A Pair of 170∼250 GHz Up-Converter Mixer with Enhanced Psat and Down-Converter Mixer with Broad IF Bandwidth

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***Abstract* — This paper presents a pair of 170∼250 GHz up- and down-converter mixers. The up-converter mixer is designed with enhanced Psat and the down-converter mixer is optimized with a broad IF bandwidth. The up-converter mixer is designed based on the fundamentally pumped Gilbert cell with a differential pair of common-base transistors stacked on top. The down-converter mixer is also modified from the Gilbert cell topology, while the IF outputs are DC-coupled through an optimized emitter-follower stage for a broad IF bandwidth. Both up- and down-converter mixers are designed with the IQ-balanced configuration and fabricated in Infineon's 90 nm SiGe BiCMOS technology. At an IF frequency of 4 GHz, the up-converter mixer shows a measured conversion gain of around 15 dB over 170∼250 GHz and a typical Psat is +1 dBm. The down-converter mixer covers a similar RF-bandwidth of around 170∼250 GHz with a maximum conversion gain of 0 dB. At an LO frequency of 245 GHz, an IF bandwidth of 22 GHz is obtained.**

***Keywords* — Y-band, 170∼250 GHz, mixer, up-converter, down-converter, Gilbert, emitter-follower, Psat, broadband.**

I. Introduction

The rapid growth of millimeter-wave and terahertz (THz) communication systems is driven by the need for multi-gigabit and eventually terabit-per-second communication links in emerging applications such as short-range backhaul, high-resolution sensing, and chip-to-chip interconnects. Y-band (170∼260 GHz) provides a favorable trade-off between available atmospheric transmission windows, feasible on-chip device performance, and compact high-gain antenna integration. Compared to lower millimeter-wave bands, this frequency range offers substantially larger spectral resources, enabling ultra-wideband modulation formats.

In modern high-speed communication systems, a high output saturation power (Psat) in a transmitter is a key requirement to support high-order modulation and maintain linearity. A traditional Gilbert up-converter mixer delivers limited output power [1][2], and a power amplifier is usually cascaded at the RF output of the mixer in a transmitter[3][4]. As the frequency increases above 200 GHz, power amplifiers become increasingly challenging. Therefore, an up-converter mixer with sufficiently high Psat relaxes the gain and linearity requirements of subsequent amplifier stages, improving overall transmitter efficiency. On the receiver side, a wide intermediate-frequency (IF) bandwidth in the down-converter mixer is essential to accommodate wideband modulation for high-data-rate communication. The baseband inductive peaking technique has been demonstrated to improve the conversion gain IF bandwidth, but a good IF port matching is challenging to obtain over a broad bandwidth [5]. Adding a broadband transimpedance amplifier at the IF was reported to maximize the bandwidth at the expense of higher DC consumption [6].

This work presents a pair of 170∼250 GHz up- and down-converter mixers designed for next-generation high-speed communication systems. The up-converter mixer is aimed for high saturation output power and the down-converter mixer is targeted for broad IF bandwidth with broad IF port matching. The mixers are designed in Infineon's 90 nm SiGe BiCMOS technology (B12HFC), which features a current gain cutoff frequency (f_t) of 300 GHz and a maximum oscillation frequency (f_{max}) of 530 GHz [7]. Apart from the top aluminum layer for pads, seven metal layers are available in this process, in which the two upper thick layers are mostly used for signals and the five thin layers beneath enable flexible routing for both signal and biasing.

II. Design

Mixers are essential function blocks in modern communication, radar, and sensing systems. An IQ-mixer, which provides full complex (I/Q) control of the RF waveform, enables high-order digital modulation, sideband suppression, and seamless integration with baseband processing. Aiming for a broadband homodyne transmitter and receiver, both up- and down-converter mixers are designed with an IQ-balanced topology, which not only enables the benefits described above but also suppresses the LO leakage intrinsically.

A. Up-Converter Mixer

Fig. 1 shows the simplified schematic of the up-converter mixer, in which the biasing network and matching structures are not illustrated. It includes two identical fundamentally pumped Gilbert mixer cells. One cell for the I-channel, and the other one for the Q-channel. The LO input signal is split into two ways with a broadside-coupled 90° coupler, and further fed into two identical baluns to generate the desired balanced LO for each Gilbert cell. The differential RF outputs from the two Gilbert cells are merged correspondingly, and a differential pair of common-base transistors (Q_1 and Q_2) is stacked on

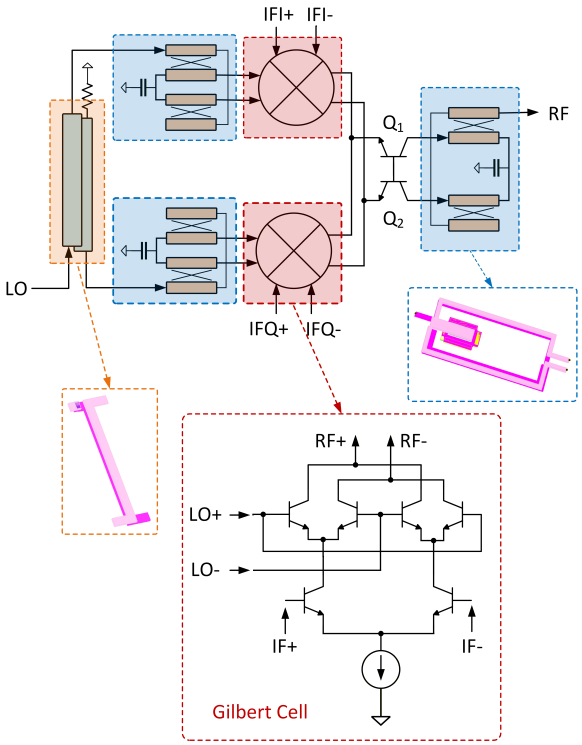


Fig. 1. Simplified schematic of the up-converter mixer.

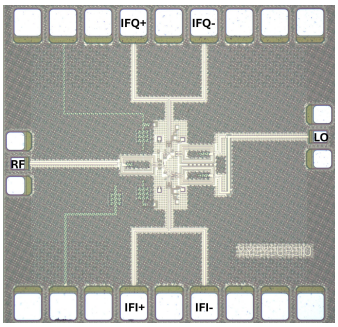


Fig. 2. Chip photo of the up-converter mixer. Size: 940×900 μm^2 (Core area:350×250 μm^2).

top to enhance the output power. Then a balun converts the differential RF signals into a single-ended output. In both the LO distribution network and the RF path, the Marchand balun is chosen because of its broadband feature. The two upper thick layers (M7 and M6) are broadside coupled, while the line width, length and offset distances are optimized and EM simulated with RFPro. The Marchand balun is folded for area efficiency and a relatively large capacitor is shunt connected to the folded coupled line ends where it is traditionally grounded. This also enables DC biasing through the balun.

Fig. 2 shows the chip photo. The designed up-converter mixer has a size of 940×900 μm^2, in which the core area is 350×250 μm^2.

B. Down-Converter Mixer

Similarly like the up-converter mixer, the down-converter mixer also contains two Gilbert cell. Fig. 3 shows the simplified schematic of the down-converter mixer, in which the

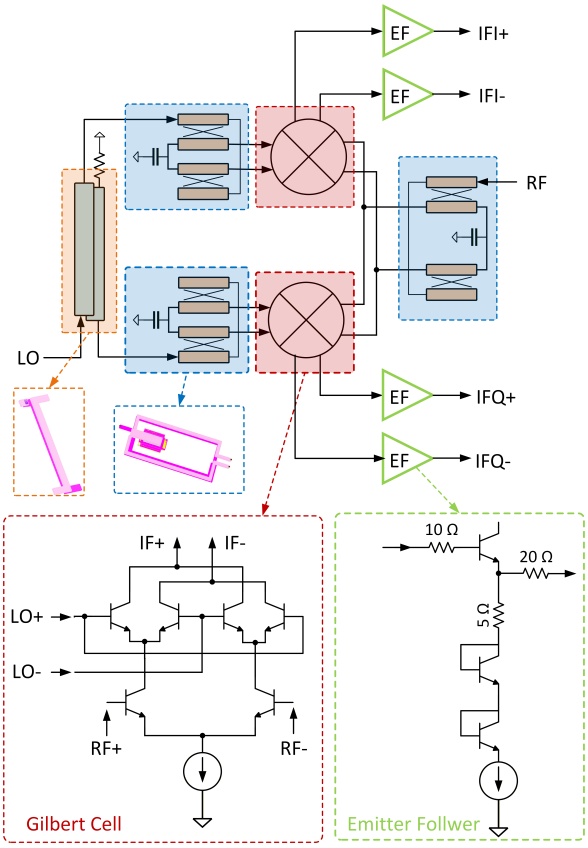


Fig. 3. Simplified schematic of the down-converter mixer.

biasing network and matching structures are not shown. The LO quadrature-phase network and RF balun is similar like the ones in the up-convter mixer. Target for a homodyne receiver with a broad IF bandwidth, the IF outputs from the Gilbert cells are DC coupled to an emitter-follower (EF). By adding a small serially connected resistor to the base input and the emitter output, the IF bandwidth can be efficiently improved at the cost of lower conversion gain. The emitter-follower's collector is voltage biased from the top Vcc and the current is controlled by a current source, which is a current mirror, at the bottom. Two extra stacked diodes contribute as the voltage ladder and set the voltage potential at the emitter properly.

Fig. 4 shows the chip photo. The designed up-converter mixer has a size of 940×900 μm^2, in which the core area is 350×520 μm^2.

III. Measurement

The designed mixers were characterized on-wafer. For both up- and down-converter mixers, the conversion gain was measured with a Keysight PNA-x 67 GHz N5247B, which has an option for mixer measurement. Four IF ports are combined into a single-ended port through two off-chip commercial baluns (Marki BAL-0050) and a 90-degree hybrid (Marki QH-0440). The combined single-ended IF is connected to port 2 of the PNA-x, while the mixer's RF port is connected to port 1 of the PNA-x through a VDI-WR4.3 frequency extender. LO signal is provided from port 3 of PNA-x followed by a

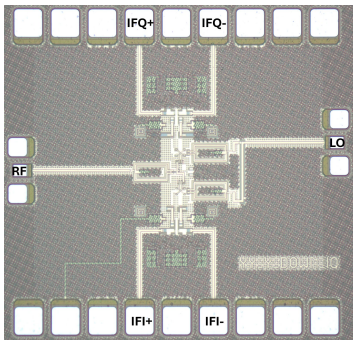


Fig. 4. Chip photo of the down-converter mixer. Size: 940×900 μm^2 (Core area:350×520 μm^2).

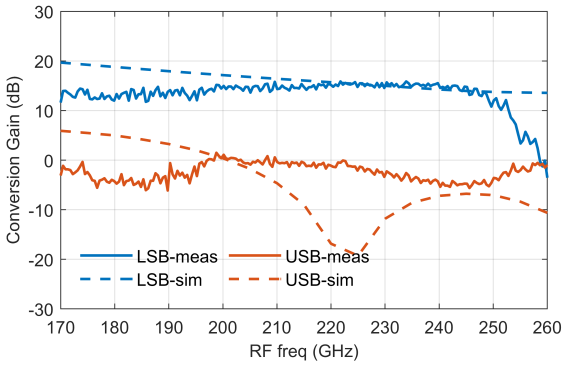


Fig. 5. Measured and simulated conversion gain of the up-converter mixer vs. RF frequency at the IF frequency of 4 GHz.

VDI WR-4.3 extender as a ×18 frequency multiplier and a VDI WR-4.3 broadband amplifier, which can provide around 10 dBm LO power on-wafer.

A. *Up-Converter Mixer Results*

The designed up-converter mixer requires two voltage biases, Vcc and Vbb. In the measurement, it draws 22 mA current from a 4.7 V Vcc and 29 mA from a 4 V Vbb, which corresponds to a total DC power consumption of 220 mW.

At the IF frequency of 4 GHz, Fig. 5 shows the measured and simulated conversion gain over Y-band. A maximum conversion gain of 15 dB is obtained and the 3-dB RF bandwidth covers from 170 GHz to 250 GHz. The sideband suppression shows around 15 dB. At the LO frequency of 245 GHz, Fig. 6 shows the conversion gain versus IF frequency. Over 30 GHz IF bandwidth is obtained. FIg. 7 shows the measured and simulated RF output power versus the IF input power at the LO frequency of 220 GHz and the IF frequency of 4 GHz. A Psat of 1.6 dBm and OIP1dB of -0.8 dBm are obtained in the measurement. Fig. 8 shows the measured RF saturated output power (Psat) with an input IF power of 0 dBm and IF frequency of 4 GHz. A typical Psat of 1 dBm is achieved at the RF frequency of 170-250 GHz. At the frequency above 250 GHz, the performance degrades drastically due to the insufficient LO power in the measurement setup.

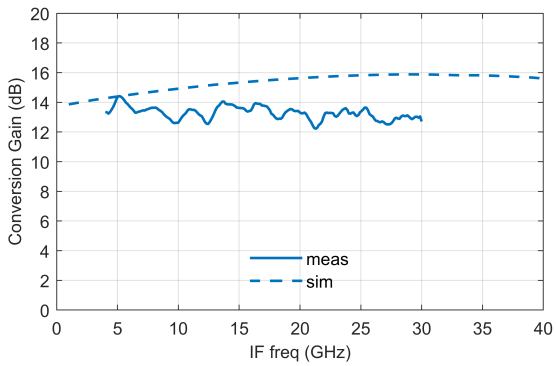


Fig. 6. Measured and simulated conversion gain of the up-converter mixer vs. IF frequency at the LO frequency of 245 GHz.

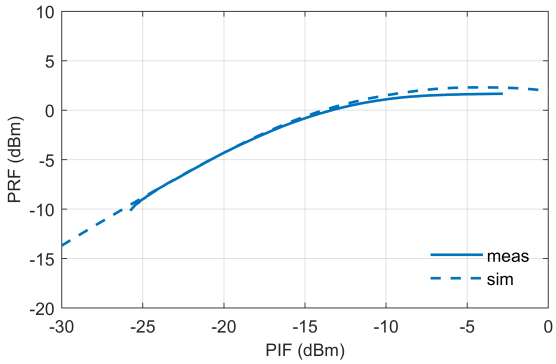


Fig. 7. Measured and simulated RF output power of the up-converter mixer vs. IF input power at the LO frequency of 220 GHz and IF frequency of 4 GHz.

B. *Down-Converter Mixer Results*

In measurement, the down-converter mixer draws 24 mA current from a 4 V Vcc and 8.5 mA current from a 1.1 V Vcm (bias for the current mirror at the bottom of the emitter-followers), which corresponds to a total DC power consumption of 106 mW. At an IF frequency of 4 GHz, Fig. 9 shows the conversion gain versus RF frequency. It exhibits a maximum conversion gain of 0 dB and a sideband suppression of over 12 dB. At the LO frequency of 245 GHz, Fig. 10 shows the conversion gain versus IF frequency. A 3-dB IF bandwidth of 40 GHz is obtained in the simulation, in which the four IF outputs are combined into a single-ended IF with ideal baluns and an ideal hybrid. In the measurement setup, the off-chip IF network, which includes two baluns and a hybrid, is considered as part of the DUT. The measured conversion gain of the designed mixer is obtained by subtracting the insertion loss of the off-chip IF network. In such a case, the non-ideal phase response is not de-embedded. Nevertheless, a 3-dB IF bandwidth of 22 GHz is obtained in the measurement. In a homodyne IQ down-converter mixer, IF-port matching is essential because the IF nodes directly carry the complex baseband signal. Benefits from the well-optimized emitter-follower, the down-converter mixer exhibits a great matching over a broad IF bandwidth, as can be seen from Fig. 11. Limited by the measurement setup and the chip layout configuration, one-port S11 calibration is

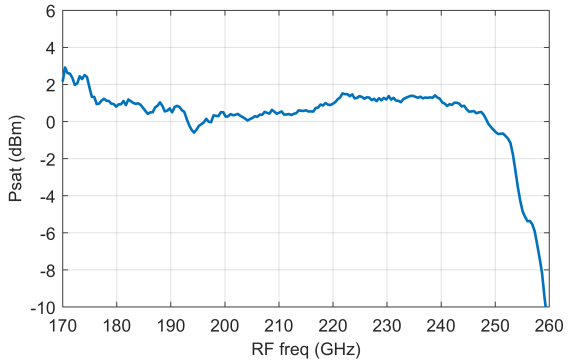


Fig. 8. Measured saturated RF output power of the up-converter mixer vs. RF frequency at the IF frequency of 4 GHz.

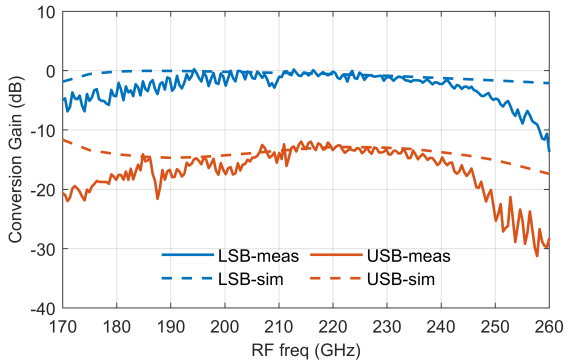


Fig. 9. Measured and simulated conversion gain of the down-converter mixer vs. RF frequency at the IF frequency of 4 GHz.

carried out at the coaxial cable instead of on-wafer. The S11 is measured up to 26 GHz and is well below -10 dB.

IV. Conclution

Aiming for high data rate communication applications, a pair of up- and down-converter mixers is designed for 170∼250 GHz frequency range in Infineon's 90 nm SiGe BiCMOS technology (B12HFC). The up-converter mixer is designed in an IQ-balanced topology that includes two identical fundamentally pumped Gilbert mixer cells. A differential pair of common-base transistors is stacked on top of the Gilbert cells' switching quad to enhance the RF output power. The up-converter mixer shows a maximum conversion gain of 15 dB and a typical Psat of around 1 dBm. The down-converter mixer is also designed in an IQ-balanced topology with two Gilbert cells. IF outputs are coupled out through well-optimized emitter-followers for a broad IF bandwidth. The down-converter mixer shows a maximum measured conversion gain of 0 dB, a 3-dB IF bandwidth of 22 GHz, and an IF port reflection below -10 dB.

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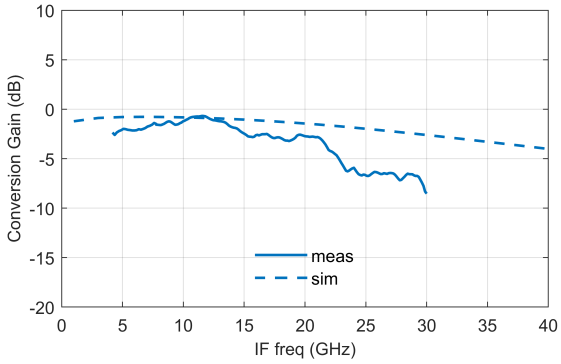


Fig. 10. Measured and simulated conversion gain of the down-converter mixer vs. IF frequency at the LO frequency of 245 GHz.

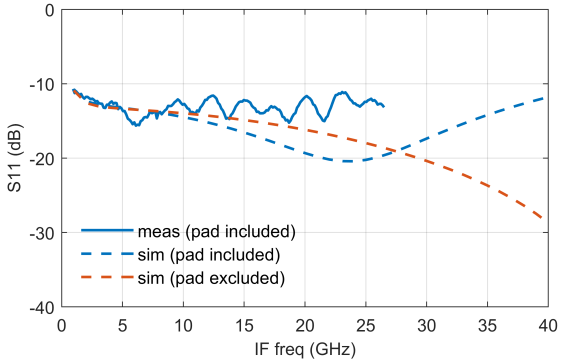


Fig. 11. Measured and simulated reflection coefficient at the IF ports.

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