IN-CIRCUIT ELECTRO-OPTIC FIELD MAPPING FOR FUNCTION TEST AND CHARACTERIZATION OF MMICS

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ABSTRACT

In this paper, the results of 2D electro-optic mapping of electric field distributions in two coplanar MMICs are presented. It is demonstrated that the obtained images of the field distributions can be used for function test, failure localization and for a quantitative high frequency characterization of the circuits.

INTRODUCTION

For research, development and fabrication of MMICs an accurate microwave characterization method is a key requirement. Nowadays this characterization is carried out by on-wafer measurements using wafer probes. This measurement technique, however, exhibits basic limitations because internal ports are not accessible. In contrast, electro-optic probing has been demonstrated to be a powerful tool for measurements of high frequency signals inside MMICs [1-6], providing high bandwidth, noninvasiveness and high spatial resolution. The practical application of this technique and therefore the usefulness for the microwave engineer, however, requires not only capabilities for a qualitative function test and failure localization but also for a quantitative analysis of the measurement results allowing a comparison with the predicted performance of the circuit.

In this paper, a function test and quantitative analysis of two different MMICs based on 2D electro-optic field mapping are presented. In particular, circuit-internal measurements in a mixer-IC and a microwave amplifier are carried out revealing wave propagation phenomena and nonlinear characteristics. A quantitative evaluation of the measured results is further performed by a comparison with CAD calculations of circuit-internal potential distributions.

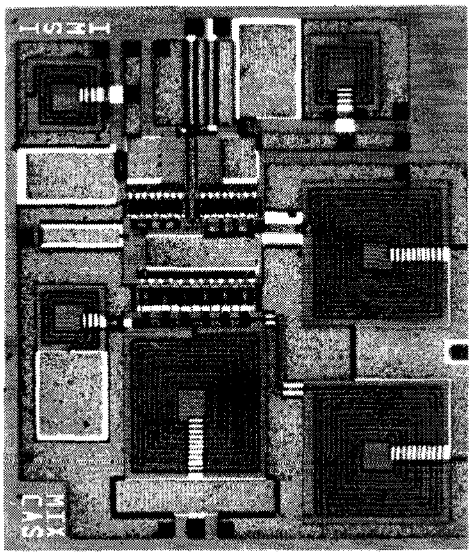
EXPERIMENTAL RESULTS

The experimental setup consists of a direct electro-optic measurement system [2]. Using this setup the field distributions are electro-optically probed with a spatial resolution down to < 0.5 μm [3] and a bandwidth exceeding 100 GHz.

The two MMICs exhibit different concepts of coplanar design and working frequencies from 100 MHz to 21 GHz. The first MMIC is a mixer-IC and realized with lumped elements. The second MMIC is an amplifier and is based on distributed elements to achieve matching conditions.

Mixer-IC

The examined mixer IC (Fig. 1(a)) is designed for a local oscillator (LO) signal of 900 MHz, an RF signal of 1000 MHz and an intermediate frequency (IF) signal of 100 MHz. Fig. 1 (b) shows the circuit diagram. The mixer reveals a conversion gain of 15 dB.



(a)

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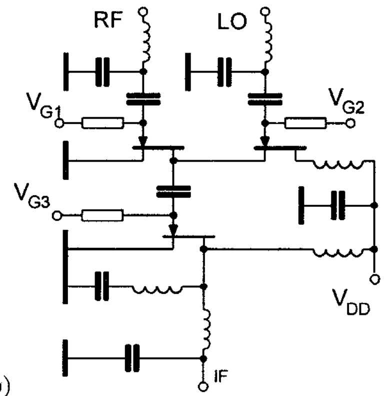

(b)

Fig. 1. MMIC mixer, (a) photo, size: 1400 μm x 1600 μm, (b) basic circuit diagram

Figs. 2 and 3 show the field maps at 1000 MHz (RF signal) and at 900 MHz (LO signal). The gate voltages V_{GS} of the RF and LO stage are set to zero Volts, which drives the RF transistor into saturation conditions while the LO transistor is operating in the active region. This slight mismatch can be detected in the field maps comparing the different electro-optic signals in the region of the transistors. The amplifications of the LO and the RF signals are obvious leading to maximum signals in the MIM capacitor. The microwave signal is also detected in the bias networks, especially in the bias network providing the drain source voltage for the LO and the RF transistors. As a further result, the reduction of the signal levels in all inductors reveals that the microwaves propagate along the spiral of the inductor revealing clearly that the inductor behaves as a waveguide structure.

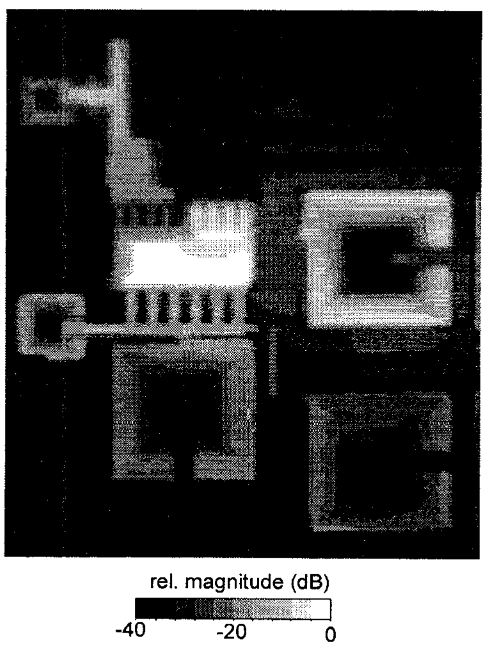

Fig. 2. 2D field map of RF signal in the mixer (f_{RF} = 1000 MHz, input power: -5 dBm)

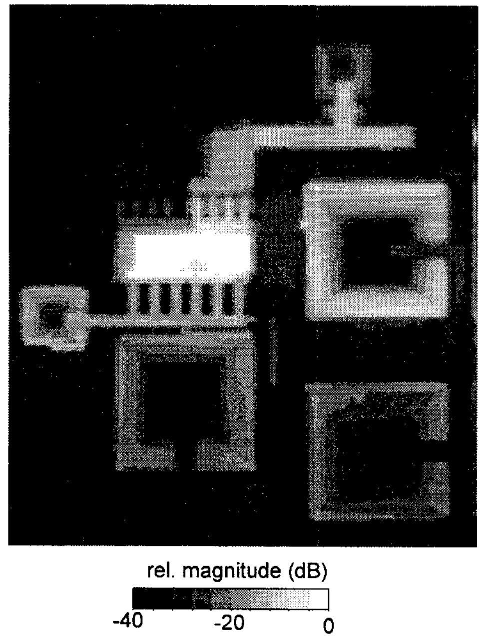

Fig. 3. 2D field map of the LO signal in the mixer (f_{LO} = 900 MHz, input power: 5 dBm)

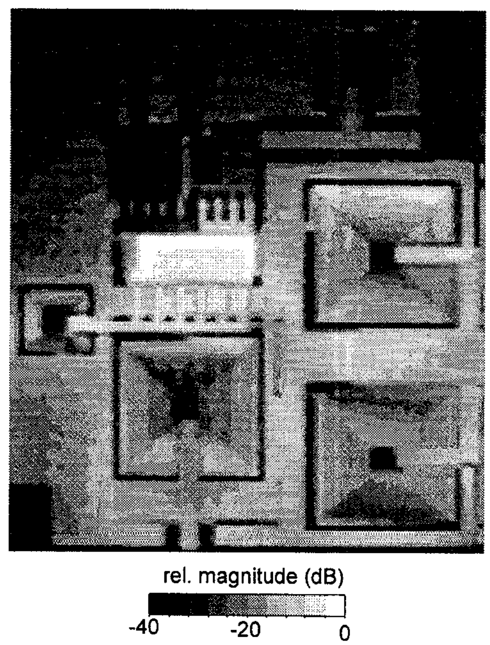

Fig. 4. 2D field map of the IF signal in the mixer (f_{IF} = 100 MHz)

Fig. 4 shows the field map at 100 MHz (IF signal). The IF signal is generated at the mixing gate of the IF transistor but is also detected in front of the transistor in the MIM capacitor. The decrease of the electro-optic signal in the inductors is smaller than the decrease of the electro-optic signal of the LO and the RF signals providing a direct insight into the function, for example, of the IF filter at the output.

18-21 GHz two stage amplifier

Fig. 5 shows the examined coplanar 18-21 GHz two-stage amplifier [5,7]. Coplanar transmission lines and interdigital capacitors have been used as matching networks.

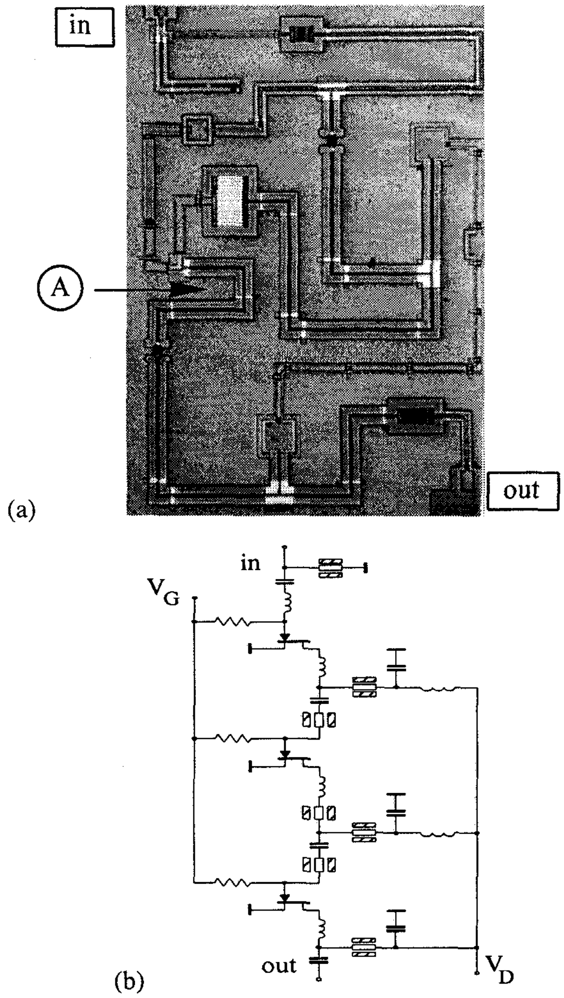

Fig. 5. Coplanar MMIC two-stage amplifier (18-21 GHz), (a) photo, (b) circuit diagram

The characterization of the microwave propagation in the complete amplifier is carried out by measuring the electro-optic signal along the center conductor of the transmission lines passing the discrete devices of the circuit. Fig. 6 shows the signal trace from the input to the output port of the amplifier at a frequency of 18.5 GHz (input power: -10 dBm). Obviously, the key devices of the MMIC can be located by their specific behavior. It can also be seen that the electro-optic signal does not increase monotonously but shows several minima and maxima. The total amplification measured between the input and the output is 13 dB which is also the externally measured amplification at this frequency.

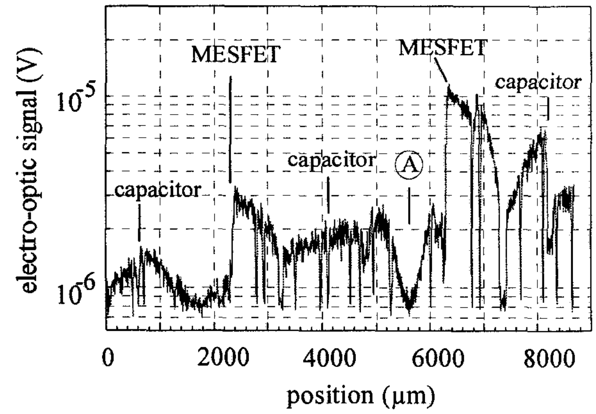

Fig. 6. Signal trace along center conductor of the MMIC in Fig. 5 at 18.5 GHz; RF input: -10 dBm Note that the signal drops not marked, are produced by more than 20 air-bridges used in the MMIC

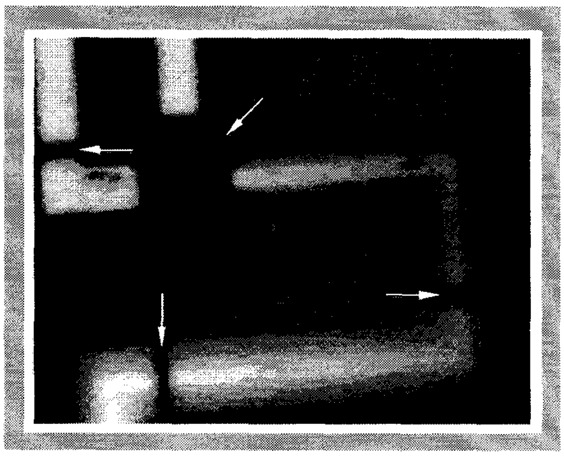

Fig. 7. 2D map of CPW-bend at position A in Fig. 6(a) at 19.5 GHz, scanned area: 500 µm X 350 µm; the signal drops to the level of the ground signal (marked by arrows) are caused by air-bridges used in the MMIC

In the region of the bend at position A (see Fig. 5(a) and Fig. 6 a minimum of the electro-optic signal is detected. The minimum which is also obvious in the 2D field map in Fig. 7 changes its position with the microwave frequency and also the applied microwave input power. This behavior implies a standing wave pattern in this section of the MMIC which is apparently generated by a reflection at the MESFET following the bend.

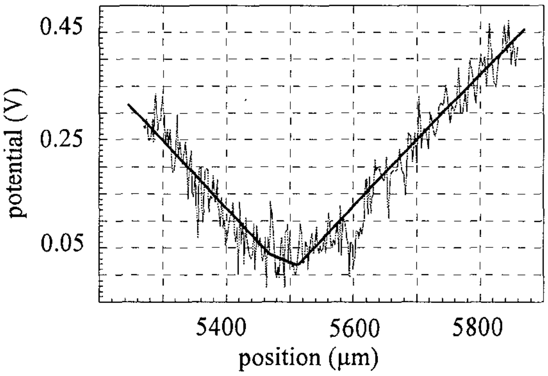

Fig. 8. Signal trace in the region of the bend, 20 GHz, —— experimental, — calculated

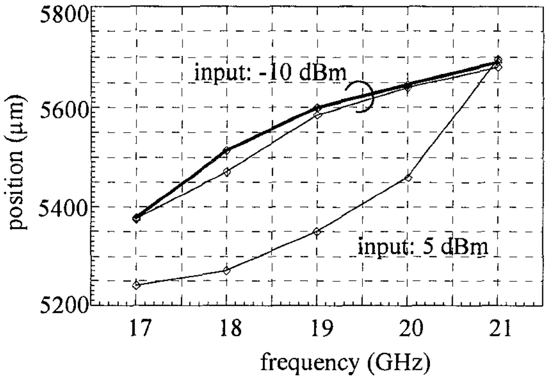

Fig. 9. Comparison of positions of minima in front of the second MESFET vs. frequency, —— experimental, — calculated

The CAD software LIBRA 4.0 is used to calculate the potential distribution along the transmission line in the bend. For that purpose the line is separated into 20 transmission lines with equal length and the potential is calculated at each node. Also these calculations show minima. As can be seen, for example from Fig. 8, a good agreement in the shape of measured and calculated graphs is obtained at low input powers. In Fig. 9 the positions of the measured minima at two input power levels and of the calculated results are compared. Obviously, a good agreement between measured and calculated results is achieved with respect to the position of the minima while distinct differences appear at high input power. These results reveal a change in the angle of the reflection coefficient depending on the input microwave power while simultaneously the magnitude of the reflection coefficient remains almost constant. This behavior of the reflection coefficient agrees well with the general characteristics of a MESFET.

CONCLUSIONS

Experimental results of 2D electro-optic field mapping are presented revealing wave propagation effects in two different MMICs. Moreover, the results show a nonlinear behaviour of the circuits such as generation of an IF signal in a mixer-IC and the saturation characteristics of a circuit-integrated transistor. Furtheron, a quantitative comparison of the electro-optically obtained results with potential simulations by CAD tools is demonstrated. In summary, it is shown that the 2D electro-optic probing technique can provide a quantitative and a spatially resolved characterization of MMICs.

REFERENCES

1 B.H. Kolner and D.M. Bloom, "Electrooptic sampling in GaAs integrated circuits", IEEE J. Quantum Electron., vol. QE-22, (1986), 79-93.
2 M.J.W. Rodwell, M. Riaziat, K.J. Weingarten, B.A. Auld, and D.M. Bloom, "Internal microwave propagation and distortion characteristics of a traveling-wave amplifier studied by electrooptic sampling", IEEE Trans. Microwave Theory Tech., vol. MTT-34,1986, 1356-1362
3 G. David, P. Bussek, U. Auer, F.J. Tegude, and D. Jäger, "Electro-optic probing of RF-signals in sub-μm MMIC-devices, Electron. Lett., 1995, vol. 31, 25, 2188-2189
4 G. David, S. Redlich, W. Mertin, R.M. Bertenburg, S. Koßlowski, F.J. Tegude, and D. Jäger, "Two-dimensional direct electro-optic field mapping in a monolithic integrated GaAs amplifier", Proc. 23rd EuMC, Sept. 6-9, 1993, Madrid, Spain, 497-499
5 G. David, A. Ising, Y. Kalayci, R. Tempel, I. Wolff, and D. Jäger, "Circuit-internal characterization of MMICs using two-dimensional electro-optic field mapping in combination with microwave CAD", Proc. 24th EuMC, Sept. 5-8, 1994, Cannes, France, 1378-1383
6 G. David, W. Schroeder, D. Jäger, I. Wolff. " 2D electro-optic probing in combination with field theoretical multimode extraction technique, A new approach to on wafer measurement", 1995 MTT-S International Microwave Symposium Digest, 1995, Orlando, USA, 1049-1052
7 Y. Kalayci, R. Tempel, B. Hopf, J.J. Borkes, R. Gründler, and I. Wolff, "Miniaturising of K-band coplanar MMIC-amplifiers by using lumped elements", 24th EuMC, 1994, 343-348