A 38/76 GHz Automotive Radar Chip Set Fabricated by a Low Cost PHEMT Technology

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Abstract — **Two complex transmit MMICs have been developed for the conversion of a 38 GHz VCO signal to 76 GHz. They consist of a 38 GHz driver amplifier, a frequency doubler and 76 GHz output amplifiers. These MMICs achieve a saturated output power of 14 dBm at 76 GHz and a maximum conversion gain of 9 dB and 12 dB, respectively. The transmit chips are supplemented by a 38 GHz voltage-controlled oscillator with 1.5 GHz tuning bandwidth and 10 dBm output power. The devoloped MMICs are designed for flip-chip mounting and have been fabricated by a production oriented PHEMT technology. They are suited for low cost automotive radar systems.**

I. Introduction

Inexpensive GaAs MMICs are essential for future low cost automotive radar systems operating in the 76-77 GHz band. So far, only a few fundamental oscillators have been published for this frequency range, e. g. [1, 2]. Typical frontend architectures therefore use a lower frequency VCO followed by one or more frequency multipliers [3, 4]. This concept also facilitates the generation of stable low phase noise signals. Frequency doublers for a fundamental input frequency of 38-38.5 GHz are thus key components of complex transmit MMICs for 76-77 GHz applications.

This paper reports about a chip set for automotive radar frontends, consisting of a 38 GHz VCO and two different transmit MMICs. The circuit designs are based on finite ground coplanar transmission lines and are suited for both flip-chip and conventional wire-bond mounting techniques. The monolithic circuits have been fabricated by a production oriented low cost GaAs PHEMT technology [5].

II. 38 GHz VCO

Fig. 1 shows a photograph of the monolithic VCO. The dimensions of the chip are 1.76 mm x 2.94 mm. The circuit consists of an oscillator with feedback topology and a single-stage buffer amplifier. The active part of the oscillator is a two-stage amplifier. Like the buffer, each of these stages employs a PHEMT device with 2x40 μm gate width operated at 3 V drain-to-source voltage. The output signal of the two-stage amplifier is split by a power divider. One part is transferred to the output port via the buffer stage, the other half enters the feedback path. Here, the signal passes a voltage-controlled phase shifter made up of 10 HEMT devices operated as passive varactor diodes and connected by short inductive transmission line sections. By changing the phase shift in the feedback path,

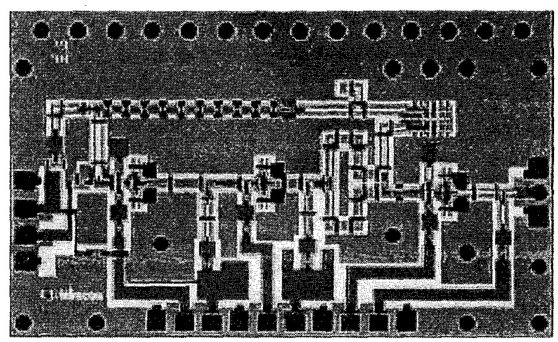

Fig. 1. Chipphoto of the monolithic 38 GHz voltage-controlled oscillator with single-stage buffer amplifier.

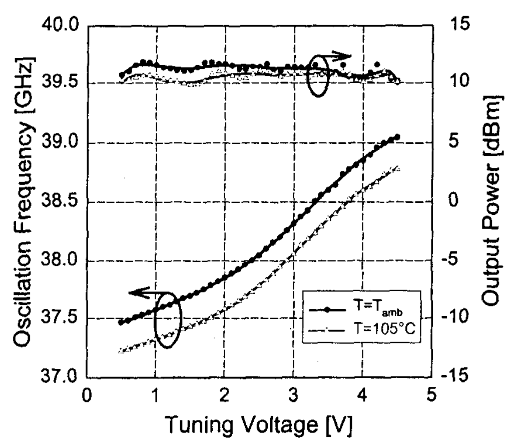

Fig. 2. Measured oscillation frequency and output power of the monolithic 38 GHz VCO as a function of the external tuning voltage.

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the oscillation frequency can be tuned. More details on this concept are given in [6].

Typical measurement results of the VCO at room temperature and 105°C are depicted in Fig. 2. The oscillator can be tuned over a frequency range of more than 1.5 GHz and delivers an output power of at least 10 dBm at ambient temperature. When heated to 105°C, the power drops by less than 1.5 dB and the tuning curve is shifted down by 0.3 GHz. It is evident that the interesting frequency band of 38.0-38.5 GHz can be covered over a broad range of temperatures.

III. 38/76 GHZ TRANSMIT MMICS

Two transmit MMICs have been developed for the conversion of the 38 GHz VCO output signal to 76 GHz. The first transmit MMIC which is depicted in Fig. 3 has a single-ended output. It consists of the series connection of a 38 GHz driver amplifier, a 38/76 GHz frequency doubler and a 76 GHz output amplifier. The dimensions of the chip are 1.76 mm x 2.76 mm.

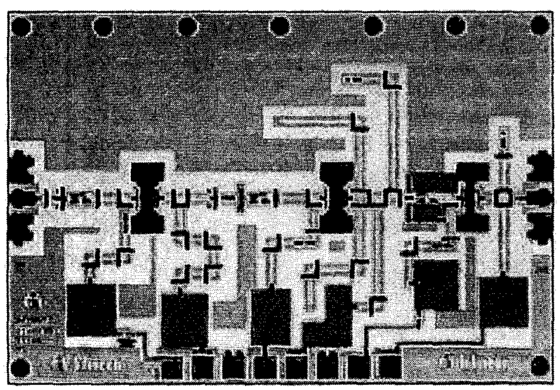

Fig. 3. Chipphoto of the single-ended transmit MMIC consisting of a 38 GHz driver amplifier, a 38/76 GHz frequency doubler and a 76 GHz output amplifier.

The 38 GHz driver amplifier has 8 dB small signal gain and consists of a PHEMT with 4x60 um gate width at nominal operating conditions for maximum gain and output power of the Infineon HEMT110 process technology (V_{DS}=3 V, I_{DS}=250 mA/mm). The frequency doubler is a PHEMT with 4x60 um gate width and operating conditions near the pinch off region (V_{GS}=-0.5 V, V_{DS}=3 V) so that high even harmonic power levels are generated. The frequency doubler achieves a high maximum conversion gain of 1 dB for 5 dBm input power [7]. The saturated 76 GHz output power level is 8 dBm. The output signal of the frequency doubler is amplified by 5 dB using a 76 GHz amplifier stage with a 4x40 um gate width PHEMT.

The measured overall performance of the single ended transmit MMIC is shown in Fig. 4 for room temperature and 105°C. The maximum conversion gain of 9 dB is achieved for 2 dBm input power at 38.25 GHz. The 76.5 GHz output power level is approximately 13 dBm for input power levels above 5 dBm at room temperature. A temperature increase from room temperature to 105°C results in a reduction of 2-3 dB in output power and conversion gain. This correlates well with a typical decrease of 0.1 dB in output power and gain per PHEMT stage and 10°C temperature rise.

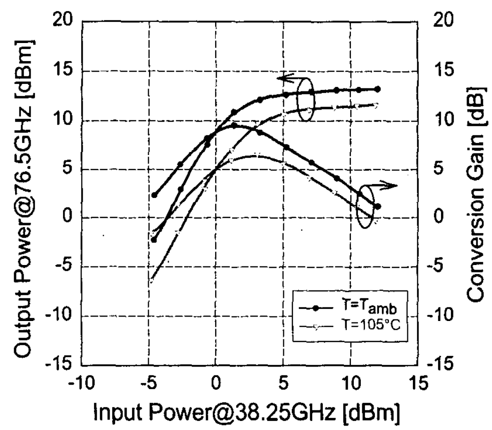

Fig. 4. Measured conversion gain and output power at 76.5 GHz versus input power at 38.25 GHz of the single-ended transmit MMIC for room temperature and 105°C.

The second 38/76 GHz transmit MMIC has one 38 GHz input port and two 76 GHz output ports and is depicted in Fig. 5. It consists of the previously described single ended transmit MMIC extended by a Wilkinson type power divider and two parallel 76 GHz two-stage medium power amplifiers. One 76 GHz output port can, for example, be connected to the transmit antenna and the other can be used to supply the LO signal for the receive mixer. The two stage medium power amplifiers consist of PHEMTs with 4x40um gate width in the first stage and 4x60um in the second stage at the operating conditions V_{DS}=3 V, I_{DS}=250 mA/mm. The dimensions of the second transmit chip are 1.76 mm x 4.35 mm.

The measured characteristics of the 38/76 GHz transmit MMIC with two parallel output ports is shown in Fig. 6 at room temperature and 105°C. The measurements refer to one of the two 76 GHz output ports. This MMIC achieves a maximum conversion gain of 12 dB for 0 dBm input power and 38.25 GHz input frequency. The 76.5 GHz output signal saturates for input power levels above 2 dBm. This transmit MMIC delivers more than 14 dBm output power at each of the two output ports.

A temperature increase from room temperature to 105°C results in a decrease of the maximum conversion gain from 12 dB to 8 dB. This correlates with the expected gain drop of 0.8 dB for each of the five cascaded PHEMT stages. The saturated output power of 12 dBm at 105°C is only 2.5 dB below the value at room temperature.

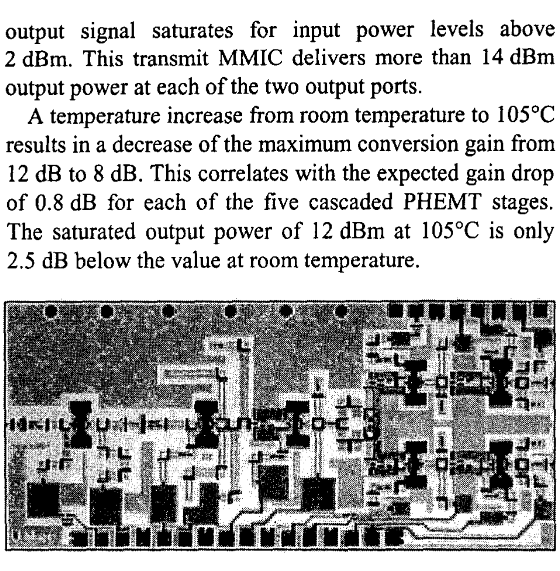

Fig. 5. Chipphoto of the 38/76 GHz transmit MMIC with two parallel 76 GHz output ports.

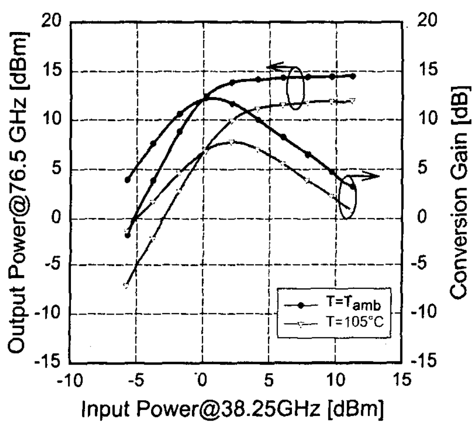

Fig. 6. Measured conversion gain and output power at 76.5 GHz versus input power at 38.25 GHz of the transmit MMIC with two parallel output ports at room temperature and 105°.

IV. LOW COST PHEMT TECHNOLOGY

The MMICs have been fabricated using the Infineon Technologies HEMT110 process technology. This process technology has been transferred from 4" to 6" wafers which is an important step towards cost reduction. The key factor of the delta doped double heterojunction PHEMTs with a gate length of 0.13 um is that only optical stepper lithography and no electron beam lithography is used during the fabrication process. This offers a much higher throughput compared to technologies using electron beam lithography for the gate formation. In addition, the coplanar designs require no via hole process and no backside metallization. More details of the PHEMT DC and RF parameters as well as the fabrication technology are given in [5].

V. APPLICATION EXAMPLES

Some examples of possible radar frontend applications of the chip set are shown in Figs. 7 and 8. In both cases the VCO chip is used as the signal source of an FMCW radar. Since monolithic oscillators generally have a poor frequency stability, a phase-locked loop (PLL) system is used to improve both the phase noise and the tuning linearity. Before entering the PLL circuit, a small fraction of the VCO signal is downconverted in a subharmonically pumped mixer (SHMIX). The stable LO signal for the SHMIX is provided by a dielectric resonator oscillator (DRO).

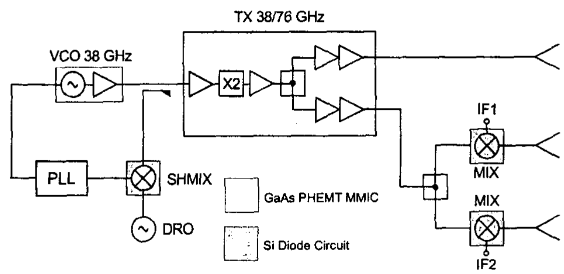

Fig. 7. Block diagram of an FMCW radar frontend with one transmit and two receive channels (monopulse receiver).

In the system shown in Fig. 7, the second transmit MMIC is employed. One of the 76 GHz output ports is connected to a transmit antenna, the second one feeds the LO ports of two receiver mixers via a power splitter. The IF signals of the two mixers may be evaluated by a monopulse algorithm in order to determine the azimuth angle of the targets. An inexpensive way to realize the mixers is to use silicon Schottky diodes in a hybrid circuit configuration [8]. The power provided by the transmitter chip is sufficient to simultaneously drive two balanced Schottky diode mixers. A silicon diode is also a suitable nonlinear element for the subharmonically pumped mixer. The two GaAs chips employed in the system of Fig. 7 have a total area of 12.8 mm².

The block diagram in Fig. 8 shows a system with even lower chip area. Replacing the second transmit MMIC by the first version results in a tota chip area of only 10.0 mm². Here, a single channel with one antenna is used for both transmit and receive functions. This is made possible by a special mixer design with a part of the LO power being transferred to the RF port to serve as the transmit signal. A suitable balanced transfer mixer with two Si Schottky diodes is described in [9]. The single-channel architecture of the frontend in Fig. 8 would require a mechanically scanned antenna to obtain angular information of the targets. A performance evaluation of the frontend architectures in Figs. 7 and 8 shows that these systems, when combined with suitable narrow beam antennas, will meet the requirements of a forward looking automotive radar.

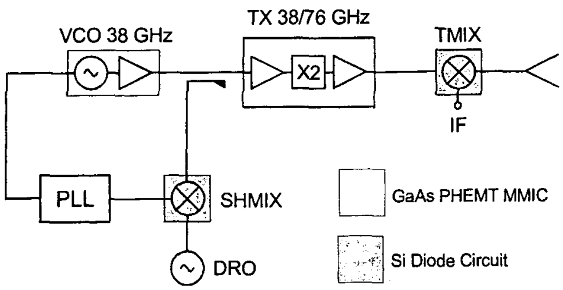

Fig. 8. Block diagram of an FMCW radar frontend with a single transmit/receive channel.

VI. CONCLUSION

A single ended 38/76 GHz transmit MMIC and a second MMIC with two parallel output ports have been developed to achieve a frequency multiplication by two and amplification to output power levels appropriate for automotive radar applications. The single ended transmit MMIC demonstrates 9 dB conversion gain and achieves a saturated output power of 13 dBm at 76.5 GHz. The output power decreases to 11.5 dBm at 105°C.

The second transmit MMIC has two parallel output ports. In a typical radar frontend, one 76 GHz output port can be connected to the transmit antenna and the other can be used to provide the LO signal for the receive mixer. This MMIC achieves a maximum conversion gain of 12 dB in conjunction with a saturated 76.5 GHz output power level of 14 dBm at each port. The saturated output power decreases to a value of 12 dBm at 105°C.

The 38 GHz VCO demonstrates a tuning bandwidth of more than 1.5 GHz in conjunction with 10 dBm output power.

All chips are suited for commonly used bond wire and also for flip-chip mounting. The latter technique has the potential for a significant reduction of the assembly cost.

The VCO and the transmit MMICs have been developed for automotive radar applications. These GaAs chips can, for example, be combined with discrete silicon Schottky diodes to realize radar frontends with low fabrication cost.

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