Measurements of Field Distributions and Scattering Parameters in Multiconductor Structures Using an Electric Field Probe

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ABSTRACT

A simple electric coaxial field probe for application in the 0.05-20 GHz band has been developed, which can measure not only the magnitude and the phase of the microwave field distribution inside multiconductor RF and microwave circuits, but also the scattering parameters at arbitrary reference planes inside the structures can be measured using this technique.

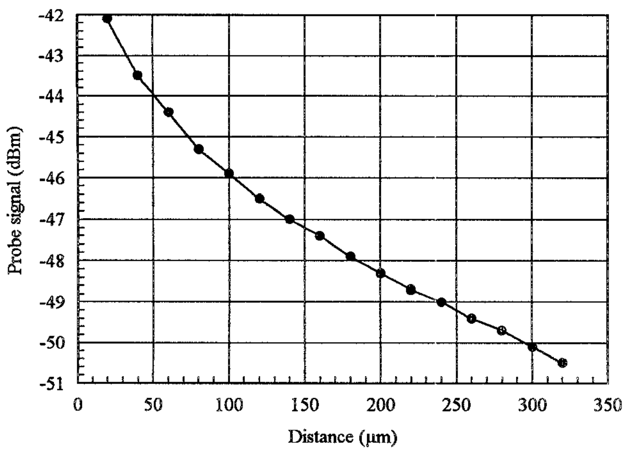
INTRODUCTION

In the last years great progress has been made in the development of microwave - elements and - circuits. The development of complex circuits and systems requests a complete new test system in microwave regime. The measurement only of input and output signals using a network analyzer (NWA) is not sufficient to analyze the function and errors, because in many cases the obtained information is not sufficient to localize the reason of the error. A nonconducting scanning microwave field probing technique has been developed which measures the surface electric [1] and magnetic [2, 3] field distributions of the circuits. A measurement technique for scattering parameters has been introduced by Osofsky [2] on the basis of a magnetic field probe and by Majidi-Ahy [4] using an electrooptic sampling. In this paper it will be reported on measurements of scattering parameters in complex microwave circuits. The results of the measurements demonstrate that such simple and cheap coaxial electric field probes can be used to get much better results than with other complex probe techniques.

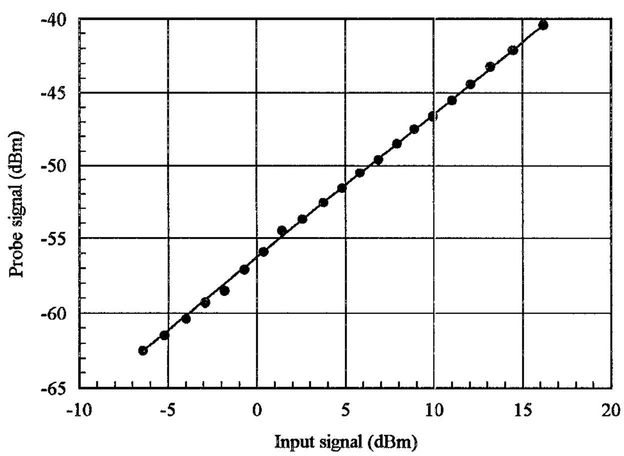
PROBE CHARACTERIZATION

The electric near field probe for measuring the electric field in z-direction is a very simple construction from a 50 Ω semirigid coaxial cable with 508 μm outer diameter and 112 μm inner conductor extending 300 μm beyond the outer conducting shield, as shown in [1]. The measurement system has been discussed in [3], but instead of a NWA a spectrum analyzer is used here to characterize the probe.

A microstrip line terminated with a coaxial 50 Ω load is used as DUT for characterizing the probe. Firstly the probe signal changing with the distance between the probe and the DUT is tested. For this purpose a microstrip transmission line is excited with 10 dBm input power at 1 GHz. The probe signal is measured using a spectrum analyzer. The measured amplitude of the probe signal is shown in Fig. 1(a). For this measurement the probe signal was changed by about 8.5 dB, when the distance was changed from 20 μm to 320 μm. The probe signal decreases rapidly with the distance, when the probe is near the DUT, for example in a distance of 100 μm. The probe signal changing with the input power of the microstrip line at 1 GHz is shown in Fig. 1(b). Because the electric field probe is a passive probe, the probe signal is linearly proportional to the input power of the microstrip line. The maximum error is about 0.3 dBm. The sensitivity of the measurement system is also tested by measuring the change of the probe signal with the variation of the input signal. The sensitivity of the near field measurement system is below 0.5 dBm.



(a)



(b)

Figure 1: (a) the probe signal changes with the distance between the probe and the DUT, (b) the probe signal changes with the input signal of the microstrip line at 1 GHz.

In order to test the spatial resolution of the probe a five finger interdigital capacitor has been fabricated as shown in Fig.2. It is fabricated on a ceramic substrate (ε_r = 9.8, h = 635 μm). The finger widths and the gap widths are both 100 μm. The vertical electric field distribution of the interdigital structure at 7.0 GHz, which is measured with the electric probe, is shown in Fig.3. For the measurements shown below a vector network analyzer is used as a transmitter and receiver. From the experimental results it can be seen that a spatial resolution of the field probe smaller than 100 μm can be reached.

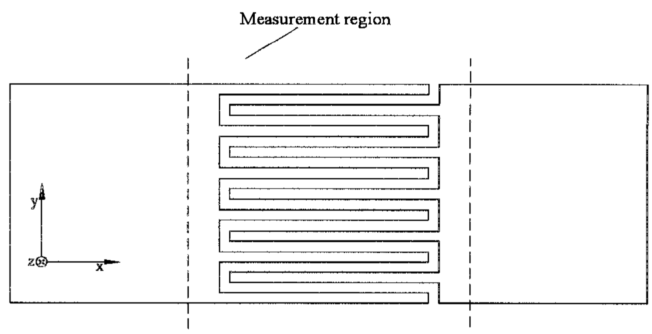


Figure 2: The layout of a five finger interdigital capacitor.

MEASUREMENT OF SCATTERING PARAMETERS

For the function and error investigation of microwave circuits the contactless near field diagnostic system has the advantage of small disturbances on the DUT. For the measurement of the scattering parameters the near field diagnostic system has not the limitation with respect to the number of ports as in the case of the network analyzer. It can be used to measure the scattering parameters almost at any place inside the circuit. To determine reflection coefficients, two complex voltages at two different points must be measured. To determine transmission coefficients of a symmetric, reciprocal 2-port, it is necessary to measure complex voltages at four points - two at each port. The probe signal U_p is proportional to the voltage U on the circuit:

$$U_p = AU \quad (1)$$

where A is a constant. In transmission line theory the voltage of a propagating wave on a transmission line can be described by:

$$U(l) = U_i e^{j\beta l} + U_r e^{-j\beta l}, \quad (2)$$

where U_i is the voltage of the incident wave, U_r is the voltage of the reflected wave. β is the phase coefficient and l is the distance from one port.

For a symmetric and reciprocal 2 - port circuit the scattering parameters can be calculated as follows:

$$S_{11} = S_{22} = b_1 / a_1 \big|_{a_2=0} = b_2 / a_2 \big|_{a_1=0} \quad (3)$$

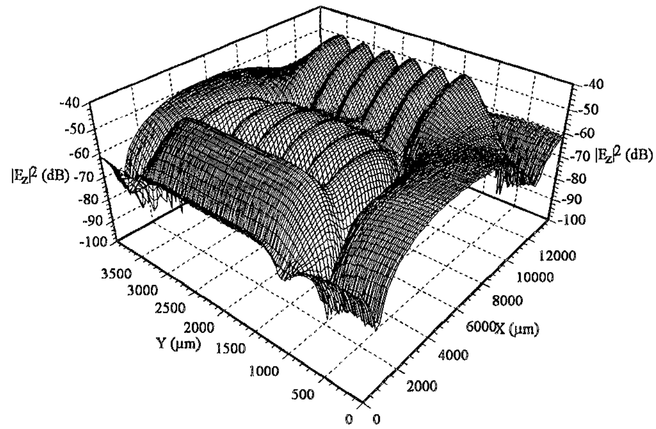
and

$$S_{12} = S_{21} = b_1 / a_2 \big|_{a_1=0} = b_2 / a_1 \big|_{a_2=0}, \quad (4)$$

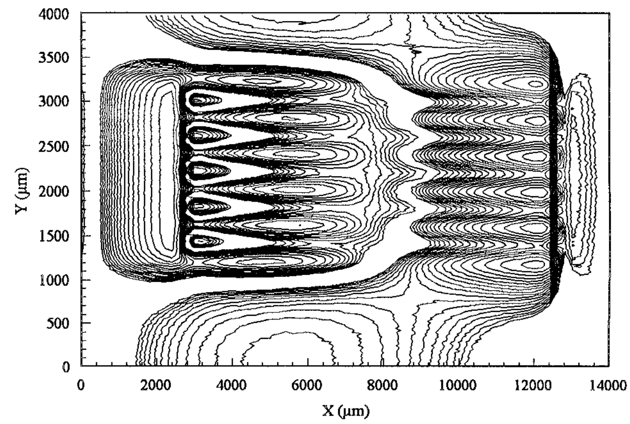
where $$a = U_i / \sqrt{Z_l} \quad (5)$$

and $$b = U_r / \sqrt{Z_l}. \quad (6)$$

With equs. (1)-(6) and the four measured complex voltages the scattering parameters can be calculated. For a normal 2 - port network it is necessary to measure complex voltages at eight different points - four at each port.



(a)



(b) $|E_z|^2 = 1.0$ dB / level

Figure 3: Measured $|E_z|^2$ for a five finger interdigital capacitor at 7.0 GHz.

A band pass filter is taken to test the reciprocal 2 - port circuit, which is shown in Fig. 4 [5]. It is a three stage coupled line filter fabricated on RT Duroid substrate ($\varepsilon_r = 10.8$, h = 635 µm). For the calculation of the s-parameters four complex voltages are measured at the two ports. The measured results are shown in Fig. 5. A comparison of the measured results using the near field probe and the NWA is shown. From the results it can be seen that the agreement of S_{11} is good, but the agreement of S_{21} in the stop band is not good. The reason is that inside the stop band the transmission parameter is very small. The field probe can not measure such small signals. At some frequencies the s-parameters have small deviations from the mean value, because the reflection coefficient of the field probe is not constant in the frequency band. In order to avoid these problems, the field probe must be calibrated against frequency.

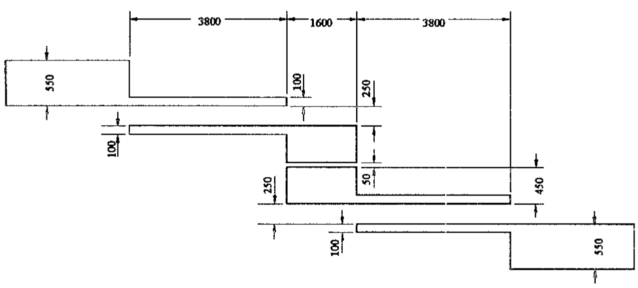


Figure 4: The layout of a band pass filter, dimensions are in micrometers.

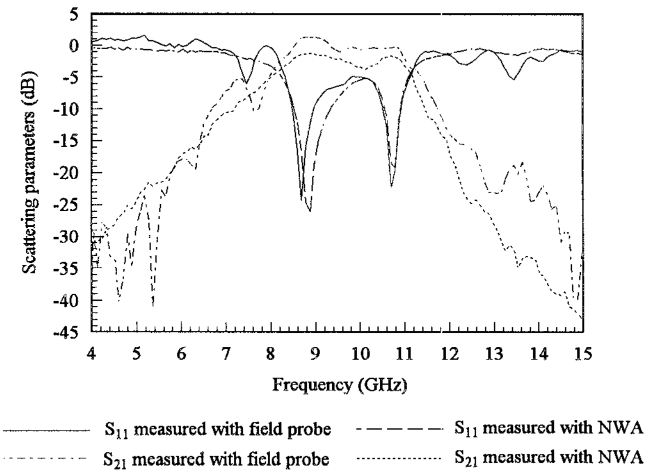


Figure 5: Measured scattering parameters of a band pass filter.

CONCLUSIONS

A simple coaxial electric field probe can be used not only for mapping the electric field distribution above the microwave circuits [1], but also for measuring the scattering parameters at each position inside a microwave integrated circuit.

REFERENCES

[1] Y. J. Gao and I. Wolff, "A simple electric near field probe for microwave circuit diagnostics", in: *1996 IEEE MTT-S Int.* Microwave Symp. Dig., vol.3, paper TH3C-4, pp. 1537-1540, June 1996.

[2] S. Osofsky and S. E. Schwarz, "Design and performance of a non-contacting probe for measurements on high-frequency planar circuits", *IEEE Trans. Microwave Theory Techn.*, vol. 40, no. 8, pp. 1701-1708, Aug. 1992.

[3] Y. J. Gao and I. Wolff, "A new miniature magnetic field probe for measuring three-dimensional fields in planar high-frequency circuits," *IEEE Trans. Microwave Theory Tech.*, vol. 44, no. 6, pp. 911-918, June. 1996.

[4] R. Majidi-Ahy, B. A. Auld and D. M. Bloom, "100 GHz on-wafer S-parameter measurements by electrooptic sampling", in: *1989 IEEE MTT-S Int.* Microwave Symp. Dig., pp. 299-302, June 1989.

[5] T. P. Budka, E. M. Tentzeris, S. D. Waclawik, N. I. Dob, L. P. B. Katehi and G. M. Rebeiz, "An experimental and theoretical comparison of the electric fields above a coupled line bandpass filter", in: *1996 IEEE MTT-S Int.* Microwave Symp. Dig., pp. 1487-1490, June 1996.