HIGH-RESOLUTION ELECTRO-OPTIC MAPPING OF NEAR-FIELD DISTRIBUTIONS IN INTEGRATED MICROWAVE CIRCUITS

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Abstract

A field mapping system based on external electro-optic sampling has been developed in order to determine all components of the electric near-field distribution of guided microwaves with high spatial resolution. The capabilities of the setup are demonstrated by 2D-measurements of normal and tangential fields in a microwave distribution network.

Introduction

Electromagnetic field probes are used for a variety of applications in RF metrology, including such diverse areas as the characterization of near-field patterns of antennas and antenna arrays, electromagnetic compatibility (EMC) measurements and integrated circuit failure diagnosis. For applications requiring high bandwidth, low interference with the device under test (DUT) and high spatial resolution, electro-optic sampling [1,2] is a promising candidate. This is because it provides THz bandwidth and a spatial resolution the size of the laser beam diameter or even less. Furthermore it does not require electrodes or ground planes as a part of the field probe so that, compared with conventional dipole-type probes, the invasiveness is minimized.

Electro-optic measurements of field distributions of guided microwaves have been demonstrated extensively with monolithic microwave integrated circuits, using the substrate of the circuits as the sensor element (internal electro-optic sampling). These measurements have revealed information for circuit characterization and failure detection [3]. However, if the substrate does not exhibit the linear electro-optic effect, and moreover when field patterns outside the substrate need to be known, external electro-optic sampling, which is substrate-independent, has to be used. Electro-optic probes have already been employed for measurements of near field patterns of antennas and simple waveguide structures [4,5]. However, the potential of the technique with respect to the full characterization of the electric field, i.e. in terms of all the different field components in amplitude and phase, has not been shown up to now. In this paper measurements of near-field distributions of guided waves above integrated microwave circuits are demonstrated using a distribution network with structure sizes down to 20 μm as an example DUT. The measurements are carried out using two different probes, which reveal distinct field distributions of either the normal or the tangential field components in amplitude and phase inside the circuit. Using this complete information the performance of circuit elements has been analyzed up to 20 GHz thus far.

Measurement System Configuration

The measurement setup used is shown in Fig.1. The optical beam from a phase-stabilized Ti:Sapphire laser (pulse length 50 fs) is focused inside the probe crystal. The incident beam is totally reflected inside the crystal, so that no illumination of the circuit under test occurs. The reflected beam is analyzed with respect to the change of the polarization state, which is sensitive to the circuit electric field reaching the probe. Due to the phase-locked-loop-electronics of the laser system, it is possible to synchronize cw signals from a microwave synthesizer to the laser pulse train so that measurements in amplitude and phase can be performed.

The probes are fabricated from Bismuth Silicate (BSO) and Lithium Tantalate ($LiTaO_3$), which allow the determination of the normal and the tangential field components, respectively. The crystals have a footprint of 90 x 70 μm for the BSO, and 84 x 84 μm for the $LiTaO_3$. High spatial resolution is obtained by

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focusing the laser beam to a small spot at the bottom of the probe. The distance between probe and DUT is adjusted to be 5-7 µm. The minimum detectable voltage is measured to be about 1 mV or -45 dBm for 50 Ω geometries, and the sensitivity is 40 $\mu V/\sqrt{Hz}$. The DUT is mounted on a computer-controlled xy-translation stage and the microwave signal is applied via on-wafer probes. Typical measurements including 6400 points are carried out in approximately 45 min. This duration is mainly limited by the speed of the translation stage and therefore can be further improved.

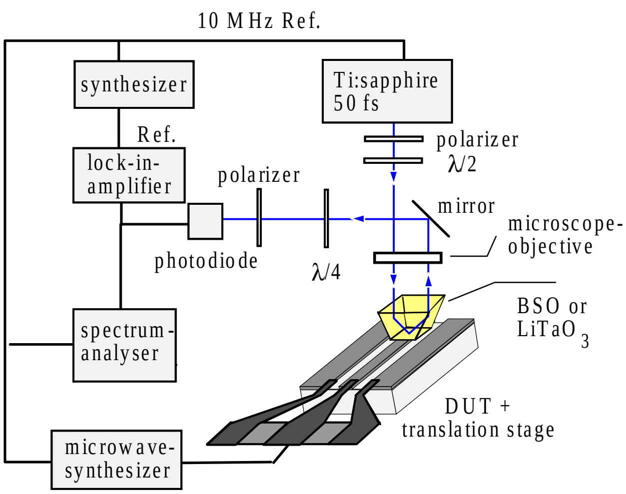


Fig. 1. Electro-optic probe station

Experimental Results

The examined distribution network circuit is a coplanar design (Fig. 4) fabricated on high-resistivity Si. It is based on two Wilkinson power dividers, which distribute the input microwave signal to four output ports. The ports are terminated with 50 Ω thin film resistors. The circuit is designed for a working frequency of 15 GHz.

Figures 2 and 3 demonstrate typical electro-optic mapping of the electric normal and tangential field components for a CPW even mode in the transverse direction. Figure 2 shows one-dimensional mapping at pos. A in Fig. 4 at 5 GHz using BSO, with a high electro-optic signal on the center conductor and low electro-optic signal on the ground conductor corres-ponding to the field strength of the normal component. A phase change of 180 degrees between the three conductors is observed. Figure 3 shows a 1-D meas-urement at 15 GHz using the $LiTaO_3$ probe. Here the maximum signal appears above the spacings corresponding to the strength of the tangential field component with a phase change of 180 degrees on the center conductor. It can be seen that the distribution of both components can easily be resolved.

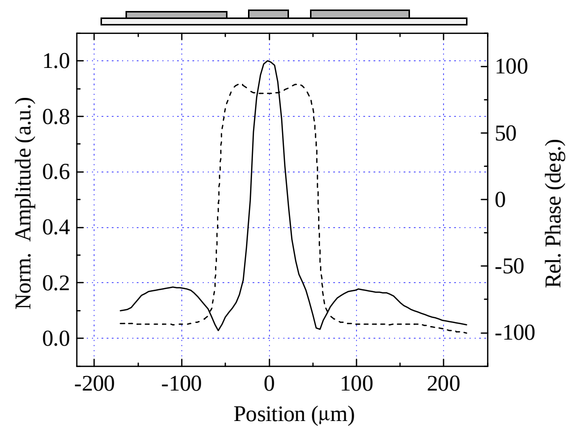


Fig. 2. Electro-optic mapping of the normal field component of the CPW even mode at pos. A in Fig. 4 (transverse direction) measured using BSO, f = 5 GHz; solid line: normalized amplitude, dashed line: phase; (the center conductor has a width of 40 µm and the spacing a width of 24 µm).

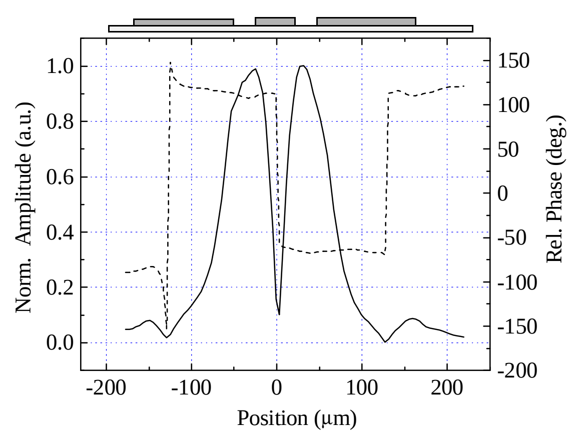


Fig. 3. Electro-optic mapping of the tangential field component of the CPW even mode at pos. A in Fig. 4 (transverse direction) measured using $LiTaO_3$, f = 15 GHz; solid line: normalized amplitude, dashed line: phase

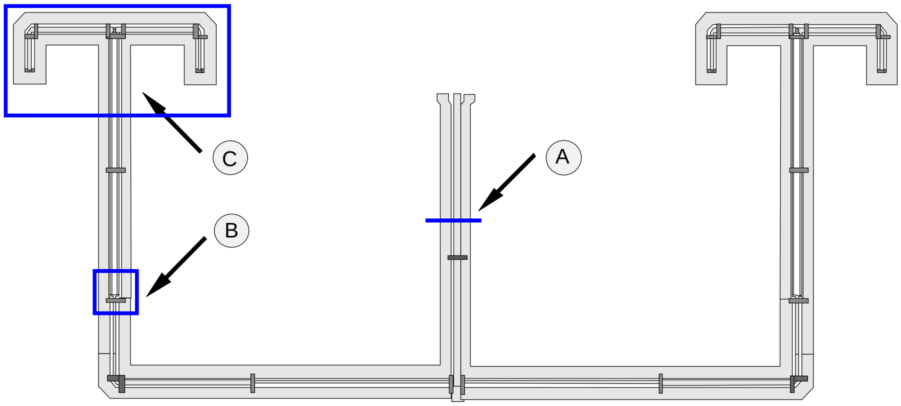


Fig. 4. Distribution network circuit with investigated areas, chip size: 8.3 mm x 3.7 mm.

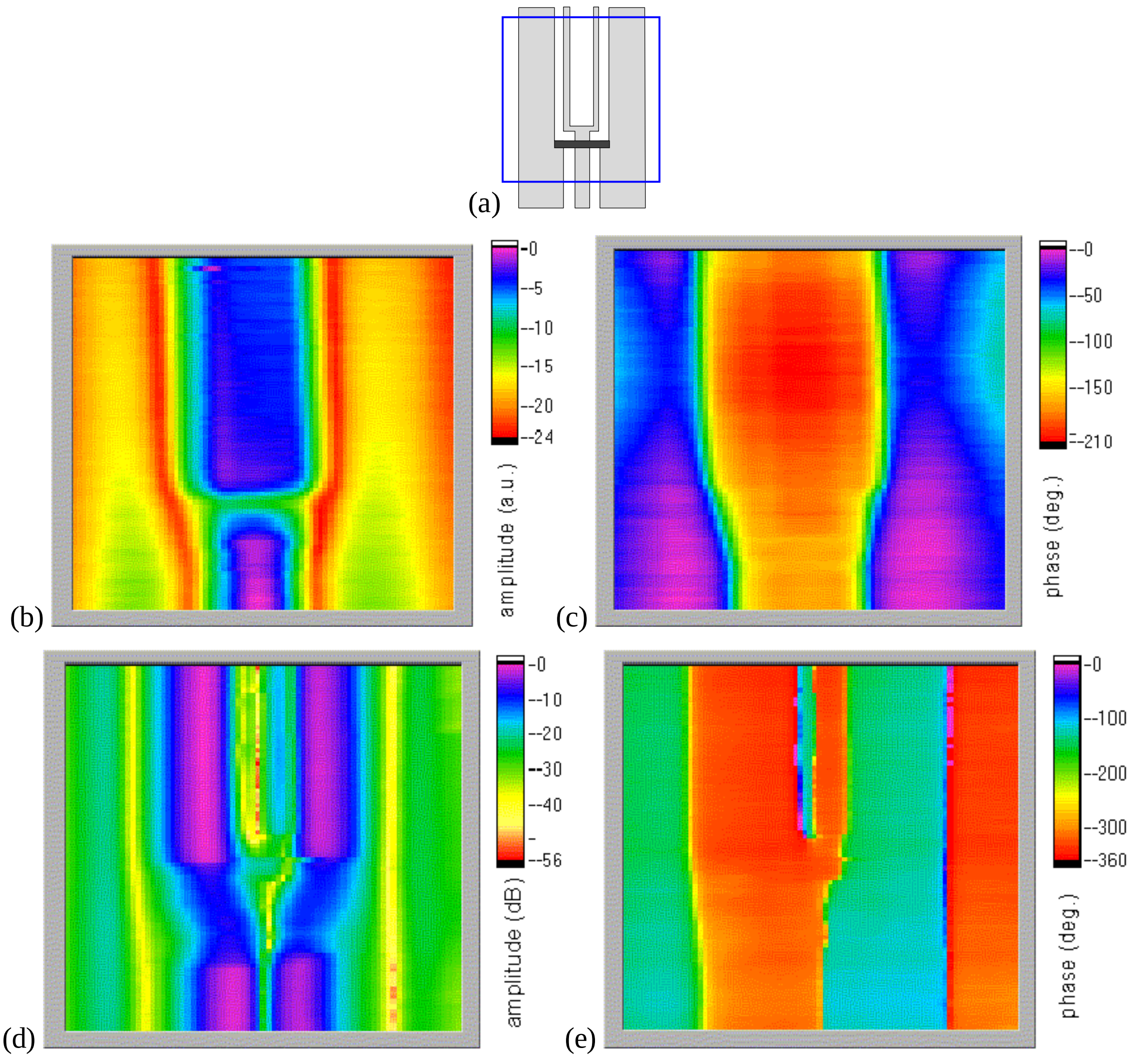
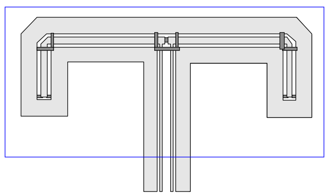
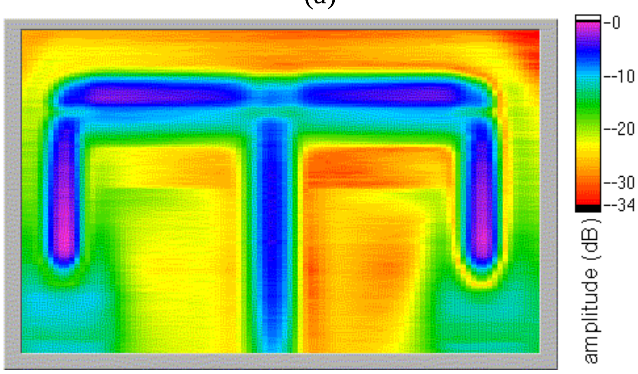


Fig. 5. Electro-optic field mapping at the input of the Wilkinson power divider at pos. B in Fig. 4; f = 15 GHz; (a) sketch of scanned area (marked by rectangle, size: 400 µm x 400 µm), (b) normalized amplitude of normal component in dB, (c) relative phase of the normal component in deg., (d) normalized amplitude of tangential component in dB, (e) relative phase of the tangential component in deg.

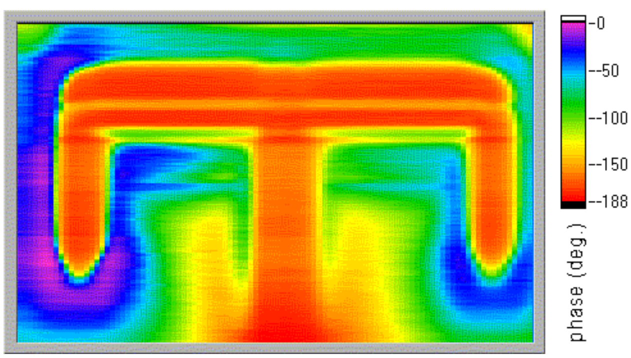
Figure 5 displays the normal and the tangential field distribution at the input of the Wilkinson power divider in two dimensions (pos. B in fig. 4). Figure 5(b) and (c) show both that a small asymmetric coupling into both signal lines of the divider occurs. From Fig. 5(d) and (e) it can also be concluded that at this frequency no significant coupling between the two transmission lines is present, because only small tangential field components can be measured in the spacing between them.



(a)



(b)



(c)

Fig. 6. Electro-optic mapping of the normal field component of the output of the Wilkinson divider including termination at pos. C in Fig. 4, f = 15 GHz; (a) sketch of scanned area (marked by rectangle, size: 3200 μm x 940 μm), (b) normalized amplitude in dB, (c) relative phase in deg.

Figure 6 shows the 2-D normal field distribution of the output of the Wilkinson power divider feeding the two output ports. Here the effect of a standing wave with maximum at the termination can be observed, revealing a mismatch of the termination thin film resistors.

Conclusions

High resolution, 2D near field mapping of a microwave distribution network is performed, revealing insight into the distributions of normal and tangential field components inside the circuit. The microwave performance of single components within the circuit could be observed. In conclusion, the results demonstrated that the measurement technique is a powerful tool for a wide range of applications in rf near-field characterization.

Acknowledgment -This work has been funded by the MURI-project on "Power Combining Systems" under contract: DAAG 55-97-0132, by the National Science Foundation through the Center for Ultrafast Optical Science under STC PHY 8920108, and by the Alexander von Humboldt-Foundation, Germany.

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