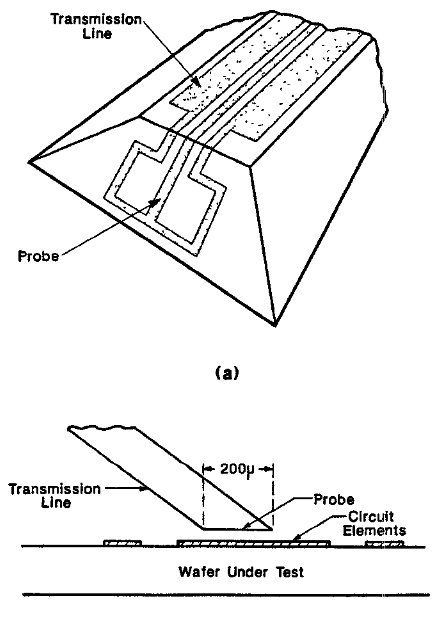

Figure 1 a) Probe on angled face of silicon wafer. b) Probe over circuit elements

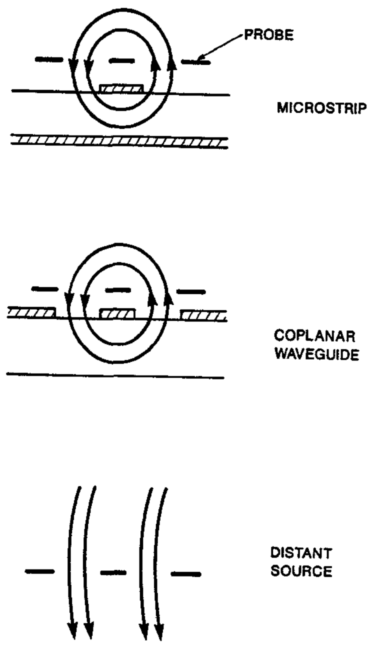

Figure 2 Field coupling between the probe and various sources

A typical measurement setup is shown in Figure 3. The current induced in the probe passes through a CPW transmission line to a spectrum analyzer. By this means, measurements of current amplitude can be made. If phase measurements are required, a reference signal of the same frequency and adjustable phase is added to the probe signal. The reference signal's phase is varied until the amplitude seen by the spectrum analyzer is maximum.

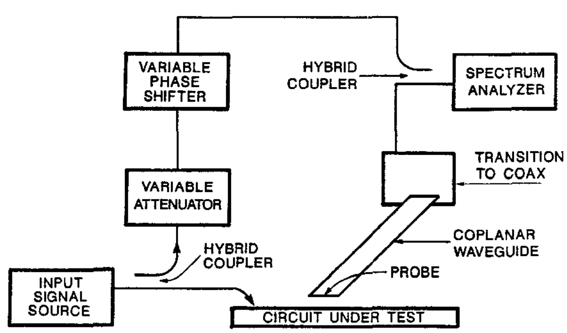

Figure 3. Probe measurement setup

SCALE MODEL MEASUREMENTS

By means of repeated modeling experiments, needed to find the best proportions and dimensions, the design of the probe has been optimized. A typical measurement of the standing wave on a shorted microstrip made with an enlarged 165 MHz scale model is shown in Figure 4. Spurious signals can come from other waveguides adjacent to the waveguide being probed. Figure 5 shows the signal received by the model probe as it is moved from side to side over the same 165 MHz waveguide. A signal from a waveguide 5 centimeters away from the waveguide under test, equivalent to 250 microns away at 33 GHz, would be reduced by 37 dB. The tri-lobed pattern seen in Figure 5 can be explained as follows. The probe signal is a maximum over the center of the waveguide where the field strength is equal in both loops but opposite in direction. As the probe moves across the waveguide, the direction of the field through the loops changes to the same direction through both loops. This new configuration is similar to that of a signal from a distant source. The probe rejects this signal and an output null is observed. As the probe moves over the ground plane, the magnetic field goes mainly through one loop. A secondary maximum is observed. As the probe moves further away from the waveguide, the field through the loops and the output signal continue to decrease.

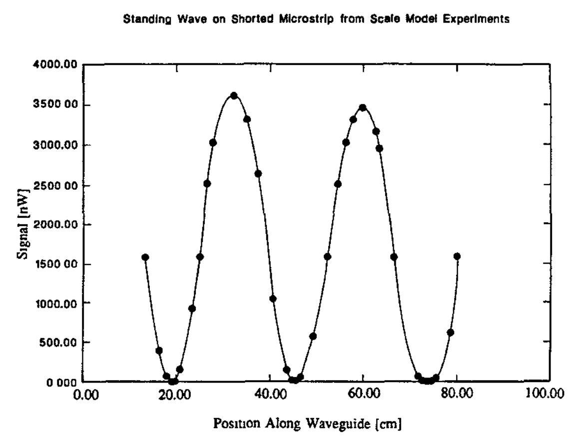

Figure 4 Power Standing Wave measured on shorted microstrip at 0.165 GHz Microstrip width=1.0 cm Loop width=0.8 cm Height above microstrip=0.5cm

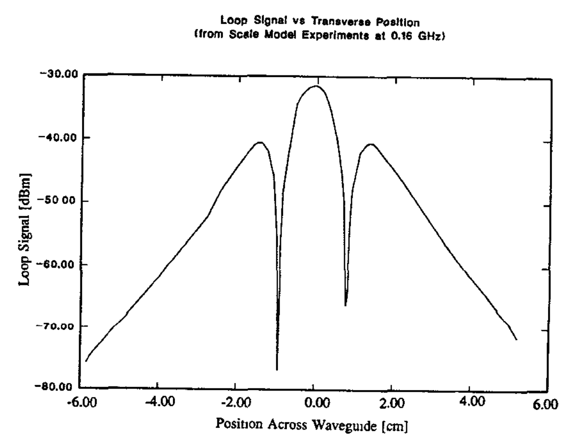

Figure 5 Probe Signal vs Transverse Position over microstrip measured at 0.165 GHz

33 GHz MEASURMENTS

Probes were microfabricated on high-resistivity silicon substrates for use in the 26.5-40 GHz band, as shown in Figure 1. The silicon wafer was anisotropically etched to produce the 54.7-degree angled face on which the probe is located. Photolithography was used to define the probe on the angled face and the coplanar waveguide on the large surface of the wafer. A special wafer holder was used to align the two patterns.

It is necessary to place the probe close enough to the line under test, in order to obtain a large signal and thus discriminate against distant sources. On the other hand, one cannot come too close without disturbing the circuit under test. We find that a position 25 to 50 microns above the waveguide provides sufficient coupling and discrimination while producing a negligible effect on the circuit under test.

Measurements made at 33 GHz on a CPW are shown in Figure 6. The launcher transition from the coaxial line to the CPW was a Wiltron K connector with a sliding contact. From these data the presence of a second mode of propagation, in addition to the principal CPW mode, is clearly seen. This illustrates the utility of the probe, since without this measurement it would be difficult to know the other mode was present. The transverse probe pattern over the waveguide was also measured as shown in Figure 7. The same tri-lobed structure as in the model was observed.

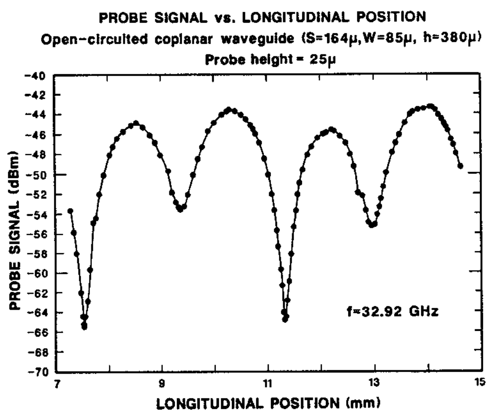

Figure 6 Power Standing Wave on coplanar waveguide measured at 32 92 GHz

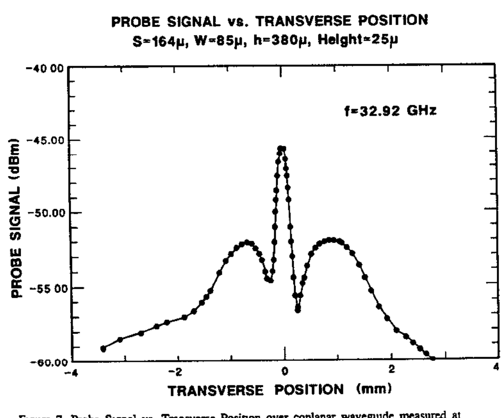

Figure 7. Probe Signal vs Transverse Position over coplanar waveguide measured at 32 92 GHz

CONCLUSION

The magnetic field probe has a variety of applications in various phases of microcircuit design and production testing. Circuit operation can be verified, and S-parameters of embedded passive and active components can be measured. A second probe can be used for signal injection. This would permit rapid verification of individual fabrication steps, or production testing before wafer dicing.

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