Low Cost GaAs PHEMT MMICs for Millimeter-Wave Sensor Applications

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ABSTRACT

A chip set for millimeter-wave sensor applications, especially automotive radar systems, is described. It consists of a highly integrated transceiver chip, a voltage controlled oscillator, a harmonic mixer and a medium power amplifier. The MMICs operate in the 76-77 GHz frequency range and have been fabricated by a production oriented GaAs PHEMT technology.

INTRODUCTION

Sensor systems are among the most important commercial applications of millimeter-waves [1]. In particular, the forward-looking automotive radar is expected to emerge into a high-volume market within the next few years. A promising way to meet the stringent cost requirements of these systems is the use of monolithic microwave integrated circuits (MMICs) based on pseudomorphic high electron mobility transistor (PHEMT) technologies. A chip set covering all functions of a homodyne FMCW radar frontend operating in the 76-77 GHz frequency range has been presented in [2]. The overall cost is minimized by compact coplanar chip designs and a production oriented HEMT technology.

This paper describes significant improvements of that chip set [2]. The main difference is a new transceiver chip, which integrates most of the functions of the formerly separate transmitter and receiver MMICs. It is supplemented by a new medium power amplifier and redesigned versions of both the voltage controlled oscillator and the harmonic mixer. The new chip set makes sensor systems possible with less total GaAs chip area and thus lower cost. It is particularly suited for system architectures with a common transmit and receive antenna. Single antenna systems best comply with the demand for low dimensions of the sensor module, an important aspect for automotive applications.

FABRICATION TECHNOLOGY

The MMICs have been fabricated using the Siemens HEMT110 process technology. The number indicates that the active devices show a current-gain cut-off frequency of 110 GHz at normal DC operating conditions, i. e. at a drain-to-source voltage of 2 V and a normalized drain current of 250 mA/mm. The maximum extrinsic transconductance is beyond 700 mS/mm and the gate-to-drain breakdown voltage is better than 5 V. The delta-doped double-heterojunction pseudomorphic HEMT layers were grown in-house by molecular beam epitaxy on 3-inch GaAs substrates. Optical stepper lithography is applied throughout the whole process. By using phase-shift masks and a sidewall spacer process a gate length of 0.12 µm is achieved without the need for electron-beam lithography. The T-shaped gate consists of a refractory metal and a highly conductive gold overlay. The complete process includes metal-insulator-metal (MIM) capacitors, electroplated airbridges and optional NiCr thin film resistors. The technology is suited for high-throughput production of low cost millimeter-wave integrated circuits. More details are given in [2].

CHIP DESIGN AND MEASUREMENTS

All circuit designs use coplanar waveguide transmission lines in order to achieve compact dimensions and to avoid backside processing and via holes. The large-signal HEMT model described in [3] has been implemented into a commercial CAD system for nonlinear simulations.

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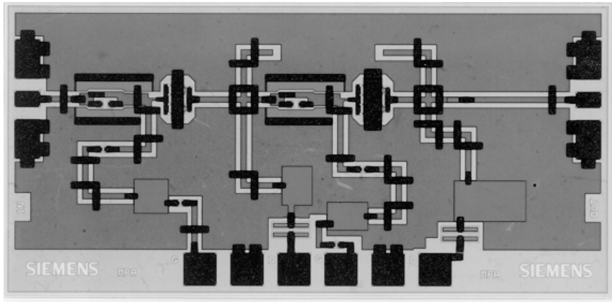

Fig. 1. Chip photograph of the 2-stage medium power amplifier (1.0 mm x 2.0 mm).

Fig. 1 shows a photograph of the newly developed 2-stage medium power amplifier (MPA). The size of the chip is 1.0 mm x 2.0 mm. The diagram in Fig. 2 summarizes the results of an automatic characterization of the amplifier across a complete 3-inch wafer. The output power has been measured for a fixed input power level of 5.5 dBm. The peak of the distribution is located at an output power of 13 dBm corresponding to a power gain of 7.5 dB. The typical small signal gain is about 11 dB. Taking into account a total number of 95 chips on the wafer and a specified minimum output power of 12 dBm, a yield of 64% is obtained from the data in Fig. 2.

The redesigned version of the voltage controlled oscillator (VCO) is shown in Fig. 3. The dimensions of the chip are 2.0 mm x 2.0 mm. In addition to minor changes of the oscillator circuit itself, the former 1-stage buffer amplifier has been replaced by the new 2-stage MPA. This results in higher output power and less susceptibility to load impedance variations. Fig. 4 shows test results for one wafer. Out of the 95 available chips, 46 were oscillating. In the diagram, the measured output powers are plotted against the oscillation frequency. For the majority of oscillating circuits, output powers in the range of 5-8 dBm

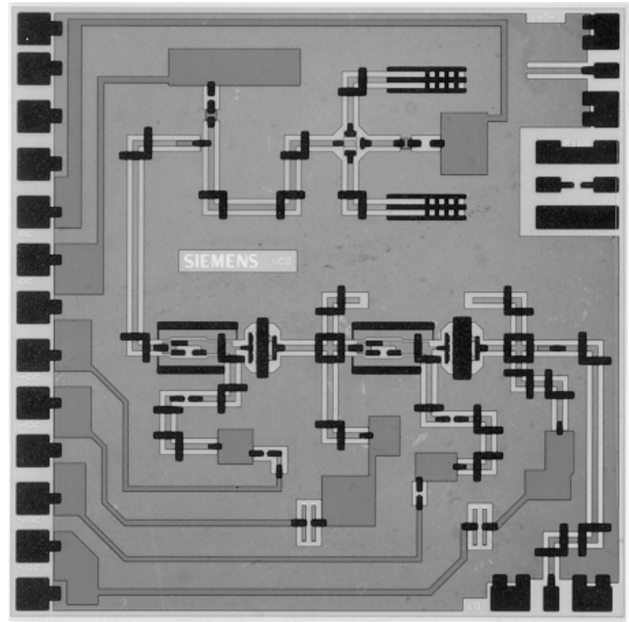

Fig. 3. Chip photograph of the voltage controlled oscillator with buffer amplifier (2.0 mm x 2.0 mm).

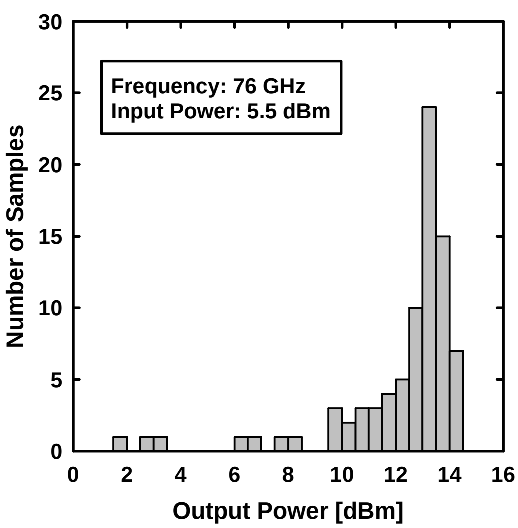

Fig. 2. Distribution of measured output power of the medium power amplifier chips from one wafer.

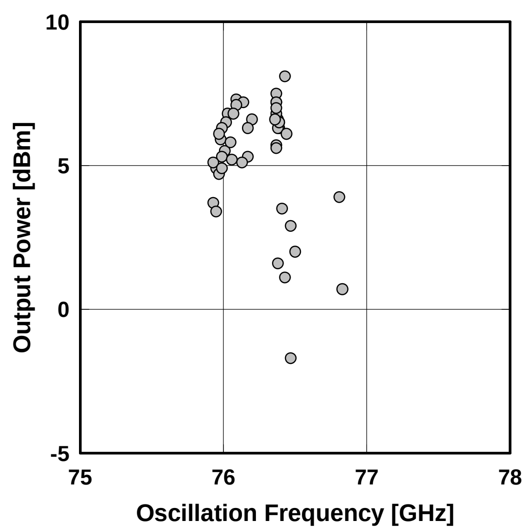

Fig. 4. Measured output power and oscillation frequency of the oscillator chips from one wafer.

and frequencies between 75.9 GHz and 76.5 GHz have been measured. These frequencies are at the lower edge of the electronic tuning range. By varying the gate voltage of the oscillator transistor, the frequency can be shifted up by typically 0.8 GHz. The phase noise of the VCO is approximately -80 dBc/Hz at 1 MHz offset frequency.

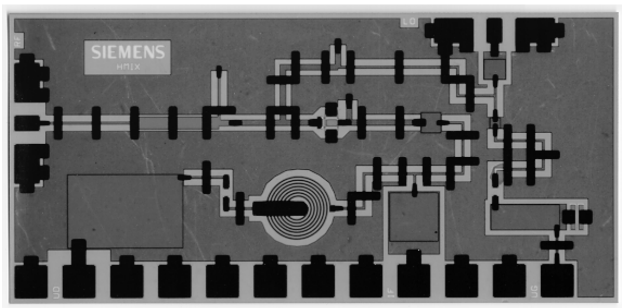

Fig. 5. Chip photograph of the active harmonic mixer (1.0 mm x 2.0mm).

Fig. 5 shows the active harmonic mixer (HMIX), which has a size of 1.0 mm x 2.0 mm. The design modifications aimed at an improved conversion gain at IF frequencies below 1 GHz. The measurement results in Fig. 6 confirm that the redesign has been successful [4]. For mixing with the 5th harmonic of a fixed LO signal at 15.1 GHz an almost constant conversion loss of 18-19 dB is obtained across the RF frequency range of 76-77 GHz. The corresponding IF frequencies are 0.5-1.5 GHz.

A block diagram and a photograph of the transceiver (TRX) which has dimensions of 2.0 mm x 3.0 mm are

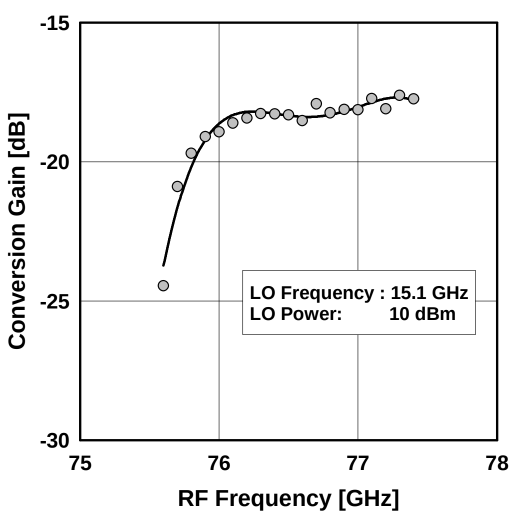

Fig. 6. Measured conversion gain of the harmonic mixer .

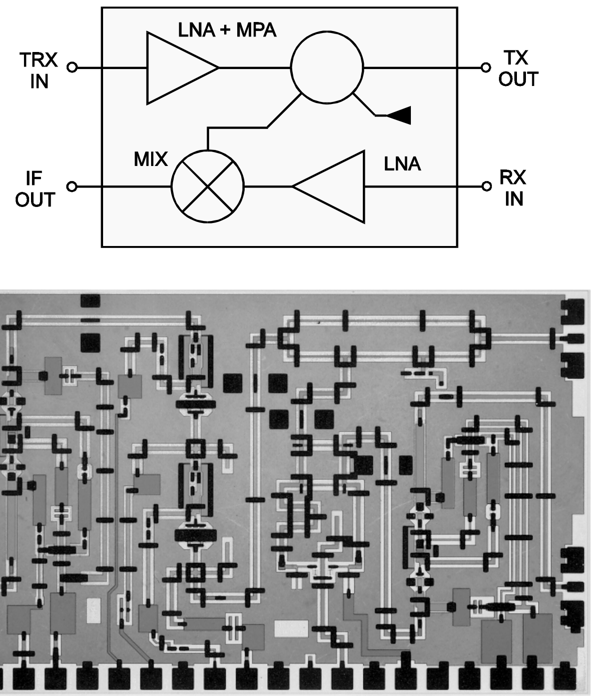

Fig. 7. Block diagram and chip photograph of the transceiver MMIC (2.0 mm x 3.0 mm).

shown in Fig. 7. The receiver input port is connected to a newly designed 2-stage low noise amplifier (LNA), which is followed by a single-balanced Schottky diode mixer. The 4-stage transmit amplifier is a combination of the LNA and MPA circuit designs. Via a rat-race coupler half of the amplifier output power is delivered to the transmitter output port, the other half serves as the LO signal of the mixer. The fourth port of the coupler, normally terminated by a 50-Ohm resistor, can alternatively be connected to the LNA input by minor airbridge changes. In this case the transmitter output port is also utilized as the receiver input port with the coupler taking over the additional function of a transmit-receive diplexer. By this option the transceiver can easily be adapted to different antenna feed configurations.

Measured results of the transceiver are shown in Fig. 8. The transmitter output power and the receiver conversion gain are plotted versus the input power of the 4-stage amplifier. The conversion gain saturates at around 1 dB indicating that the LNA gain roughly equals the loss of the mixer. With a -3 dBm input signal 9 dBm of output power is available at the transmitter output port.

A second version of the transceiver has been designed with a resistive HEMT mixer replacing the diode mixer. This version is described in [5].

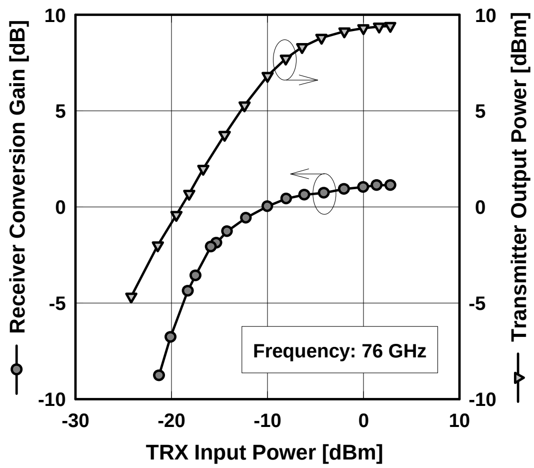

Fig. 8. Measured receiver conversion gain and transmitter output power of the transceiver.

APPLICATION EXAMPLE

Automotive radar systems are the most important applications of the chip set. As an example Fig. 9 shows the block diagram of a possible FMCW radar frontend. One transceiver is assigned to each of 3 transmit-receive beams. Separate antenna feeds are assumed here which, however, share a single dielectric lens to form a compact high gain antenna. The input signals of the transceivers are supplied by the VCO via a passive distribution network. A part of the oscillator signal is downconverted to a low frequency by the harmonic mixer. This signal can be processed for VCO linearization and stabilization purposes. The total GaAs chip area required for this system is 24 mm² only. A variety of other sensor systems may be designed with these MMICs. The MPA is available as a universal gain block to raise the power level at different places within a system, if necessary.

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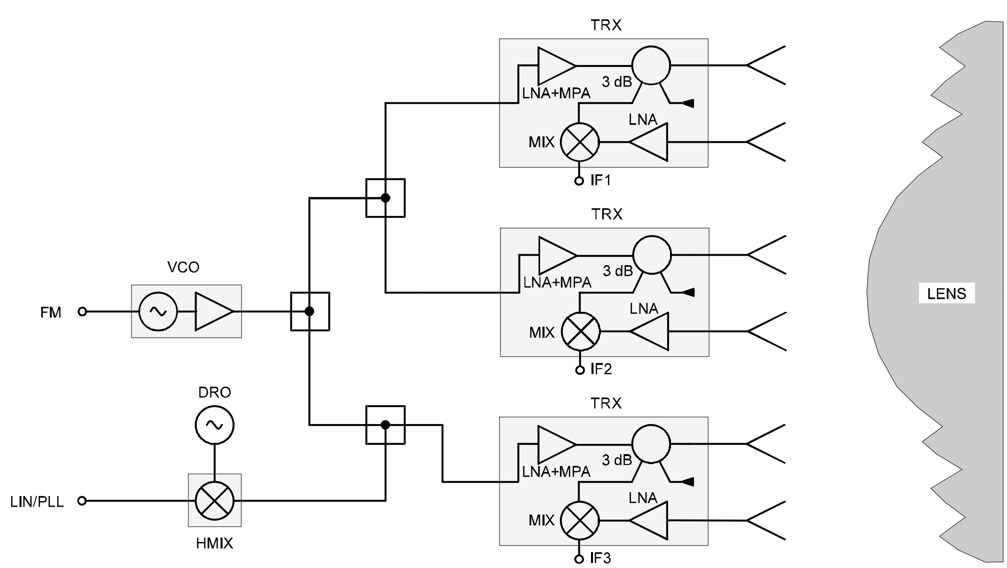

Fig. 9. Block diagram of a 3-beam FMCW radar frontend as an application example of the chip set.