Coplanar Transceive MMIC for 77 GHz Automotive Applications Based on a Nonlinear Design Approach

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Abstract - **Integrated transceive MMICs for automotive applications were realized in coplanar waveguide technology, using a 0.15 µm PM-HEMT process. Based on an analytical nonlinear HEMT model, harmonic balance simulations of the entire chip, comprising up to 7 devices, showed good agreement with the measured power performance of the transmit and the receive paths. For the resistive mixer, a DSB noise temperature of only 297 K was measured.**

I. Introduction

W-band radar systems for automotive applications have focused interest on cost effective integrated circuits on GaAs. With compact transmit and receive MMICs in coplanar technology, having a chip size of 3 x 2 mm² each, the required system performance at 77 GHz has been demonstrated [1, 2]. In comparison, a single chip transceiver for 94 GHz, being realized in microstrip technology, required an area of 6.9 x 3.9 mm² [3].

For meeting the targets of high volume markets, two goals are of crucial importance: Minimizing the total chip area necessary for a complete FMCW system at 77 GHz and reliable predictions of the nonlinear circuit performance. Both goals have been achieved in designing and fabricating a very compact integrated transceive MMIC with a 0.15 µm T-gate PMHEMT process in coplanar technology. An in-house analytical HEMT-model [4], implemented as symbolically defined device (SDD) in HP-MDS, has been used for performing harmonic balance simulations of the entire multifunction IC, comprising four transistors in the transmit path and up to three devices in the receive path. As will be shown in a more detailed description of the MMIC's electrical performance below, measured and simulated output power at 76 GHz as well as conversion characteristics agree very well, allowing a detailed in-situ power analysis of the transmit and the receive path. To our knowledge, this is the first time the performance of an entire multifunction chip for mmW-frequencies has been analyzed by means of harmonic balance simulations.

II. Mixer Types

Various types of coplanar FET mixers have been investigated for use in the transceive MMIC [5, 6]. Resistive mixers, where the FET operates in a

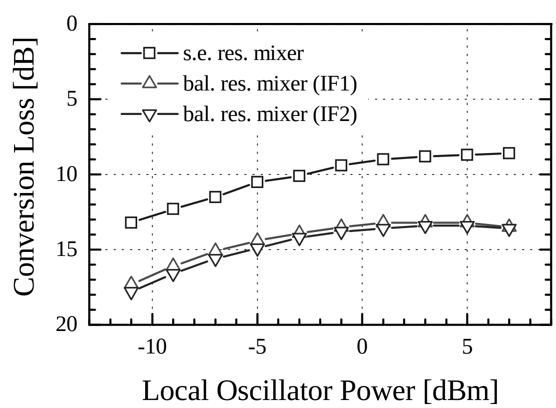

Fig. 1: Measured conversion loss of resistive MMIC mixers vs. LO power.

passive mode, achieved lower conversion loss than HEMT diode mixers. As can be seen in Fig. 1, the single ended and the balanced resistive mixer exhibit minimum conversion losses of 8 dB and 10 dB, respectively, for an LO power of only 3 dBm, when biased near pinch-off. From Fig. 2, where the conversion gain of the single ended resistive mixer is depicted as a function of RF input power, it can be seen that a 1 dB increase of the conversion loss occurs for an RF input power of +5 dBm. For a higher LO power of +9 dBm, the 1 dB compression point can be increased to +10 dBm RF input power.

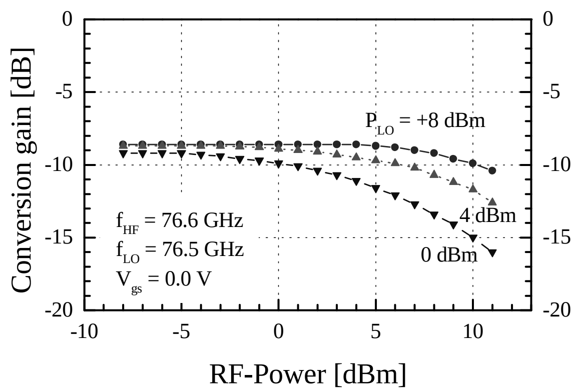

Fig. 2: Measured conversion loss of single ended resistive FET mixer vs. RF power.

The intermodulation characteristics of the resistive mixers have been investigated in dependence of gate bias. The input power of -13 dBm for two RF signals with a frequency difference of 5 MHz was chosen, being low enough for not saturating the mixer and still sufficiently high for detecting the power levels of the intermodulation products by means of a spectrum analyzer. From these power measurements, the third order intercept point (TOI) was deduced in dependence of the bias points for three LO power levels. The result can be seen in Fig. 3. For 5 dBm LO power and for a bias of 0.0 V, where the mixer needs minimum LO power for minimum conversion loss, an input TOI of +14 dBm was determined. Thus, the TOI is about 10 dB higher than the 1 dB compression point, being in good agreement with a rough estimation made in [7].

The lower limit of the dynamic range of the mixer is determined by its noise figure. By means of hot-cold-measurements, the DSB noise figure was determined for an IF of 1.5 GHz, being outside from the 1/f-noise region of the HEMT. Measuring the SSB noise figure requires a bandpass filter with a steep slope to suppress the image frequency, whereas the RF signal can pass. Assuming that RF and image frequency equally contribute to the DSB noise figure, the SSB noise figure is twice the DSB value. In Fig. 4, the DSB noise figure is depicted as a function of LO power. For an LO power of 3 dBm, where the resistive mixers already exhibit minimum conversion loss (cf. Fig. 1), DSB noise figures of 3 dB and 5 dB were measured for the single ended and for the balanced version, respectively, corresponding to equivalent noise temperatures of 297 K and 607 K. For the single ended resistive mixer, this is the lowest DSB noise temperature measured at room temperature reported so far in this frequency range [8].

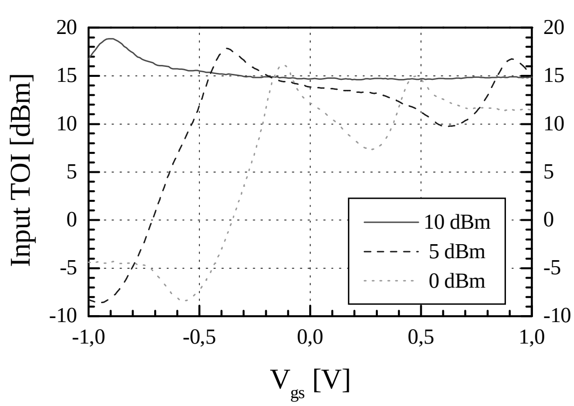

Fig. 3: Measured input third order intercept point of single ended resistive FET mixer vs. bias for different LO power levels.

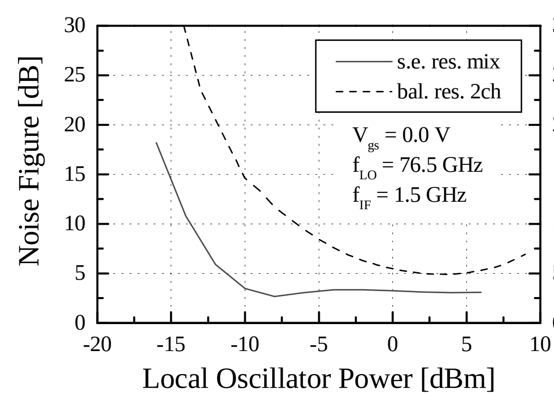

Fig. 4: Measured DSB noise figure of resistive FET mixers vs. LO power.

III. Architecture of Transceive MMIC

Different topologies of an integrated transceive MMIC have been investigated, whose basic features are depicted in the block diagram in Fig. 5. The power of a 4-stage medium power amplifier is split in half via a rat-race coupler to the antenna port (P_4) and to the LO port of the mixer (P_2). The received signal is fed to a resistive FET mixer either directly or via a 2-stage low noise amplifier. In the configuration shown in Fig. 5, the chip is suited for systems with separate TX and RX antennas. By minor changes in the air bridge layer, however, the receiver input can be connected to port 3 of the rat-race coupler. This modification enables the bidirectional operation of a single TX-RX antenna at port 4. The chip, shown in the photograph of Fig. 6, requires an area of only 3x2 mm².

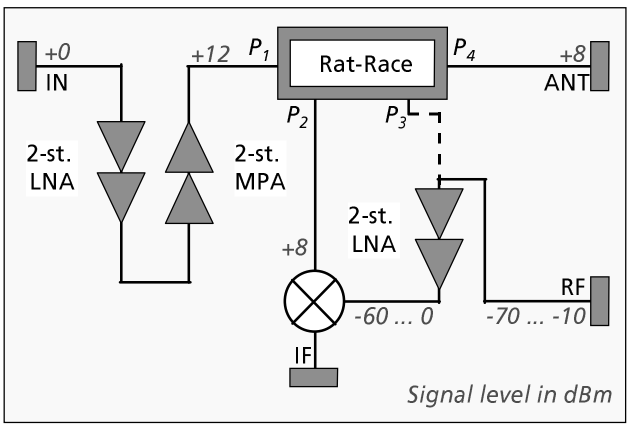

Fig. 5: Block diagram of integrated 76 GHz transceive MMIC.

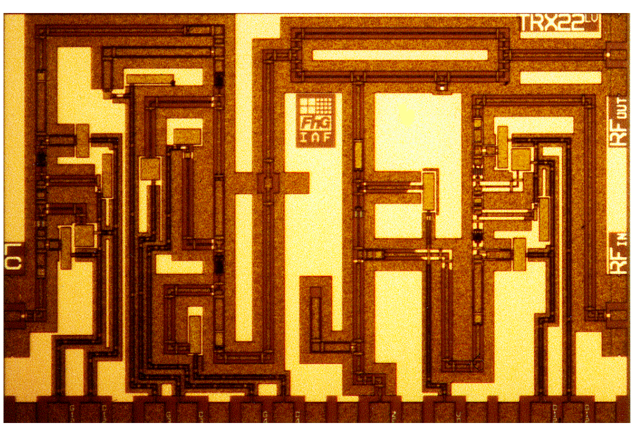

Fig. 6: Chip photograph of coplanar transceive MMIC (3x2 mm²).

IV. Performance of Transceive MMIC

The measured and simulated performance of the transceive MMIC can be seen for the transmit path in Fig. 7 and for the receive path in Fig. 8. An output power at the antenna port of 8.5 dBm was measured for an input power of only 0 dBm. A 2-stage amplifier compensates for the conversion loss of the resistive mixer of 8 dB and increases the overall conversion gain to 0 dB. The nonlinear performance of the transceive MMIC has been analyzed by harmonic balance simulations, using our in-house analytical HEMT model. For an input power of 0 dBm, the simulated output power of the 4-stage amplifier is 12.5 dBm at port 1, saturating at more than 14 dBm. At the LO port of the mixer (P_2) and at the antenna port (P_4), a power of 8 dBm is available. The dissipated DC power of the MMIC was 550 mW.

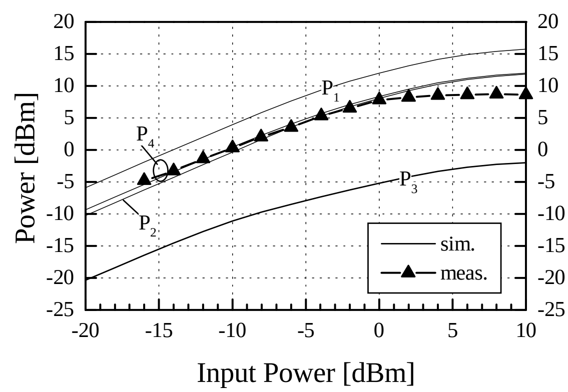

Fig. 7: Measured and simulated power of transmit path of transceive MMIC vs. input power.

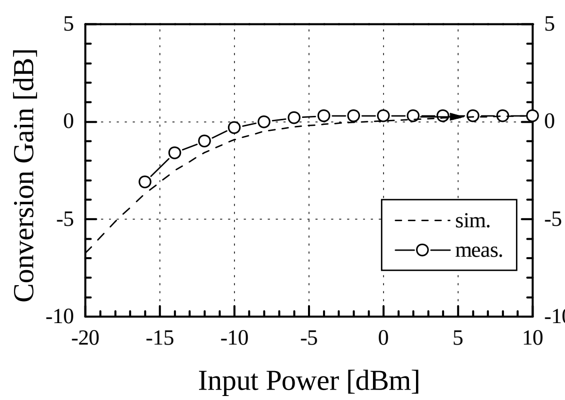

Fig. 8: Measured and simulated conversion gain of receive path of transceive MMIC vs. input power.

By means of 2-port test structures, the performance of the coplanar rat-race coupler was analyzed from DC to 120 GHz on the basis of our CPW library [9]. As can be seen in Fig. 9, an isolation of more than 30 dB between ports 1 and 3 was achieved at 77 GHz, with the remaining ports internally matched with 50 Ω resistors. However, under normal operating conditions, the isolation is degraded in the transceive MMIC. With 12.5 dBm at port 1 (Fig. 5), a power of -5 dBm instead of -17.5 dBm is present at port 3, caused by nonideal loads at ports 1 and 2 of the coupler.

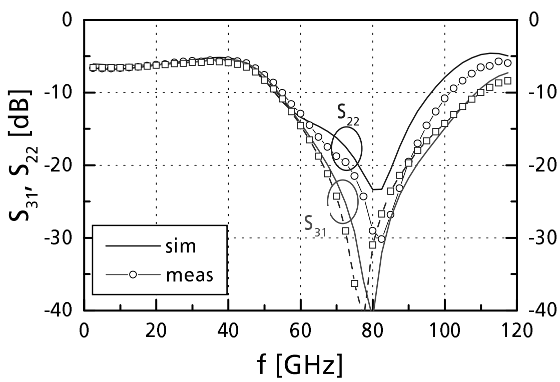

Fig. 9: Measured and simulated S-parameters of coplanar rat-race coupler.

Since the model was implemented as symbolically defined device in HP-MDS, the harmonic balance simulation for an LO power sweep with 11 points still took about 90 minutes on a HP C120 workstation. However, simulation time can be reduced significantly if compiled models are used.

V. Conclusion

A compact integrated transceive MMIC for use in automotive radars at 77 GHz was designed and fabricated in coplanar technology. The IC combines the functionality of two formerly presented transmit and receive MMICs, requiring the chip area of only one of them. Harmonic balance simulations allowed an in-situ power analysis of the entire chip and revealed interactions between different building blocks in the integrated circuit with impact on the MMIC performance. The resistive FET mixers showed 8 dB conversion loss for an LO power of only 3 dBm. Furthermore, they provide a high dynamic range due to a reduced noise figure and good intermodulation characteristics. The approach in coplanar waveguide technology results in chips of small size and therefore offers an enormous potential to meet the cost target for a high volume production of MMICs for automotive applications.

Acknowledgement

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