Monolithic Coplanar 77 GHz Balanced HEMT Mixer with Very Small Chip Size

Heinz J. Siweris and Harald Tischer

TriQuint Semiconductor Europe, mm-Wave R&D, Konrad-Zuse-Platz 1, 81829 Munich, Germany

Abstract — **A balanced HEMT mixer for 76-77 GHz car radar applications has been designed and fabricated on a 6-inch GaAs production line. The monolithic circuit has a very small chip size of only 0.56 mm². With 2 dBm of LO power, a conversion loss below 11 dB was measured in the 76-77 GHz band. The results demonstrate that the single-device concept used in the circuit design is suitable for very compact monolithic millimeter-wave mixers.**

I. Introduction

While microwave mixers in general are a rather mature technology, the development of high-performance low-cost monolithic mixers still remains a challenge [1]. Since for a given fabrication technology the cost of a monolithic microwave integrated circuit (MMIC) mainly depends on the chip area, keeping the physical dimensions of the circuit as low as possible is a mandatory design goal. However, for most of today's monolithic mixers the chip area is dominated by large coupler or balun structures.

The design of a GaAs HEMT (High Electron Mobility Transistor) mixer may be based on one of the following fundamental circuit concepts:

- diode type mixer (HEMT is operated as a diode by shorting source and drain),
- active mixer (HEMT is operated at an active DC bias point),
- resistive mixer (HEMT is operated as a controlled resistor at 0 V DC drain-to-source voltage).

Among these circuit types, the resistive mixer is particularly advantageous, since it combines high linearity, low LO power requirements, good noise properties, and zero or almost zero DC power consumption [2].

A HEMT resistive mixer with a novel circuit topology has been published by Yhland et al. in 1995 [3]. The essential feature of this circuit is that only a single HEMT device is required to achieve a balanced mixer operation. Several hybrid microstrip versions of the mixer were successfully designed and built for RF frequencies up to 20 GHz [3]. In addition to the advantage of avoiding device pairing problems, the concept appears to be very attractive for compact monolithic circuits due to its low complexity. Nevertheless, to the authors' knowledge, this mixer concept has neither been realized in monolithic form yet, nor has it been used at higher frequencies or in coplanar designs.

In this paper, the first monolithic coplanar HEMT mixer utilizing the balanced single-device concept is described. The circuit was designed for RF/LO frequencies in the 76-77 GHz millimeter-wave band, thus it is intended mainly for applications in car radar frontends. By using the single-device concept in combination with a compact RF balun realized as a coplanar waveguide to coplanar stripline transition, very small chip dimensions have been obtained for the fabricated circuit. This is particularly important for cost sensitive applications like car radar systems.

II. Circuit Design

A simplified schematic diagram of the mixer illustrating the principle of operation is shown in Fig. 1. The LO signal is applied to the gate of the HEMT, thus periodically modulating the channel conductance of the device. A gate DC voltage may be used to optimize the conversion performance. The drain-to-source DC voltage, on the other hand, is equal to zero. The RF input signal is split by a balun into two signals of equal amplitude, but opposite phase, which are applied to the drain and source, respectively. The channel current includes the low frequency IF component which is filtered and transferred to the IF output port by a suitable transformer type balun. The intrinsic RF/LO isolation property of a balanced mixer results from the symmetry of the circuit with respect to the gate of the HEMT.

Fig. 2 shows the layout of the monolithic coplanar mixer circuit. The HEMT device has a single gate finger with a width of 40 μm. The 0°/180° balun for the RF input signal is realized as a very simple transition from coplanar waveguide (CPW) to coplanar stripline (CS). The CPW center conductor and one of the ground strips are transferred to the CS geometry, with an airbridge connection to the second CPW ground. Reasonable performance of this transition has been demonstrated, at least at lower frequencies [4]. The main advantage of the structure is its very small size which significantly contributes to the low overall dimensions of the mixer.

0-7803-7695-1/03/$17.00 © 2003 IEEE

The RF input is matched to 50 Ω by a short section of high impedance CPW line. At the LO port, the matching network consists of a CPW line and a parallel stub with a lumped capacitor at the end establishing an RF short. This stub is also used to supply the DC voltage to the gate via a 100-Ω series resistor. Two IF signals with opposite phase are extracted from the source and drain node, respectively, via low-pass filters. These signals are combined by an off-chip transformer as indicated in Fig. 1. The mixer was designed to operate mainly at low IF frequencies (< 10 MHz), which are typical for homodyne car radar systems.

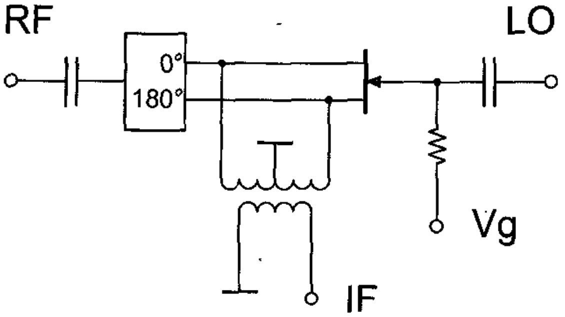

Fig. 1. Simplified schematic diagram of the single-device balanced HEMT mixer.

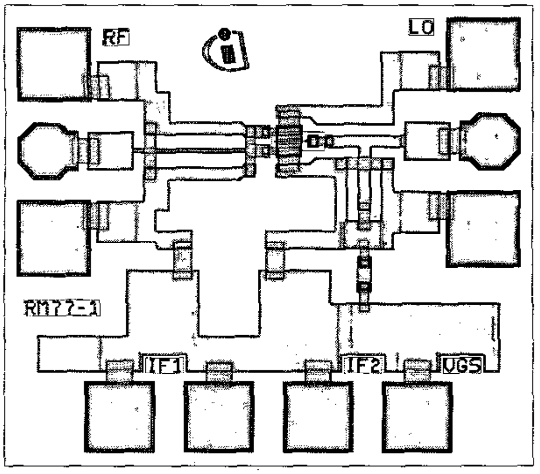

Fig. 2. Layout of the monolithic coplanar 77 GHz HEMT mixer circuit.

The circuit was simulated and optimized using a commercial harmonic balance CAD tool. A special analytic large-signal HEMT model was employed, which includes a set of equations optimized for device operation around 0 V drain-to-souce voltage [5]. The CPW-to-CS transition was modelled as an ideal lumped element balun. This approximation was regarded as sufficiently accurate for a first proof-of-concept design. The large-signal simulation predicts a conversion loss of 8 dB in the 76-77 GHz RF frequency range for 3 dBm of LO power and -0.2 V gate DC voltage.

III. CHIP FABRICATION

The mixer was fabricated by a production-oriented pseudomorphic HEMT technology on 6-inch GaAs MBE (molecular beam epitaxy) wafers. The process does not rely on electron-beam lithography for the formation of the gates. Instead, optical stepper lithography is applied in combination with a sidewall spacer process. The typical gate length is 0.13 μm, which for an active device results in a current-gain cutoff frequency f_t of about 90 GHz at standard DC bias conditions, i. e. 3 V drain-to-source voltage and 250 mA/mm drain current density. The maximum frequency of oscillation f_{max} is beyond 200 GHz. The process was developed for low-cost high volume production of millimeter-wave MMICs.

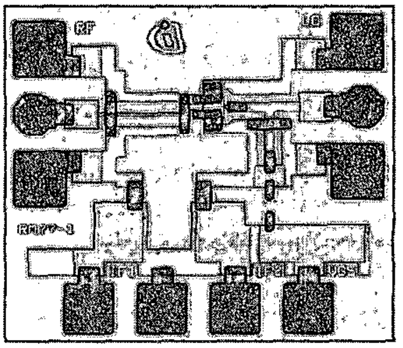

Fig. 3. Chip photograph of the monolithic HEMT mixer.

Fig. 3 shows a photograph of the fabricated monolithic HEMT mixer. The dimensions of the chip are 0.7 mm x 0.8 mm, corresponding to an area of 0.56 mm². Without the pad periphery, the intrinsic mixer occupies about half of this area only. It probably is the smallest monolithic mixer made up to now for this operating frequency.

IV. MEASUREMENT RESULTS

The mixer was characterized with a scalar W-band measurement setup with synthesized sources for both the RF and LO signals. Due to this waveguide setup, the measurements were restricted to frequencies above 74 GHz.

As a first test, the two IF output ports were terminated by separate 50-Ω resistors and the corresponding voltages were measured with an oscilloscope. Fig. 4 shows a screenshot of the oscilloscope display. The IF signals have a good balance with almost equal amplitudes and a near 180° phase difference. For the remaining tests, a 180° transformer balun was used to connect the two mixer IF ports to a single unbalanced IF output terminated by 50 Ω. All measurements were performed at 100 kHz IF frequency.

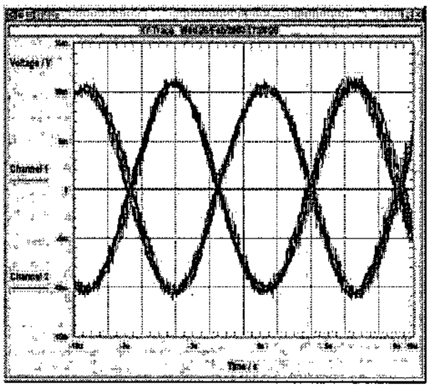

Fig. 4. Measured waveforms at the two IF output ports of the monolithic mixer circuit.

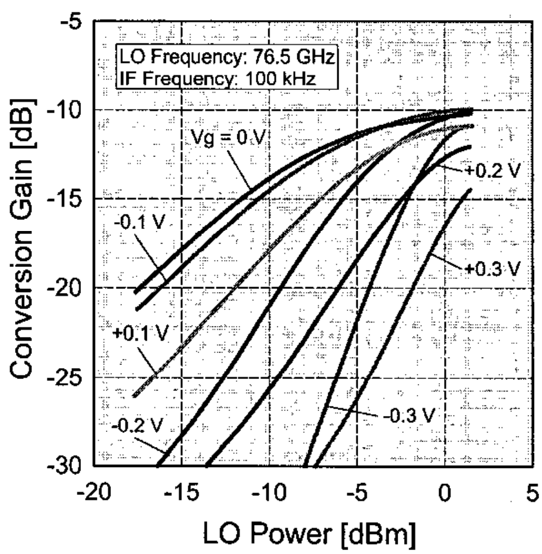

Fig. 5. Measured conversion gain as a function of LO power for different DC bias voltages.

Fig. 5 shows the measured mixer conversion gain at a fixed LO frequency of 76.5 GHz as a function of LO power for different DC bias conditions. At high LO power (> 0 dBm), the conversion gain is only a weak function of the DC bias voltage. The dependency becomes more pronounced at lower LO power levels. The best conversion performance is obtained around 0 V gate voltage. Thus, the mixer can be operated without any external DC supply. For LO power values of 0 dBm or higher, the best conversion loss is close to 10 dB. However, reasonable mixer performance is still possible with lower LO power, down to about -10 dBm. This demonstrates one of the advantages of a resistive type mixer. Measured conversion loss curves as a function of RF/LO frequency at 0 V DC bias voltage and 100 kHz IF frequency are shown in Fig. 6. The mixer has a broadband characteristic with almost constant conversion performance throughout the 76-77 GHz car radar band. At lower frequencies, a conversion loss better than 10 dB has been measured.

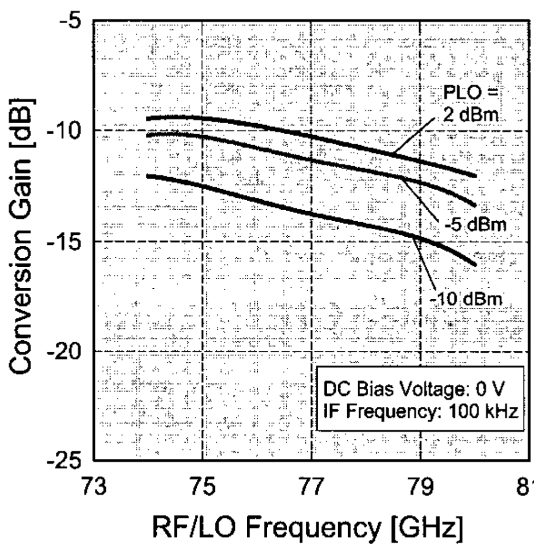

Fig. 6. Measured conversion gain as a function of RF/LO frequency for different LO power levels.

The measured return loss at both the RF and LO ports is about 8 dB at 76.5 GHz with better values at lower RF/LO frequencies. Like the data in Fig. 6, this indicates that the frequency range of optimum performance is shifted down somewhat compared to the design goal. The measured RF-to-LO isolation was approximately 12 dB at 0 V gate voltage but could be improved by setting the DC bias to a slightly positive value.

Fig. 7 shows the distribution of the measured conversion loss for all samples of the mixer on a particular wafer. The distribution peaks at a conversion loss of 10.7 dB with a very small variation. For a minimum conversion gain of -11 dB, an RF yield of better than 83 % has been achieved.

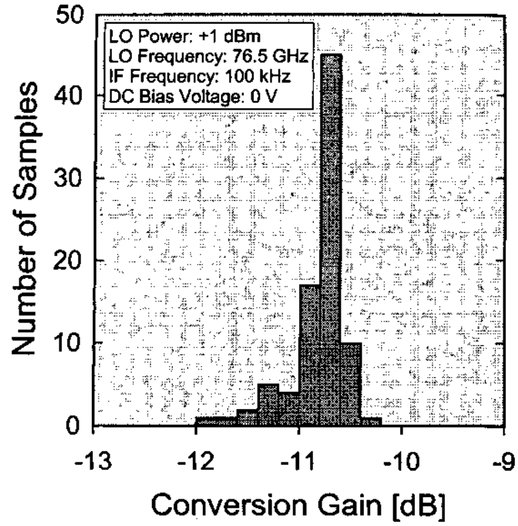

Fig. 7. Distribution of the measured mixer conversion gain for all samples from one wafer.

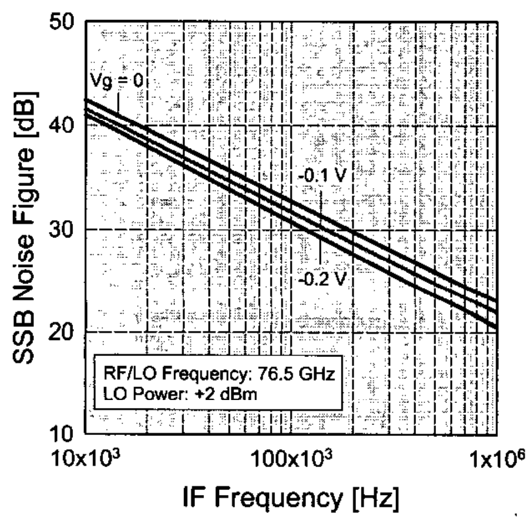

Fig. 8. Measured single-sideband noise figure as a function of IF frequency for different DC bias voltages.

Fig. 8 shows the measured single-sideband noise figure of the mixer for the range of low IF frequencies which is of interest for homodyne car radar systems. The noise figure is dominated by the 1/f noise of the HEMT device and approaches 20 dB at 1 MHz IF frequency. This result is similar to a previous resistive mixer design and corresponds to a 10-dB improvement when compared to a diode type mixer fabricated with the same technology [6]. For IF frequencies higher than about 10 MHz, the noise figure is expected to be equal to the conversion loss.

V. Conclusions

A monolithic HEMT mixer for 76-77 GHz car radar applications has been designed and fabricated. The circuit has a very small chip size of only 0.56 mm^2 and requires an LO power of not more than 2 dBm. A conversion loss better than 11 dB was measured in the 76-77 GHz band.

Several improvements are possible by a redesign. A more accurate simulation of the balun structure, e. g. by using an electromagnetic field simulator, and corresponding adjustments of the matching networks should lead to better return loss values and also to a slightly higher conversion gain. The moderate RF/LO isolation calls for a more detailed investigation of the symmetry properties of the circuit. Apparently, the coplanar stripline mode at the RF side of the HEMT device is not sufficiently decoupled from the coplanar waveguide mode at the LO or gate side. Improved isolation performance might also be achieved by replacing the simple CPW-to-CS transition by a different balun structure, e. g. [4, 7].

In summary, the results obtained so far demonstrate the advantages of the balanced single-device concept for very compact monolithic mixer circuits, especially at millimeter-wave frequencies.

References

[1] S. Maas, "Mixer technologies for modern microwave and wireless systems," *GAAS 2002 Conf. Proc.*, pp. 245-248, September 2002.

[2] S. A. Maas, "A GaAs MESFET mixer with very low intermodulation," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-35, pp. 425-429, April 1987.

[3] K. Yhland, N. Rorsman, and H. G. Zirath, "Novel single device balanced resistive HEMT mixers," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-43, pp. 2863-2867, December 1995.

[4] L. Zhu and K. Wu, "Hybrid FGCPW/CPS scheme in the building block design of low-cost uniplanar and multilayer circuit and antenna," *1999 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 867-870, June 1999.

[5] U. Schaper, A. Schäfer, A. Werthof, H. J. Siweris, H. Tischer, L. Klapproth, G. Böck, and W. Kellner, "70-90 GHz balanced resistive PHFET mixer MMIC," *Electronics Letters*, vol. 34, pp. 1377-1379, July 1998.

[6] H. J. Siweris, A. Werthof, H. Tischer, U. Schaper, A. Schäfer, L. Verweyen, T. Grave, G. Böck, M. Schlechtweg, and W. Kellner, "Low-cost GaAs pHEMT MMIC's for millimeter-wave sensor applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-46, pp. 2560-2567, December 1998.

[7] Y.-S. Lin and C. H. Chen, "Novel lumped-element coplanar waveguide-to-coplanar stripline transitions," *2001 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, pp. 615-618, May 2001.