A V-Band Up-Converting InP HEMT Active Mixer With Low LO-Power Requirements

A. Orzati, F. Robin, H. Meier, H. Benedikter, and W. Bächtold

***Abstract*—In this letter, we present a monolithically integrated up-converting active mixer that shifts a signal in the 16 GHz range up to the V-band using a 48 GHz local oscillator (LO) signal. The circuit was realized with the 0.2 μm InP HEMT in-house process of the Swiss Federal Institute of Technology in Zurich using coplanar-waveguide technology. Measurements of the fabricated circuit show a peak conversion gain of 1 dB at 64.5 GHz for −1.7 dBm LO power, LO suppression better than 30 dB and input third-order intercept point of −1.6 dBm. This mixer will be employed in the signal up-conversion path of a 60 GHz transceiver for indoor wireless LANs.**

I. Introduction

COMBINING optical fibers and millimeter-wave radio is a very promising approach for the realization of 60 GHz transceivers for wireless LANs [1], [2]. Mixers are of critical importance in the transceiver up-conversion path because they influence both the overall design and the final system performance. The main issue in their design is to obtain an acceptable conversion gain with low LO power and negligible intermodulation products.

The objective of the work described in this paper was the design and the fabrication of an up-converting mixer that shifts a signal in the 16 GHz band up to the V-band using a 48 GHz local oscillator. The circuit design was optimized to minimize the LO power requirements while keeping conversion losses as low as possible. This letter presents the used design approach and illustrates the most significant measurement results.

II. Circuit Design

A schematic representation of the designed up-converting mixer is shown in Fig. 1. The circuit is a single-device mixer which uses a two-finger InP HEMT with a gate length of 0.2 μm and a total gate width of 150 μm, fabricated with our in-house process. The device has an f_T of 135 GHz and an $f_{\max}$ of 200 GHz. We opted for a gate injection topology because it has shown the best conversion gain for low LO power levels [3]–[8]. Because of the phase modulation scheme used by the system, the modest linearity of this kind of mixers does not represent an problem. The device bias point was chosen to minimize the variation of the drain-source conductance $|g_{ds}|$ and to maximize the fundamental frequency component of the transconductance $|g_m|$. In our case, this corresponds to a gate-source voltage V_{gs} slightly above the threshold voltage V_T of the device and to a drain-source voltage V_{ds} in the saturation region. While optimizing the circuit for low LO power, it was found that the optimum large-signal matching networks both at the gate and at the drain side of the transistor can be very well approximated with matching networks calculated using only small-signal simulations of the device, which are less time-consuming to optimize in a circuit simulator. The network at the gate side of the mixer was designed to provide 50 Ω matching at both IF (16 GHz) and LO (48 GHz) frequencies. Since the two signals must be applied at the same port, the use of an external diplexer is necessary. The gate bias network also includes a small (5 Ω) resistor, which is needed to ensure unconditional stability to the circuit. This resistor has negligible negative effects on the IF signal up-conversion. The network at the drain side of the device ensures the suppression of both LO and IF signals and provides 50 Ω matching at RF frequency (64 GHz). Obtaining a good LO suppression is important because it allows the HEMT to remain in the saturation region over the entire LO cycle thus keeping $|g_{ds}|$ as constant as possible. This is achieved by an open circuit stub with an electrical length of 90° at 48 GHz. The suppression of the IF signal is obtained using an LC resonator instead of a stub in order to keep the circuit size small. Since no models were available in the circuit simulator (Agilent ADS), coplanar discontinuities such as cross-junctions, T-junctions, open circuits, and short circuits were modeled using the SONNET electromagnetic simulator. The designed circuit was fabricated on a 600 μm semi-insulating InP substrate using coplanar-waveguide technology. A photograph of the mixer is shown in Fig. 2. Chip size is 3.7 × 1.4 mm^2.

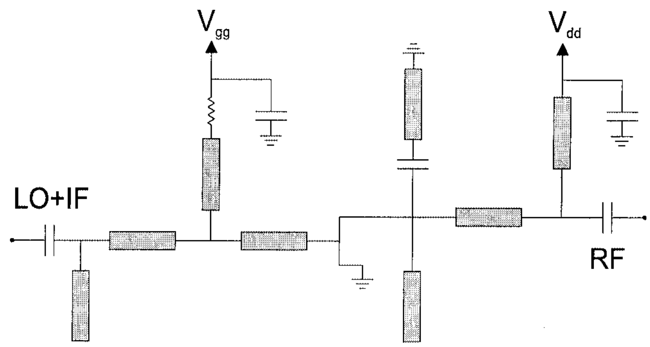

Fig. 1. Circuit schematic of the designed up-converting mixer.

III. Measurement Results

After fabrication, the characteristics of the up-converting mixer were measured; this was done on-wafer using a Cascade

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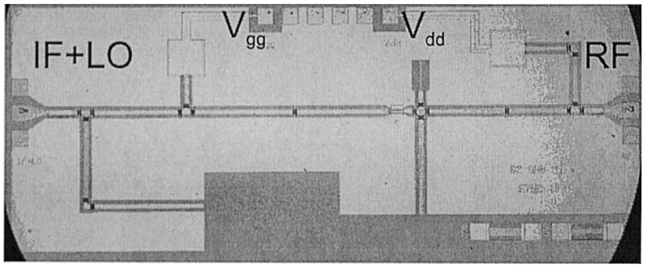

Fig. 2. Photograph of the fabricated V-band up-converting mixer. Chip size is 3.7 × 1.4 mm^2.

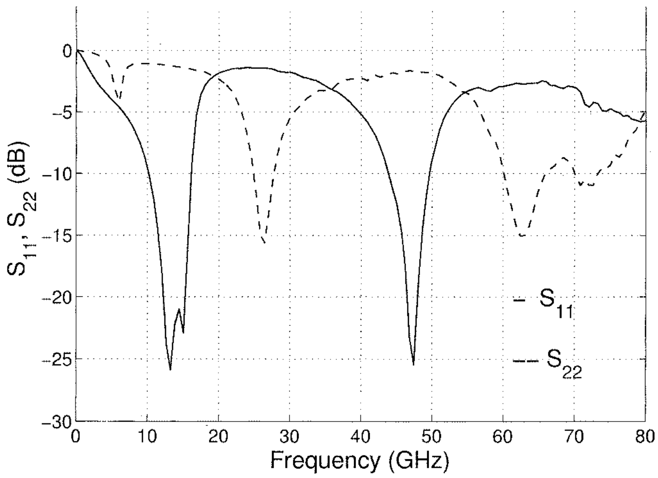

Fig. 3. Measured return losses at ports 1 (IF and LO) and 2 (RF) of the up-converting mixer. The device bias point is $(V_{gs}, V_{ds}) = (-0.3$ V, 1.2 V$)$.

Microtech probe station. Measured small-signal return losses at the input and output ports of the mixer are shown in Fig. 3. 50 Ω matching is excellent both for the IF signal (16 GHz) and the LO signal (48 GHz) as well as at RF frequency (64 GHz). After measuring the S-parameter, the nonlinear characteristics of the circuit were tested. In order to combine LO and IF signal at the gate port a Test Port Combiner from HP was used. In Fig. 4, the mixer conversion gain at 64 GHz is plotted versus the LO power. For an LO power of −10 dBm the conversion gain is −3 dB and keeps increasing with increasing LO power until it reaches its peak value for a LO power of 0 dBm. In a LO power range between −4 and 0 dBm, conversion gain remains almost constant, showing a variation of only 0.5 dB. This validates the low-power design approach described in the previous section. For an LO power higher than 0 dBm, the conversion gain drops dramatically. This is due to the fact that, for a greater LO power, acceptable return losses at IF and RF frequencies are not guaranteed anymore, since the matching is optimized for small-signal behavior. LO suppression was also measured and was found to be higher than 30 dB at 48 GHz. Measured conversion gain versus RF frequency is shown in Fig. 5 for a LO power of −1.7 dBm and a IF power of −30 dBm. The peak conversion gain is 1 dB at 64.5 GHz. The strong frequency dependence of conversion gain is due to narrow-band behavior of the input matching at IF frequency. In order to evaluate the linearity of the up-converting mixer, the 1 dB compression point and the third order intercept point (IP3) were measured. This was done at a IF frequency of 15.9 GHz with −3 dBm LO

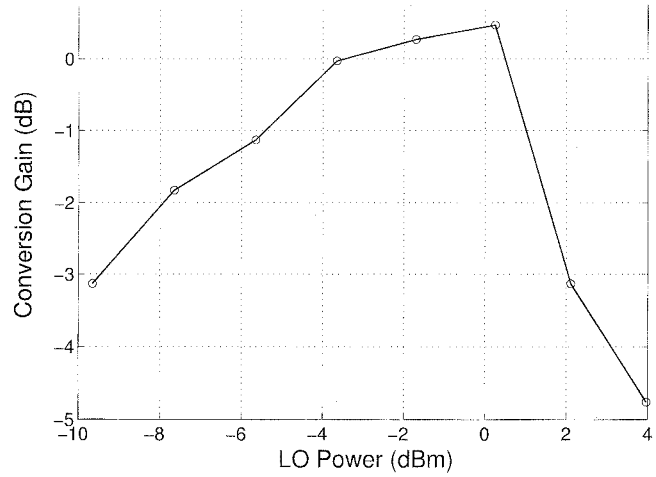

Fig. 4. Measured conversion gain versus LO power. The device bias point is $(V_{gs}, V_{ds}) = (-0.3$ V, 1.2 V$)$, IF frequency is 16 GHz, IF power is −30 dBm.

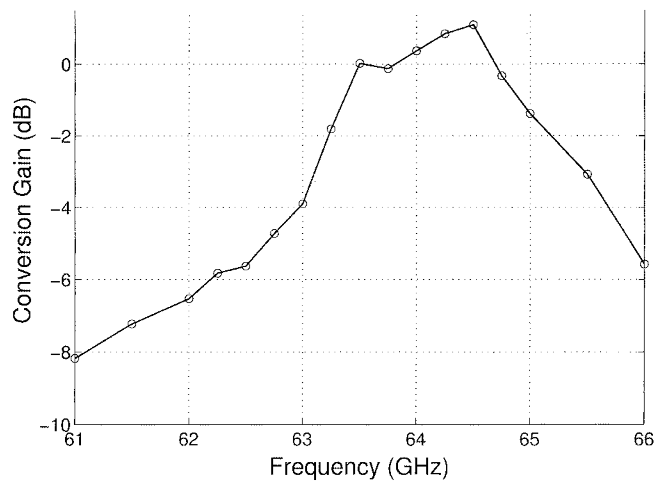

Fig. 5. Measured conversion gain as a function of the RF frequency. The device bias point is $(V_{gs}, V_{ds}) = (-0.3$ V, 1.2 V$)$, LO power is −1.7 dBm, IF power is −30 dBm.

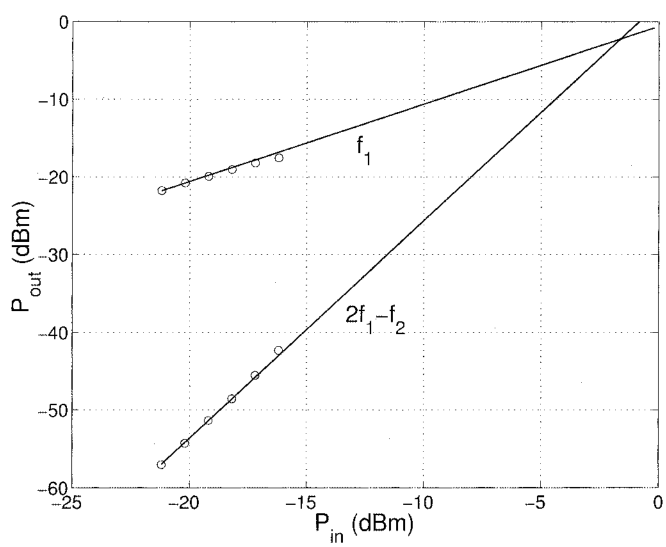

Fig. 6. Measured third order intercept point of the up-converting mixer. The device bias point is $(V_{gs}, V_{ds}) = (-0.3$ V, 1.2 V$)$, LO power is −3 dBm, $f_1 = 15.9$ GHz, $f_2 = 15.901$ GHz.

power. The 1 dB compression point was reached for an IF power of −10 dBm. The IP3 was found to be −1.6 dBm, as can be seen from Fig. 6. Since the maximum expected IF power is −15 dbm, the low compression point and IP3 are compatible with the application the mixer was designed for.

IV. Conclusions

In this letter, an MMIC V-band up-converting mixer was presented. The circuit was fabricated on a InP HEMT 0.2 μm in-house process using coplanar waveguide technology. The design was optimized to reduce LO power requirements without adding significant penalties for the conversion gain. On-wafer characterization of the up-converting mixer was performed. Measurement results showed 1 dB conversion gain at 64.5 GHz for −1.7 dBm LO power, over 30 dB LO suppression at 48 GHz, −10 dBm input 1 dB compression point, and −1.6 dBm input IP3. To the authors' knowledge, this results, in terms of both LO power requirements and conversion gain, are the best ever reported for a single-transistor up-converting mixer in the V-band.

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