ACTIVE, MONOLITHICALLY INTEGRATED COPLANAR V-BAND MIXER

M. Schefer, U. Lott, H. Benedickter, Hp. Meier, W. Patrick, and W. Bächtold

Laboratory for Electromagnetic Fields and Microwave Electronics
Gloriastr. 35, 8092 Zürich, Switzerland
phone: +41 1 632 54 07, fax: +41 1 632 11 98, e-mail: schefer@ifh.ee.ethz.ch

Abstract

An active V-band mixer is presented. The device used for mixing is an InP HEMT. The measured maximum mixer conversion gain is 5 dB. This is to the authors' knowledge the highest reported gain in the mm-wave range for a mixer that does not include a pre-amplifier or IF amplifier.

Introduction

Commercially available wireless LANs have transmission rates of only a few Mb/s [1] which is low compared to conventional wired networks. To be able to handle higher data rates, future wireless LANs will probably have to be designed in the mm-wave frequency range where the available bandwidths are larger. Other possible applications for mm-wave systems exist, for example, in collision avoidance radar [2], [3] or broadband wireless TV distribution. Standards for wireless TV distribution are being developed for the 28 GHz and 42 GHz bands and prototype systems have successfully been tested in the US and Europe [4]. A key component for frontends and transmitters in these systems is the mixer. This work describes an active, monolithically integrated coplanar HEMT mixer. The advantages of this mixer are the high gain and the compact dimensions which make the circuit suitable for integrated systems.

Process Technology

The active device is an InP HEMT with a T-gate of 0.2 µm gate length [5]. The transit frequency and the maximum frequency of oscillation of the standard HEMT device, with two gate fingers of a total gate width of 150 µm, are $f_t = 150$ GHz and $f_{max} \approx 200$ GHz. Coplanar technology is used to simplify the processing since it requires no wafer thinning and no via holes.

Circuit Design

The scattering parameters of the standard HEMT were measured up to 78 GHz under various bias conditions. From this data, the small-signal equivalent circuit elements were derived. Because the mixer circuit was simulated only with a small-signal equivalent circuit, the bias voltage for maximum mixer gain first had to be determined.

The mixer was designed as a transconductance mixer because this mode is most advantageous with respect to gain and noise figure [6]. The local oscillator signal (LO) is applied at the gate and modulates the transconductance g_m of the HEMT. The radio frequency (RF) is also applied at the gate. When the RF is small, the drain-current can be calculated as follows:

$$i_d(t) = g_m(t) v_{RF}(t) \qquad (1)$$

The transconductance can be expressed as a Fourier series

$$g_m(t) = \frac{1}{2}a_0 + \sum_{1}^{\infty} a_n \cos(n\omega_{LO} t), \qquad (2)$$

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$$a_n = \frac{2}{T}\int_0^T g_m(t)\cos(n\omega_{LO}t)dt,\ T = \frac{2\pi}{\omega_{LO}}.$$

Equations (1) and (2) reveal that the desired mixing product (ω_{LO}-ω_{RF}) is maximized when the first Fourier coefficient a_1 of the transconductance $g_m(t)$ is maximized. Fig. 1

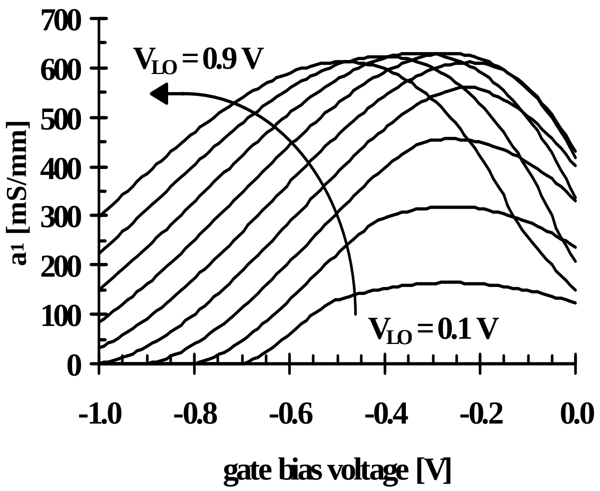

Fig. 1: Calculated first Fourier coefficient a_1 of the transconductance vs. gate bias voltage. The LO amplitude was swept from 0.1 to 0.9 V in 0.1 V steps.

shows the calculated first Fourier coefficient a_1 of the transconductance for different LO amplitudes. The optimum gate bias voltage is around -0.2 V for LO amplitudes smaller than 0.5 V. This is in the linear region of the transfer characteristic between maximum transconductance and turn-off (Fig. 2). The maximum a_1 is reached for an LO amplitude of 0.6 V and a gate bias voltage of -0.25 V. However, the mixer conversion gain depends not only on the first Fourier coefficient a_1 but also on the output resistance R_{ds}. For more negative gate voltages, R_{ds} increases whereas the fundamental component decreases only slightly (see Fig. 1). Therefore, a lower gate bias voltage and a higher LO amplitude are expected for optimum mixer gain.

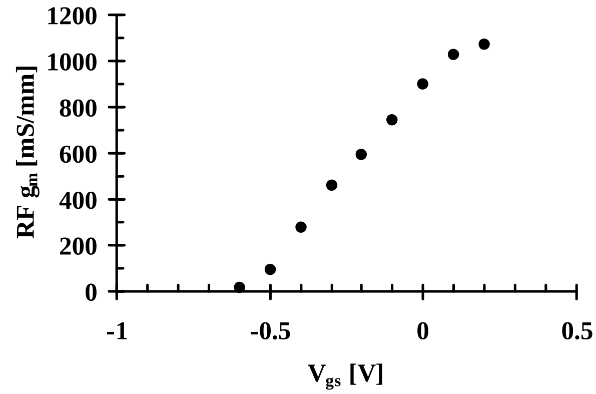

Fig. 2: RF transconductance.

The mixer was designed for down-mixing with an LO of 60 GHz and an RF of 61 GHz. The circuit consists of a standard HEMT with matching and bias networks (Fig. 3). The LO

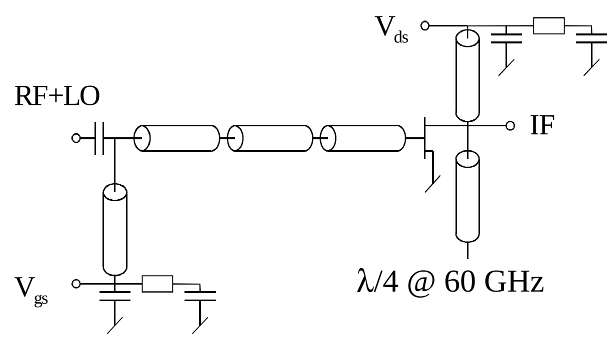

Fig. 3: Schematic of the active V-band HEMT mixer. CPW technology was used for the transmission lines.

and the RF are both applied at the gate of the HEMT. Matching is achieved by three coplanar waveguides (CPW) connected in series. The LO is suppressed by the open λ/4-stub at the drain. This ensures the operation of the transistor in the saturated region over the whole LO cycle. Therefore, the maximum possible gain can be attained. The intermediate frequency (IF) is extracted at the drain. The drain could not be matched on-chip because the IF is too low to use transmission lines for matching and because the losses of the available on-chip inductors were too high.

With the small-signal equivalent circuit, the mixer was optimized for LO match at the gate and LO suppression at the drain.

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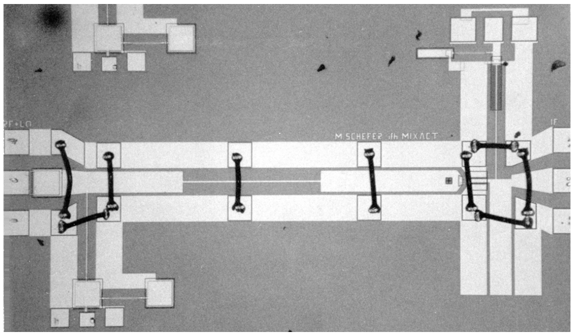

Fig. 4: Photograph of the active HEMT mixer circuit (1200·2250 µm^2). Bonding wires are used to short any parasitic slotline mode on the CPW.

Furthermore, the stability of the active mixer was carefully analyzed. The resistors included in the bias networks at the gate and drain guarantee unconditional stability of the mixer circuit.
Fig. 4 shows a photograph of the fabricated V-band mixer. The mixer occupies only 2.7 mm² chip area. Since no accurate CPW models were available in the simulator used, the scattering parameters of the tee and cross junctions (see Fig. 4) were calculated with an electromagnetic simulator [7]. These scattering parameters were included in the linear simulation as data files.

Measurements

For the mixer gain measurements, the LO was fixed at 60 GHz. The measured small-signal reflection at the LO port (Fig. 5) is smaller than

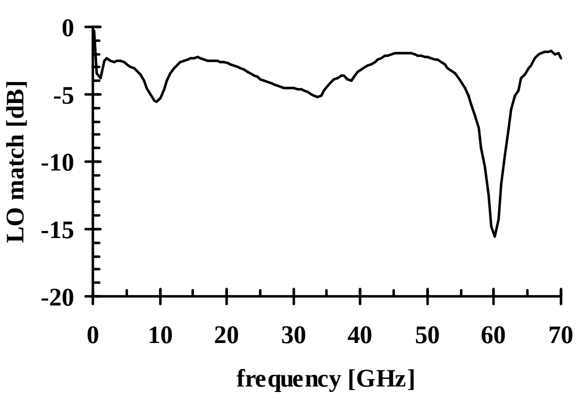

Fig. 5: Measured small-signal reflection of the active HEMT mixer at LO/RF port (V_{gs} = -0.4 V, V_{ds} = 2 V).

-15 dB at 60 GHz. The measurement set-up for the conversion gain measurement is shown in Fig. 6. The mm-wave extension of the NWA was used as source for the RF signal. The LO was generated with a 30 GHz source and a doubler. RF and LO were combined by a waveguide -10 dB directional coupler. For the gain measurements, the RF was applied at the coupled port, to ensure that there was sufficient LO power available to the mixer circuit. The RF signal was swept between 61 and 71 GHz which results in an IF of 1 to 11 GHz. For the conversion gain (Fig. 7), the losses of the tips,

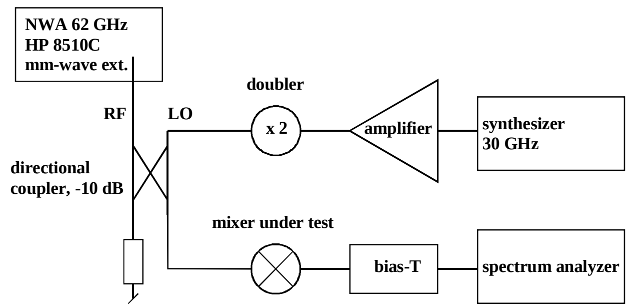

Fig. 6: Conversion gain measurement set-up.

cables and coupler were taken into account but the reflections between the circuit and the measurement equipment were neglected resulting in a ripple in the gain. The gain decreases with increasing IF frequency because the match at LO/RF port is narrowband (see Fig. 5); the maximum gain is 5 dB.
The conversion gain is strongly dependent on the

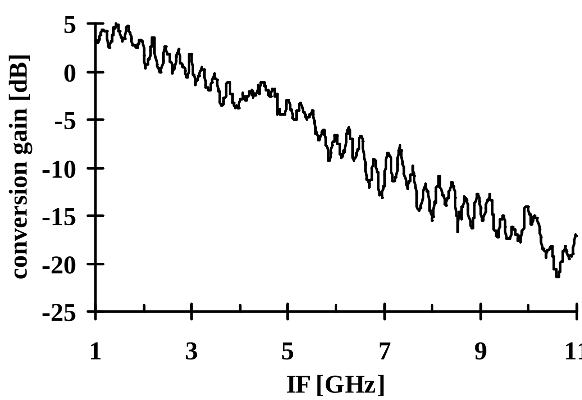

Fig. 7: Conversion gain of the V-band active HEMT mixer (LO: 60 GHz, 3.5 dBm; RF: 61-71 GHz, -17 dBm).

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LO power (Fig. 8). The maximum gain is obtained with 4.5 dBm LO power, decreasing for lower and higher LO power. The dependence of the gain on the LO power is stronger than in a MESFET mixer. This is to be expected because of the bell-shaped transconductance curve associated with the HEMT. When the LO voltage exceeds the voltage for the maximum transconductance, the time dependent transconductance $g_m(t)$ will have higher order frequency components and a lower fundamental (see Fig. 1), resulting in a reduction in the conversion gain. This is confirmed by the strong

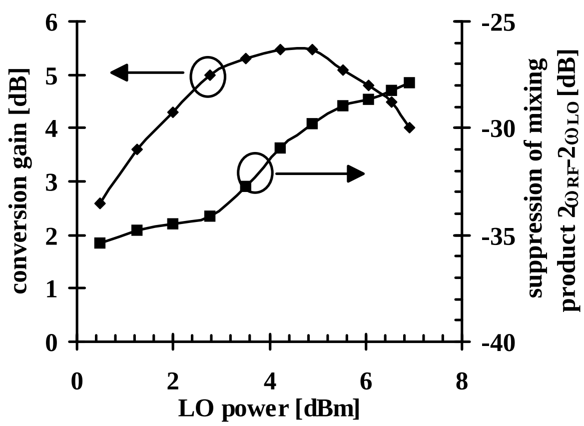

Fig. 8: Conversion gain and suppression of the mixing product $\omega = 2\omega_{RF} - 2\omega_{LO}$ relative to the IF vs. LO power. The LO and RF frequencies are 60 GHz and 61.4 GHz respectively (V_{gs} = -0.4 V, V_{ds} = 2 V).

increase of the unwanted mixing product $\omega = 2\omega_{RF} - 2\omega_{LO}$ (see Fig. 8). The suppression relative to the IF ($\omega_{IF} = \omega_{RF} - \omega_{LO}$) is better than -30 dB at maximum conversion gain.

The double side band noise figure was measured for an IF between 0.25 and 10 GHz (Fig. 9). Since there was more power available at 59 GHz, this was chosen as the LO frequency. The lowest noise figure obtained was 8.5 dB. This is not the lowest possible value because the noise source had to be connected to the direct port of the directional coupler in order to have enough excess noise ratio (ENR). The measurement was therefore limited by the low level of LO power, which was attenuated by 10 dB in the coupled path. The resulting LO power at the circuit was only 0 dBm. Consequently, the gain (see Fig. 9) is lower than the maximum gain described above.

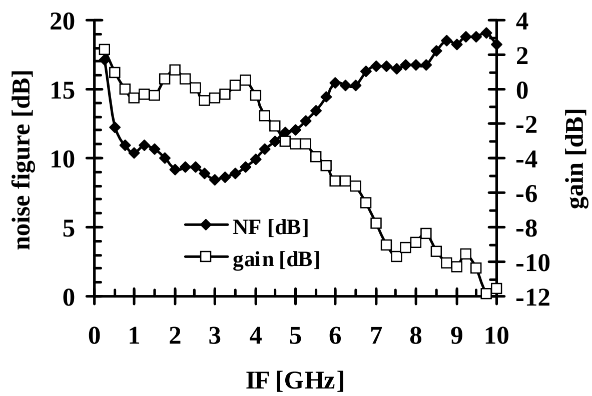

Fig. 9: Double side band noise figure and double side band conversion gain (LO: 59 GHz, 0 dBm).

Conclusion

In this work the highest conversion gain at mm-wave frequencies is reported for an active mixer without additional amplifiers at the RF or the IF port. The high gain and the compact size make this mixer suitable for integrated mm-wave systems.

Acknowledgement

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