A 53–64-GHz SiGe Up-Conversion Mixer with 4-GHz IF Bandwidth

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Abstract **— A Gilbert-cell direct up-conversion mixer is realized for 57–64-GHz unlicensed-band applications. The mixer with on-chip stacked inductors and LO, RF baluns is fabricated in 0.25-µm SiGe:C BiCMOS technology. The fabricated mixer achieves conversion gain of 4 ± 1.5 dB and 5 ± 1 dB for upper and lower sideband, respectively, in frequency range from 53 to 64 GHz. The LO-to-RF isolation is higher than 30 dB. The mixer has IF bandwidth of 4 GHz, and the output-referred 1-dB compression point of -9.5 dBm. It occupies a chip area of 0.46 mm × 0.46 mm and consumes 10 mA with supply voltage of 2.5 V.**

Index Terms **— 60-GHz unlicensed band, baluns, BiCMOS integrated circuits, inductors, millimeter wave mixers.**

I. INTRODUCTION

One of the most attractive solutions for very large bandwidth wireless communications is utilizing the unlicensed band in frequency range of 57–64 GHz. The wireless PAN standard at this band is being developed by the IEEE 802.15.3c task group [1], and low-cost 60-GHz integrated circuits have been introduced with advanced silicon technologies [2]-[3].

The performance of up-conversion mixers is important for the overall system performance of direct-conversion transmitters. In particular, in order to utilize the full spectrum of the 60-GHz unlicensed band, RF operating band and IF bandwidth have to be wider than 57–64 GHz and 3.5 GHz, respectively. High conversion gain and output-referred 1-dB compression point (OP1dB) are also important to reduce the burden on power amplifiers. In addition, high LO-to-RF isolation is necessary due to in-band LO leakage in direct-conversion transmitters.

In this paper, a Gilbert-cell direct up-conversion mixer operating from 53 to 64 GHz with 4-GHz IF bandwidth is reported. The mixer utilizes on-chip stacked spiral inductors and LO, RF baluns for compact design. For wideband operation, dual resonance with inductance of the RF balun is used. The mixer is fabricated in IHP's 0.25-µm SiGe:C BiCMOS SG25H3 technology [4]. This technology offers high-speed npn HBTs with f_T/f_{max} of 110/180 GHz and metal-insulator-metal (MIM) capacitors. The metallization layers consist of three thin layers, one 2-µm-thick layer, and top 3-µm-thick layer.

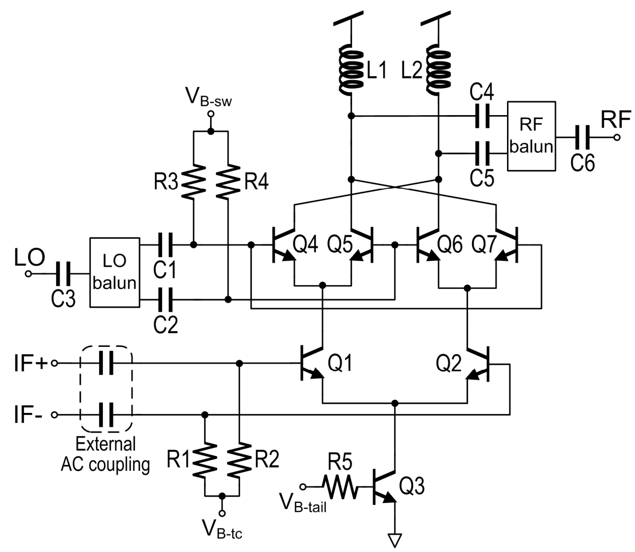

Fig. 1. Schematic of the fabricated mixer.

II. CIRCUIT DESIGN

Fig. 1 shows the schematic of the fabricated mixer. It is a 60-GHz Gilbert-cell direct up-conversion mixer which up-converts baseband signals directly into 60 GHz. It consists of Gilbert-cell core, differential IF ports, single-ended LO, RF ports with on-chip baluns, and bias voltage ports. Inductors and baluns used in this design have the three-dimensional stacked structure with two top metals [5]. The simulated Q-factor of the 150-pH inductor is about 10.5 at 60 GHz, and the insertion loss of the 60-GHz balun is about 9 dB. All circuit and electromagnetic (EM) simulations are performed with Agilent Advanced Design System.

AC-coupled IF signals through off-chip DC blockers are injected into the base of transconductance transistors, Q1 and Q2. Resistive termination with 50-Ω resistors, R1 and R2, provides input impedance matched to 50 Ω. However, parasitic capacitance of transistors causes impedance

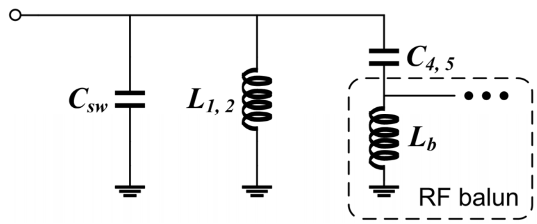

Fig. 2. Equivalent circuit of output load. C_{sw} is equivalent capacitance of LO switching quad transistors, and L_b is equivalent inductance of RF balun.

mismatch at high frequencies, limiting IF bandwidth. Therefore, Q1 and Q2 were designed to have small emitter size of 16 × 0.84 × 0.22 μm to lessen parasitic capacitance. Each of Q1 and Q2 consumes 5-mA current to get high OP1dB. A tail current source, Q3, supplies total bias current of 10 mA.

Single-ended LO port is connected to switching quad, Q4–Q7, through the LO balun. LO matching circuit, C1–C3, was designed with simulated S-parameter of the balun. The inductive load, L1 and L2, produces resonance at the load node and boosts conversion gain in a narrow band. Furthermore, dual resonance at two different frequencies is used for wideband operation. As shown in Fig. 2, equivalent inductance of the RF balun with RF matching capacitors, C4 and C5, causes another resonance. L1, L2, and C4–C6 were designed for dual resonance to cover the 57–64-GHz band. The inductance of L1 and L2 is 150 pH, and the capacitance of C4 and C5 is 100 fF, and the capacitance of C6 is 65 fF.

III. Measurement Results

Fig. 3 shows a die photograph of the fabricated mixer with a chip area of 0.46 mm × 0.46 mm. The performance of the fabricated chip was characterized by on-wafer tests with a GSGSG probe for differential IF input and GSG probes for single-ended LO input and RF output.

For conversion gain measurement, differential IF input signals were provided by a waveform generator. LO input signal was generated by a signal generator and an external frequency doubler. A variable attenuator was added to feed accurate power to LO input. LO input power was set to 0 dBm. RF output signal was observed via a spectrum analyzer. Lower-sideband and upper-sideband RF output powers were obtained separately.

Fig. 4 shows the simulated and measured conversion gain of the mixer as a function of LO frequency. With IF frequency of 1 GHz and IF power of -30 dBm, LO frequency was changed from 53 to 66 GHz. The measured conversion gain is 4 ± 1.5 dB for upper sideband and 5 ± 1 dB for lower sideband within LO frequency range from 53

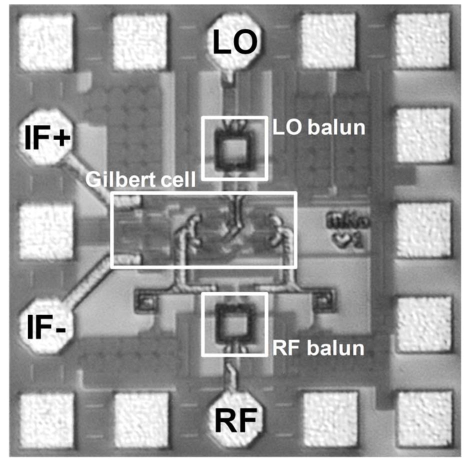

Fig. 3. Die photograph of the fabricated mixer.

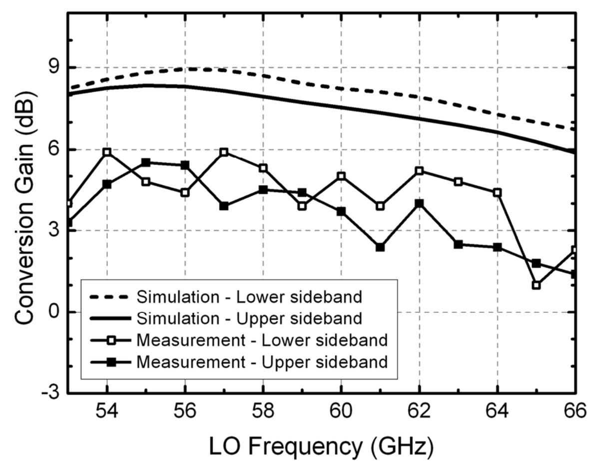

Fig. 4. Upper-sideband and lower-sideband conversion gain versus LO frequency at IF frequency of 1 GHz.

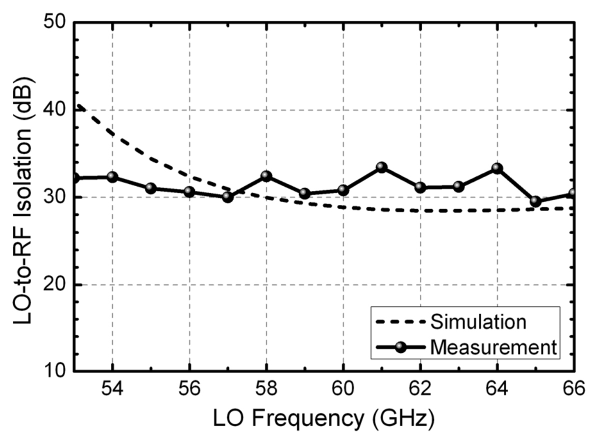

Fig. 5. LO-to-RF isolation versus LO frequency.

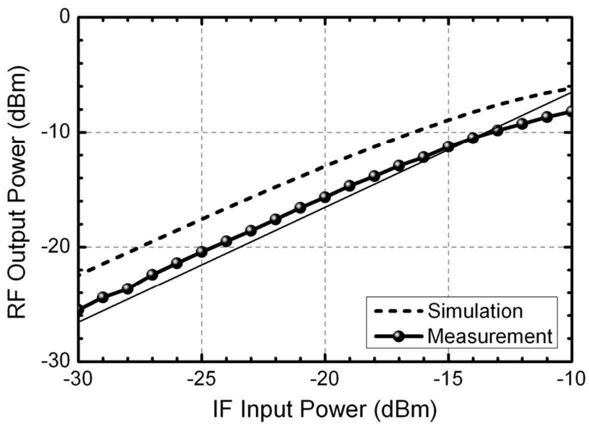

Fig. 6. Conversion gain versus IF input power at IF and LO frequencies of 1 GHz and 60 GHz, respectively.

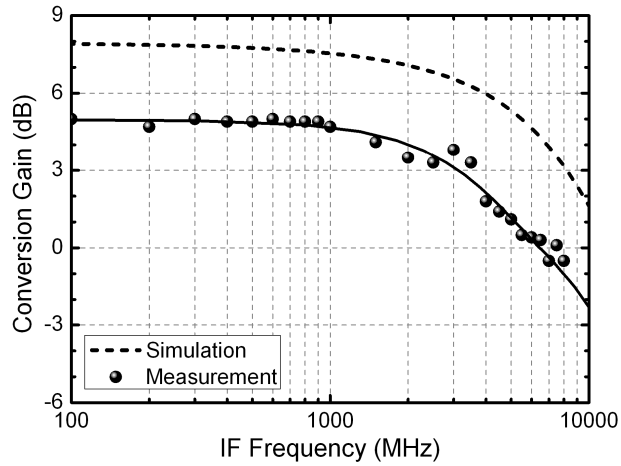

Fig. 7. Conversion gain versus IF frequency at LO frequency of 60 GHz.

to 64 GHz. The LO-to-RF isolation is shown in Fig. 5. The measured isolation from LO port to RF port is higher than 30 dB over the measured frequency range. Fig. 6 shows upper-sideband RF output power as a function of IF input power with 1-GHz IF and 60-GHz LO. The measured OP1dB is -9.5 dBm. The conversion gain versus IF frequency at LO frequency of 60 GHz is shown in Fig. 7. The measured 1-dB IF bandwidth and 3-dB IF bandwidth are 2.0 GHz and 4.0 GHz, respectively. The agreement between simulation and measurement is good except that measured RF output power is 3-dB lower than the simulated one.

The performance results of the fabricated mixer are summarized in Table I along with the results from recently reported 60-GHz up-conversion mixers in silicon-based technologies. The mixer in this work satisfies the RF and IF bandwidth requirement for 60-GHz unlicensed-band applications with high conversion gain, moderate OP1dB and LO suppression, and compact chip area.

IV. CONCLUSION

A 60-GHz double-balanced up-conversion mixer in 0.25-μm SiGe:C BiCMOS technology is presented. Within

TABLE I
PERFORMANCE SUMMARY OF 60-GHZ UP-CONVERSION MIXERS IN SILICON-BASED TECHNOLOGIES

Reference	[6]	[7]	[8]	[9]	This work
Technology	0.18-μm SiGe	0.25-μm SiGe	0.13-μm CMOS	0.13-μm CMOS	0.25-μm SiGe
Topology	Sub-harmonic Gilbert cell	Gilbert cell with RF buffer	Gilbert cell	Gilbert cell with injection-locked frequency tripler	Gilbert cell
RF Frequency (GHz)	35 ~ 65	60	59 ~ 65	58.3 ~ 62.5	53 ~ 64
Conversion Gain (dB)	-7 ± 1.5	-5	-0.7 ~ 4	-11.5 ~ -5.6*	5 ± 1 (LSB) 4 ± 1.5 (USB)
3-dB IF Frequency (GHz)	N/A	1 ~ 9*	N/A	~ 3.6	~ 4
Output P1dB (dBm)	-25	-6.5	-5.6	-21.6	-9.5
LO-to-RF Isolation (dB)	> 40	33	> 37	N/A	> 30
LO Power (dBm)	5	0	0	N/A	0
Power Consumption (mW)	14	79.2 (including buffer)	24	2.7 (mixer only)	25
Chip Area (mm^2)	0.6 × 0.45	1.1 × 1.1	0.3 × 0.7	0.78 × 0.88	0.46 × 0.46

*Estimated from the figure given in the reference

RF and IF frequency ranges of 53–64 GHz and DC–4 GHz, the mixer exhibits conversion gain of 4 ± 1.5 dB for upper sideband and 5 ± 1 dB for lower sideband, the OP1dB of -9.5 dBm, and the LO-to-RF isolation of 30 dB. The measurement results demonstrate that this mixer is promising for compact direct-conversion multi-gigabit 60-GHz transmitters.

ACKNOWLEDGEMENT

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