Coplanar Integrated Mixers for 77-GHz Automotive Applications

Ludger Verweyen, Hermann Massler, Markus Neumann, Ulrich Schaper, and William H. Haydl

***Abstract*—For integration in receivers at 77 GHz, three passive mixers, a balanced diode mixer, a single ended and a balanced resistive mixer, as well as an active single-ended gate mixer have been realized in coplanar 0.15-μm PM-HEMT technology on GaAs. The passive mixers achieved conversion losses of about 9 dB. The resistive mixers required an LO power of only 3 dBm and the diode mixer 10 dBm for optimum conversion. The gate mixer obtained a conversion gain of 1 dB for an LO power of 6 dBm, but showed higher sensitivity to the IF load.**

I. Introduction

In automotive collision-avoidance radar systems, the dynamic range of receivers affects the achievable resolution for obstacles at a given distance. Whereas the detection at large distances is limited by the signal-to-noise ratio, at short distances it is limited by the radio frequency (RF) saturation of the mixer and the resulting increase of conversion loss. The properties of the mixer determine the required number of low-noise amplifier stages in the RF path and the necessary power level of the local oscillator (LO). Increasing the integration level and simplifying the monolithic microwave integrated circuit (MMIC) process by using coplanar waveguides requires a mixer design compatible with the integrated receiver technology [1], comprising amplifiers, oscillators, and passive hybrids [2].

In recent publications on integrated receivers for automotive applications [3], [4], diode mixers were used due to the well-established modeling techniques of its nonlinear elements [5] and the extensive design work in the past. However, using a field-effect transistor (FET) as a three-terminal device in various topologies appear quite attractive for MMIC mixers, if similar device characteristics are exploited for mixing as those used in amplifiers or oscillators (for which a HEMT technology is optimized). Resistive mixers, where the FET operates in a passive mode, have achieved similar conversion losses as diode mixers up to F-band [6], with superior intermodulation characteristics, while gate mixers, operating in the active region near pinch-off, are expected to have conversion gain. Different FET mixers, realized in microstrip technology on InP, were recently investigated for 94-GHz applications [7].

Manuscript received August 29, 1997. This work was supported by the German Federal Ministry for Education, Science, Research, and Technology.

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Publisher Item Identifier S 1051-8207(98)00865-4.

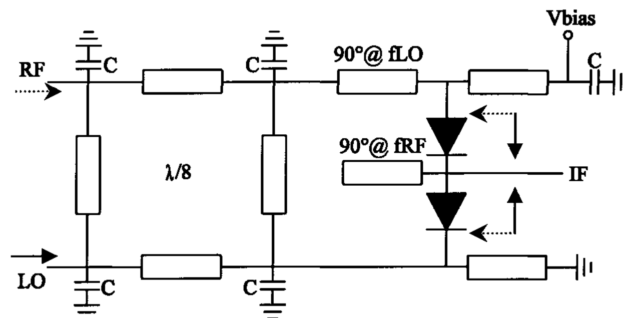

Fig. 1. Schematic diagram of balanced diode mixer for 77 GHz with capacitively loaded branch-line coupler.

In this paper, the properties of a balanced diode mixer, a single-ended and a balanced resistive mixer, and a gate mixer for 77-GHz are compared, all of them designed and realized in coplanar waveguide technology using a pseudomorphic 0.15-μm HEMT technology on GaAs.

II. Mixer Types

In a balanced diode mixer, a strong LO signal drives two diodes 180° out of phase, as shown in the schematic diagram in Fig. 1. The balance between the two diodes is achieved by a capacitively loaded branch-line coupler [8], followed by an additional transmission line of quarter wavelength in the path from the RF input to one diode. The LO and RF ports are isolated entirely by the passive hybrid. The cancellation of the LO signal at the midpoint between the two diodes provides good LO suppression at the IF port. The nonlinearity of a diode, characterized by its ideality factor, is lower for a diode realized in HEMT technology than for a p-i-n or whisker diode [9], resulting in higher conversion loss. The mixer chip, depicted in Fig. 2, uses two diodes of 20-μm width in series with a common bias for both diodes.

The resistive mixer exploits the strong nonlinearity of the output conductance of the FET at $V_{\rm ds} = 0$ V, when biased near pinchoff. As shown in the schematic in Fig. 3, LO and RF are applied to different terminals of the FET, resulting in zero dc power consumption and very low intermodulation [10]. For minimum conversion loss, determined by the ratio $|Z_{\rm on}/Z_{\rm off}|$ [11], low source and drain resistances as well as a very low channel resistance are necessary, which are device requirements comparable to those of an amplifier. For a single ended topology, the LO-to-RF isolation is given by the gate–drain capacitance, which must be equal to the gate–source capacitance of the FET in the passive mode. The gate–drain

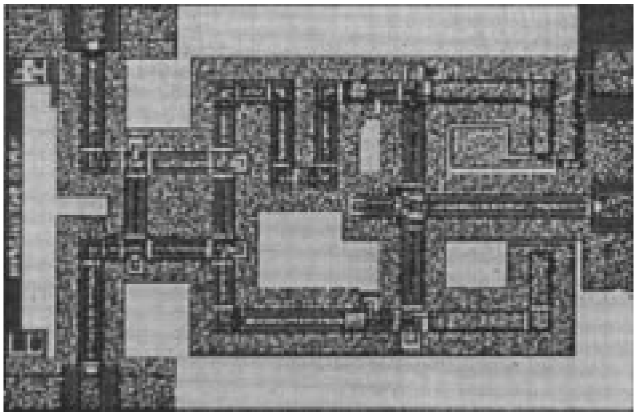

Fig. 2. Chip photo of coplanar balanced diode mixer for 77 GHz; chip size 1.5×1.0 mm^2.

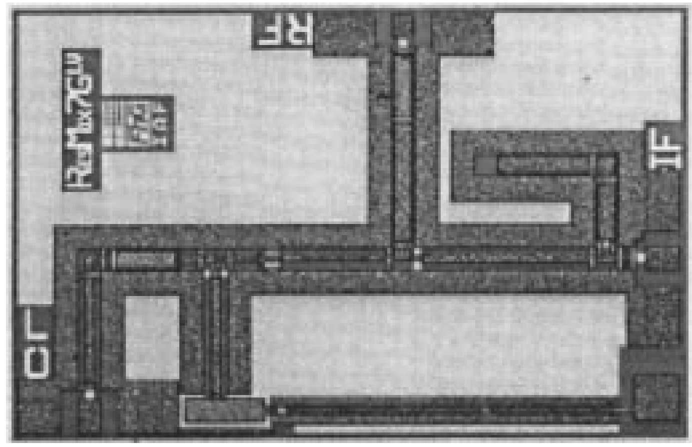

Fig. 4. Chip photo of coplanar single ended resistive mixer for 77 GHz; chip size 1.5×1.0 mm^2.

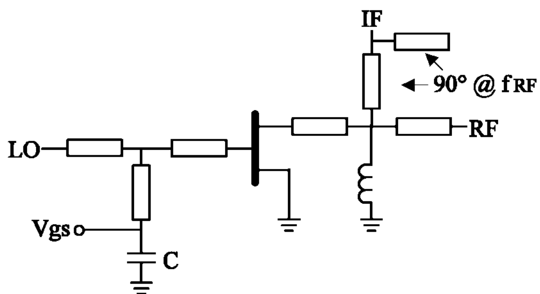

Fig. 3. Schematic diagram of single-ended resistive mixer for 77 GHz.

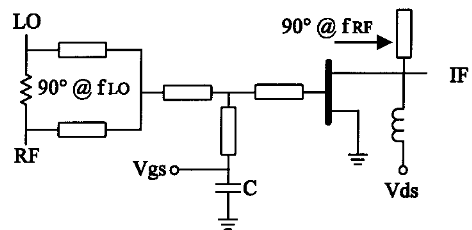

Fig. 5. Schematic diagram of single-ended gate mixer for 77 GHz.

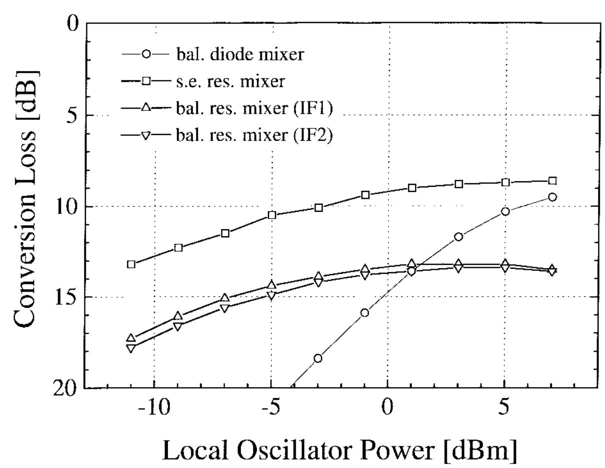

Fig. 6. Conversion gain versus local oscillator power of three passive mixers; $P_{rf} = 40$ dBm, $f_{rf} = 76.5$ GHz, $f_{lo} = 76.56$ GHz.

capacitance under these bias conditions is significantly higher than in the saturation region at maximum transconductance. The IF can be filtered from the drain via RF stubs.

The low LO-to-RF isolation of a single-ended resistive mixer can either be compensated by surrounding amplifier stages in the LO and RF paths with low reverse gain, or it can be overcome by a balanced topology, where the LO drives the gates of two FET's out of phase via a 180° delay line and is canceled at the common drain [12]. The single-ended resistive mixer, shown in Fig. 4, has an FET of 2×30 μm width, whereas the balanced resistive mixer uses two FET's of 1×30 μm width each.

The gate mixer, schematically depicted in Fig. 5, incorporates a Wilkinson combiner for applying LO and RF to the gate. At the drain, RF and LO are short-circuited, whereas the IF is connected to the load. The gate mixer is biased near pinch-off in the saturation region of the FET to exploit the nonlinearity in the transconductance for mixing. The device geometry is 2×30 μm. All mixers have a chip size of 1.5×1.0 mm^2.

III. Performance of the Mixers

The measured conversion loss of the three passive mixers can be seen in Fig. 6 as a function of LO power, for an LO frequency of 76.6 GHz and an RF frequency of 76.5 GHz. The lowest conversion loss of 8.5 dB is achieved for the single-ended resistive mixer, for an LO power of 3 dBm. The balanced diode mixer has a conversion loss of 9.5 dB, requiring an LO power of more than 7 dBm. For each IF channel of the balanced resistive mixer, a conversion loss of 13.5 dB was measured, at an LO power of 1 dBm. If both IF signals are added in phase via an external phase shifter, the total conversion loss is expected to be 10.5 dB.

The advantage of the balanced resistive mixer in comparison with the single-ended version can be seen from Fig. 7, where the LO-to-RF isolation of both mixer types is plotted versus RF frequency for an LO drive of 0 dBm. While the single-ended mixer has an isolation of only 9 dB at 77 GHz, the balanced resistive mixer achieves an isolation of more than 30 dB between LO and RF port. For the balanced diode mixer, the

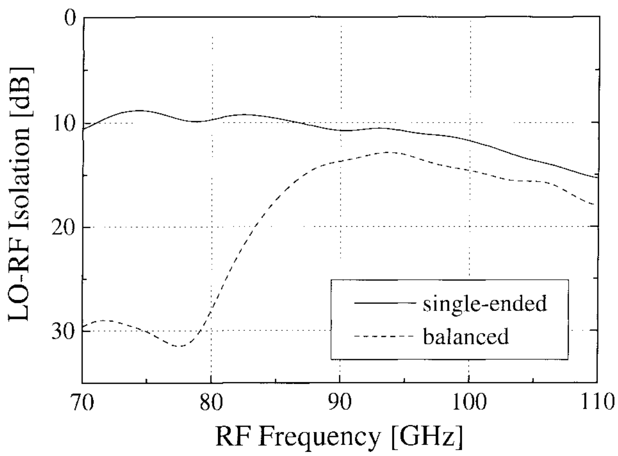

Fig. 7. LO-to-RF isolation versus RF frequency of single-ended and balanced resistive mixer; $P_{rf} = 22.5$ dBm, $f_{rf} = 76.0$ GHz, $f_{lo} = 76.4$ GHz.

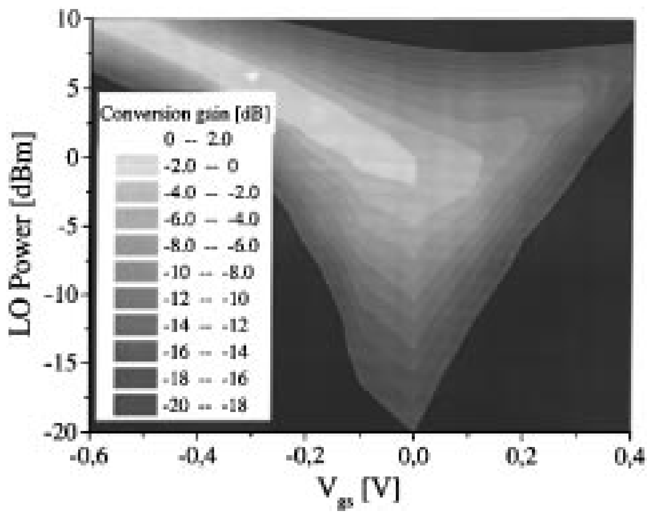

Fig. 8. Conversion gain versus gate bias and local oscillator power of single-ended gate mixer; $P_{rf} = 20$ dBm, $f_{rf} = 79$ GHz, $f_{lo} = 76.56$ GHz.

capacitively loaded branch-line coupler provides an LO-to-RF isolation of 15 dB [8].

In Fig. 8, the conversion gain of the single-ended gate mixer is plotted as a function of gate bias and LO power. Depending on the amplitude of the LO swing, causing a self-biasing effect on the FET, the gate bias can be adjusted for optimum conversion gain. For a wide range of LO power from 0 to 5 dBm, the conversion loss is between 0 and 2 dB. Applying 6 dBm to the gate, an optimum conversion gain of 1 dB is obtained, for an LO frequency of 76.5 GHz and an RF frequency of 79 GHz. In contrast to the passive mixers, a strong dependence on the IF frequency was observed for the gate mixer due to a mismatch to the 50-Ω load. Depending on the bias and the LO power, and thus the resulting match between mixer and Wilkinson combiner, an LO-to-RF isolation of more than 20 dB at 77 GHz was achieved.

IV. Conclusion

For insertion in low-cost radar systems at 77 GHz, different types of mixers have been realized in coplanar technology on GaAs. Of the three passive mixers investigated, the single-ended resistive mixer showed lowest conversion loss of 8.5 dB for an LO power of only 3 dBm, with an LO-to-RF isolation of 9 dB. The balanced diode mixer had similar conversion loss, but required an LO power of 10 dBm. Its LO-to-RF isolation, determined by the branch-line coupler, was about 15 dB. From the balanced resistive mixer with an improved LO-to-RF isolation of 30 dB a conversion loss of 10.5 dB is expected with both IF signals in phase.

An active gate mixer achieved a conversion loss of 2 dB for 0-dBm LO power. Conversion gain of 1 dB was obtained at an LO power of 6 dBm. Its LO-to-RF isolation, determined by the Wilkinson combiner, was approximately 20 dB.

Acknowledgment

The authors would like to acknowledge the contributions of their colleagues from the technology department.

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