A MINIATURE MAGNETIC FIELD PROBE FOR MEASURING FIELDS IN PLANAR HIGH-FREQUENCY CIRCUITS

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ABSTRACT

A new non-contacting miniature magnetic field probe for measuring the surface current distribution on high-frequency planar circuits in the 5 - 20 GHz band has been designed, fabricated and tested. This field probe has a very small dimension and needs no connection to the operating circuit under test, therefore there is almost no perturbation on the circuit properties. This simple and practical magnetic field probe can be used to assist the design of microwave circuits and to test products in industry.

INTRODUCTION

With the growing complexity of circuit-integration techniques, especially in Microwave Integrated Circuits (MICs), there exist many problems in circuit design for example in fault location and test procedures. Conventional network analyzer techniques can only be applied to the device ports, therefore no information on the internal circuit elements is given. To measure detailed field distributions, a miniature magnetic field probe has been developed here. This simple and practical field probe can be used in circuit design, antenna diagnostics and production tests. It is an important advantage for this probe that it does not have galvanic contact with the circuit during the measurement procedure, hence the disturbance of the circuits under test is very small. At least two authors have described magnetic field probes, which were used in similar applications [1 - 3]. Osofsky constructed probes, which consist of two loops and have the form of a magnetic quadruple and which were used in the 26.5 - 40 GHz range [1], and from 0.1 to 0.3 GHz [2]. The described configuration however has an asymmetry of the probe conductor, which therefore also works as an electric field probe in the perpendicular direction. This asymmetry disturbs the magnetic measurements, especially in the position of the magnetic field minimum, where the electrical field is maximum. In the work of Grzybowski and Bansal [3], a half-loop magnetic field probe has been discussed in which a 1 mil gold bond wire was connected to a Cascade Microtech WPH-102-250 wafer probe test head. Because the fabrication procedure is very complicated and additionally the wafer probe test head is expensive, it seems not to be suitable for practical applications. In order to solve all these problems connected with the available magnetic field probes, a the new square magnetic field probe has been designed.

PROBE AND INSTRUMENTATION

In the high frequency regime the dimensions of circuits are very small. In order to accurately measure the amplitude and phase of fields at points inside a circuit, a field probe must be as small as possible, so that the perturbation of the operating circuits by the probe can be ignored approximately. The dimensions of the probe, which was fabricated here, therefore is in a first approach 710 square micrometer.

The probe and a short transmission line were etched first on a 3 x 20 mm² RT Duorid substrate (ε_r = 2.2, h = 0.5 mm). This substrate was then bent by 90° between the probe and the transmission

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line in order to measure the magnetic field H_Z-component as shown in figure 1. The transmission line was connected to a semirigid coaxial cable, which links to a network analyzer through a SMA plug.

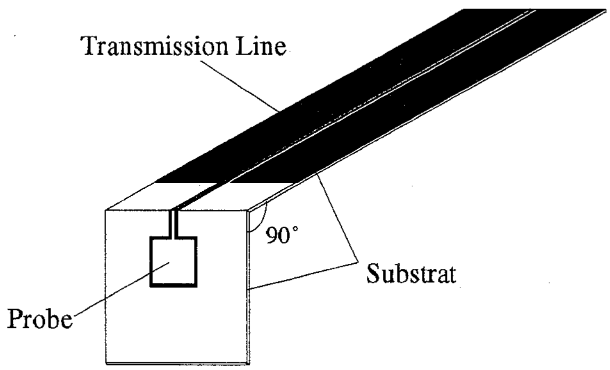


Fig.1. Square magnetic field probe

The probe is 710 μm x 710 μm in length and the conductor width is 55 μm. The conductor width is a very important factor for this probe, because, if the size of the conductor is small, the influence of the probe on the circuit will be small and it can be used for higher frequency bands. With the technology available, the width of the conductor must be larger than 80μm, because the conductor may break otherwise during the bending procedure. The probe has a geometrically symmetrical form and is a one-loop square magnetic field probe, hence the results of the measurements can be directly interpreted. Using this simple form of the probe, also the two other components of the magnetic field (x-, y-directions) can be measured, if the substrate of the probe is not bent by 90° . Using a thin film technology, the cost of the magnetic field probe is very small and a very stable field probe can be fabricated, i.e. it is suitable for industrial applications.

The probe position over the circuit is shown in figure 2. For the measurements the distance between the probe and the circuit is an important factor. If the probe is too near to the circuit, it may obtain a large signal, but it then disturbs the operation of the circuit. For the measurements shown later, the probe is set in a height of 200 μm above the circuit. It is also important, that the substrate height variations must be kept to a minimum, if the probe is placed near to the circuit.

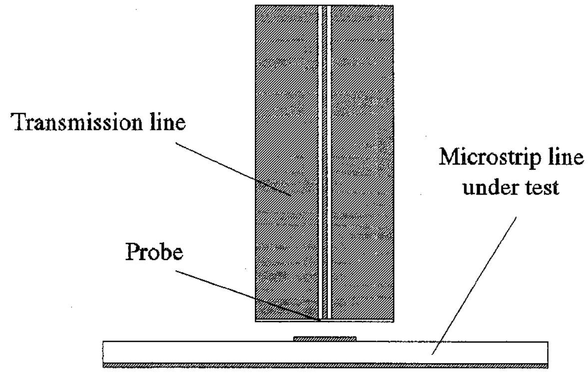


Fig. 2. Probe position over microstrip line

A block diagram of the field measurement system is shown in figure 3. The magnetic field probe is mounted on a table, movable in three dimensions, controlled by 3 motors. A normal network analyzer is used as a receiver. Alternatively simple microwave receivers can be used for cases where no network analyzer is available for this application. For the measurements here Hewlett Packard 8515 vector network analyzer is used to excite the microstrip lines and receive the signal S_{21}. It was calibrated at a single frequency with a full two-port calibration. The movement of the field probe is controlled by a computer program that also overtakes the evaluation of the measurements.

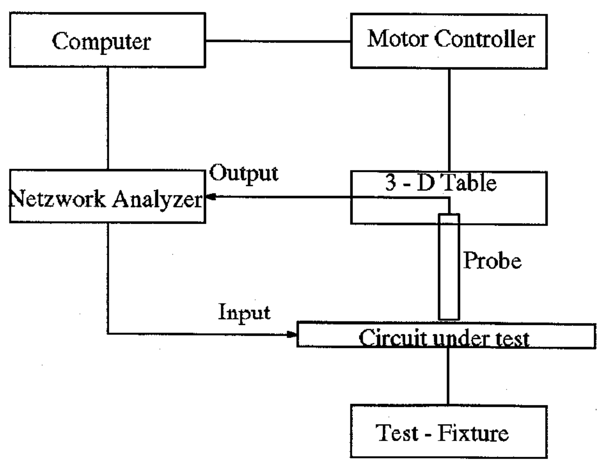


Fig.3. Block diagram of the Field Measurement System

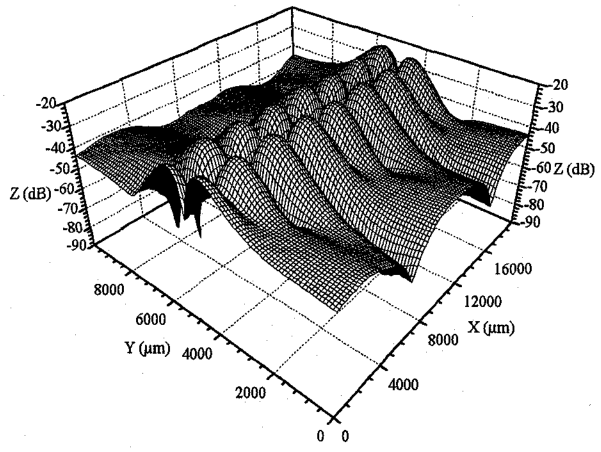
MEASUREMENTS ON MICROSTRIP LINES

In order to check the magnetic field probe, an open and a shorted 50 Ω microstrip line was constructed on ceramic substrate with size of 2.54 x 2.54 mm², a height of 635 μm and a relative permittivity $\varepsilon_r = 9.8$.

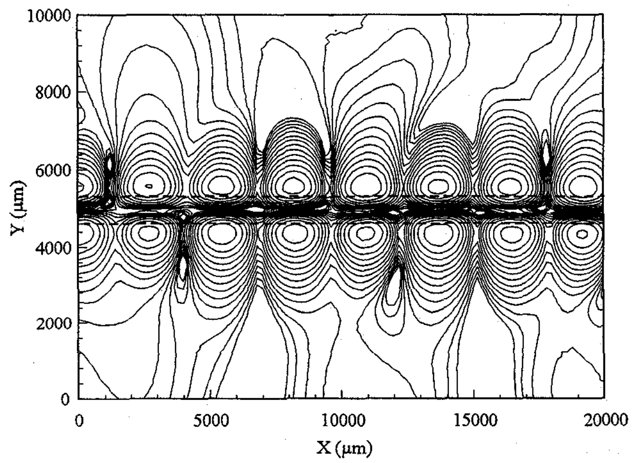
The measurements shown here were taken over a region of 10 x 20 mm² of the microstrip lines. Scanning steps of 200 μm in the x- and 100 μm in the y-direction were employed, so that 10000 field values were measured in each measurement cycle. The stepper widths depend on the structure of the circuit, the frequency and the size of the probe. If the circuit components are closely spaced, the steps must be smaller, which may lead to a long measurement time.

The measurement result of the standing wave on the shorted microstrip line at 20 GHz is shown in figure 4. Shown are the lines of constant magnetic field strength in the plane 200 μm above the circuit. The maximum signal can be measured near the edge of the conductor. From this measurement the wavelength λ and the effective dielectric constant of the microstrip line $\varepsilon_{r,eff}=(\lambda_0/\lambda)^2$ can be investigated. In figure 3(a) a three dimensional presentation of the field is shown, where the measured signal S_{21} from network analyser is between -20 and -90 dB. It will also be observed that the periodic shifts of VSWR maxima are different near the conduct and on the ground plane. The boundary of the conductor is shown in the contour picture figure 4(b) by the brocken line. From this figure λ=5.5 mm can be measured and $\varepsilon_{r,eff}$= 7.4 can be calculated.

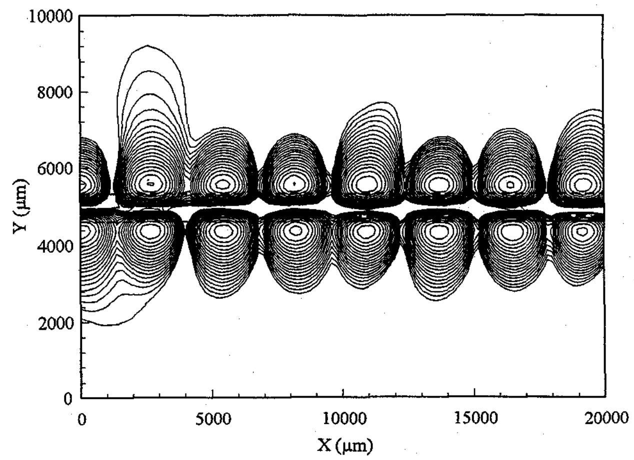
The area scan on an open microstrip line at 20 GHz given in figure 5 shows the overall field distribution. In this measurement it is seen that the magnetic field concentrates near the conductor, even at the open end. The field radiated from the open end shown in figure 5(b) too. Comparing to the measurements on shorted microstriplines the same wavelength λ can be obtained. This observation demostrates that the results of the measurement can be reproduced very well.



4(a)

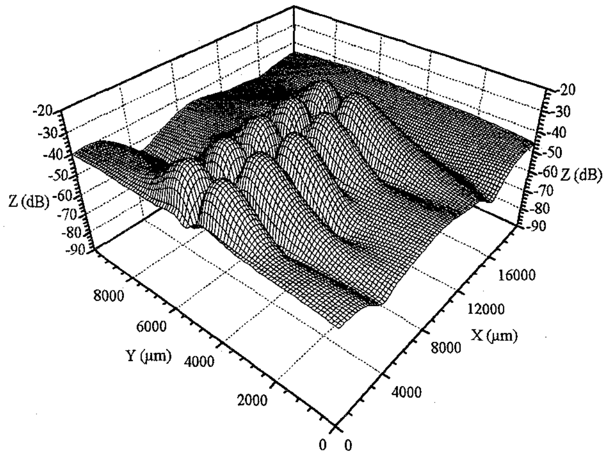


4(b). Z = 2.0 dB / level

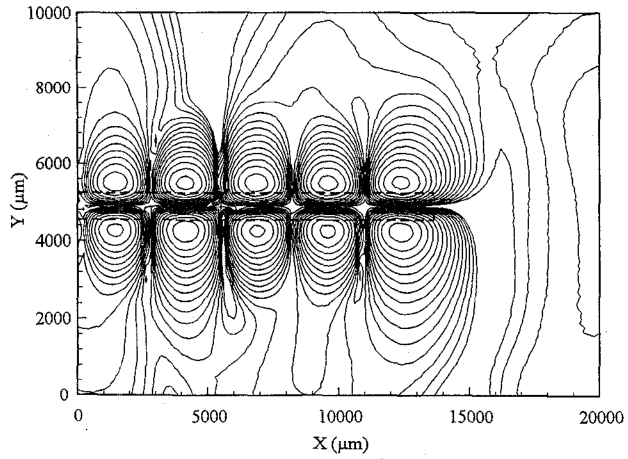


4(c). Z = 1.0 dB / level

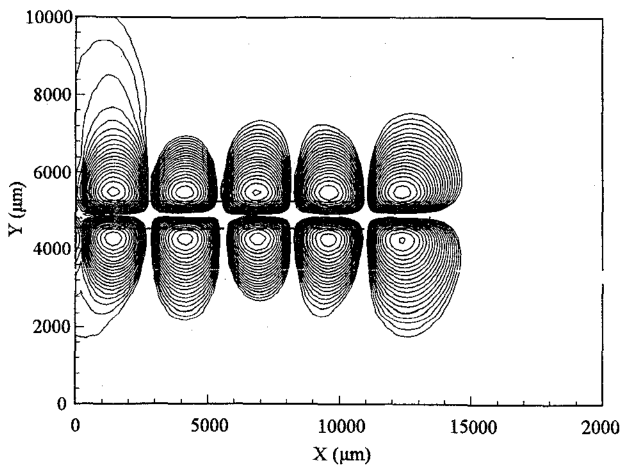
Fig.4. 50Ω short-circuited microstripline at 20 GHz



5(a)



5(b). Z = 2.0 dB / level



5(c). Z = 1.0 dB / level

Fig.5. 50Ω open-circuited microstripline at 20 GHz

CONCLUSIONS

A new square magnetic field probe for measuring the field distribution in planar high frequency circuits has been presented. Some measurement examples are given to demonstrate the capability of this probe. The aim of this work is to measure quantitatively the field distribution in planar high frequency circuits using this probe. Therefore it is necessary to calibrate the probe using some known fields. The technology of probe fabrication still can be improved to reduce the size of the probe for higher frequency regions.

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