A Compact 35-65 GHz Up-Conversion Mixer with Integrated Broadband Transformers in 0.18-μm SiGe BiCMOS Technology

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Abstract — **This paper presents a compact 35-65 GHz Gilbert cell up-convert mixer implemented in TSMC 0.18-μm SiGe BiCMOS technology. Integrated broadband transformers and meandered thin-film microstrip lines were utilized to achieve a miniature chip area of 0.6 mm × 0.45 mm. The compact MMIC has a flat measured conversion loss of 7 ± 1.5 dB and LO suppression of more than 40 dB at the RF port from 35 to 65 GHz. The power consumption is 14 mW from a 4-V supply. This is a fully integrated millimeter-wave active mixer that has the smallest chip area ever reported, and also the highest operation frequency among up-conversion mixers using silicon-based technology.**

Index Terms — **HBT, millimeter-wave (MMW), mixer, SiGe, transformer, up-converter.**

I. INTRODUCTION

Millimeter-wave (MMW) communication systems have been attracting attention because of the wider bandwidth and higher data rate that can meet the ever-increasing need in the multimedia age. In these systems, compact, low-cost, and low-power equipment is required. MMW up-conversion mixer is one of the key components in the transmitter. Since the use of direct up-conversion and down-conversion techniques is a promising approach for their potential for low-power monolithic operation and extremely broad bandwidth [1], up-conversion mixers with balanced topology are essential to suppress the LO to RF leakage. Although balanced resistive mixers can achieve wide bandwidth and consume zero dc power, they usually suffer from the large chip area required for the quarter-wavelength matching stubs and baluns [2]-[5], making them more difficult to be integrated in a low-cost, compact system. MMW up-conversion mixers using the sub-harmonic pumped (SHP) principle were also reported. However, higher LO power is required and the additional passive baluns also increase chip size [6]-[7].

In this paper, a compact up-conversion mixer that converts 1-GHz signal to 35-65 GHz is presented. The mixer utilizes a Gilbert cell multiplier, which no quarter-wavelength matching stubs are required and hence compact circuit layout is achieved. Also it is integrated with broadband transformers that have been developed for millimeter-wave applications [8] and meandered thin-film microstrip lines in the matching circuits to reduce the chip size. The chip size is 0.6 mm × 0.45 mm.

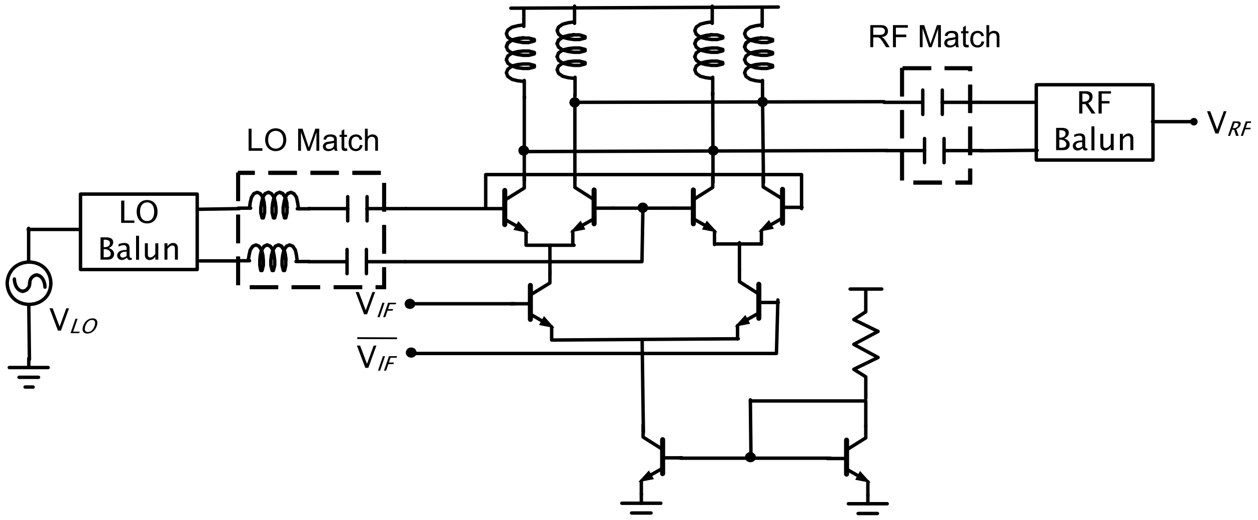
With broadband matching at the LO and RF ports, the MMIC achieve a flat conversion loss frequency response of 7 ± 1.5 dB and LO suppression of more than 40 dB at the RF port from 35 GHz to 65 GHz under power consumption of 14 mW from a 4-V supply. A comparison between recently reported MMW up-conversion mixers and this work is given in Table I. To the authors' knowledge, this is the fully integrated millimeter-wave active mixer with the smallest chip area ever reported, and also the highest operation frequency among up-conversion mixers using silicon-based technology.

II. TECHNOLOGY DESCRIPTION

The mixer was fabricated in TSMC 0.18-μm mixed-signal SiGe BiCMOS technology featuring a metal stack with 1 poly layer and 6 metal layers. The thickness of the top metal is 3.5 μm for the realization of the inductive transmission lines. The substrate conductivity is about 10 Ω-cm. In this process, the HBT has an f_T of 120 GHz and and an f_{max} of 130 GHz with a 1.5-V supply. The MIM capacitors are developed using oxide inter-metal dielectric, with capacitance of 1 fF/mm^2.

III. CIRCUIT DESIGN

Figure 1 shows the circuit schematic of the MMW up-converter. The up-converter consists of the Gilbert cell core and two compact Machand-type transformers with broadband characteristics at the LO and RF ports. The transformer is a Machand balun with each coil as a quadrature coupler [8]. However, unlike the conventional



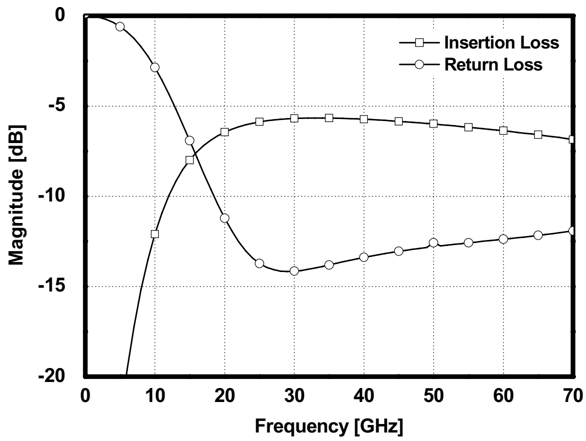


Fig. 2. Simulated return and insertion losses of the Machand-type transformer.

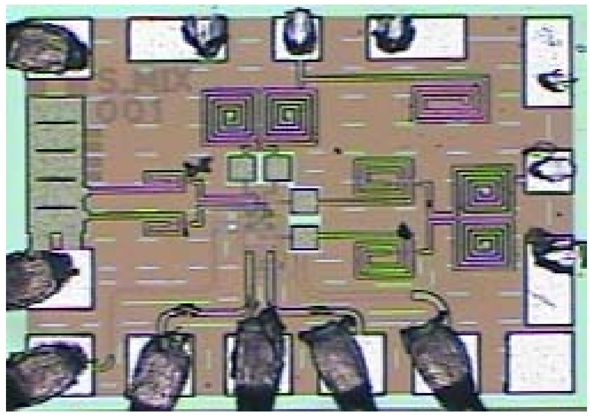


Fig. 3. Micrograph of the Gilbert cell up-converter. (0.7 mm × 0.45 mm)

design of Machand-type transformers, the linewidths and line gaps of this transformer are adapted to the design rule limit of 2.6 μm to minimize the chip area. Therefore, this transformer operates in the higher frequency and occupies a miniature chip area. By using metal 5 and 6 for low loss interconnection, the transformer achieves a broadband bandwidth with 6.5 ± 0.5 dB insertion loss from 20 to 70 GHz. The simulated return and insertion losses of the transformer are shown in Fig. 2.

The matching circuits for the LO and RF ports are designed to match the output impedance of the transformers. All the inductors in this mixer were implemented with thin-film microstrip lines. Since the signal (Metal 6) to ground (Metal 1) path is on the top of a 6 μm height oxide, it can be laid out compactly and meanderingly to minimize the chip size. The minimum line width, given by the maximum tolerable current density, has been selected for the upper metallization layer in order to minimize the line length. In this process, the thin-film microstrip line of 50-Ω characteristic impedance is about 15 μm. The line width of matching inductors are selected to be 3 μm wide ($Z_0 = 100$ Ω) for physical length and quality factor. The emitter size of the Gilbert cell up-converter was determined so that the mixer achieves broadband matching performance while maintaining the required conversion loss. The emitter size of the HBT is 0.2 μm × 4.52 μm. The devices of the gain stage were biased at 1 mA and 1.5 V at the peak g_m. The base voltage for the devices of the switching stage is biased through resistors, but that for the devices of the gain stage is biased through the off-chip IF rat-race. The fabricated Gilbert cell up-converter is shown in Fig. 3, with a chip area of 0.7 mm × 0.45 mm.

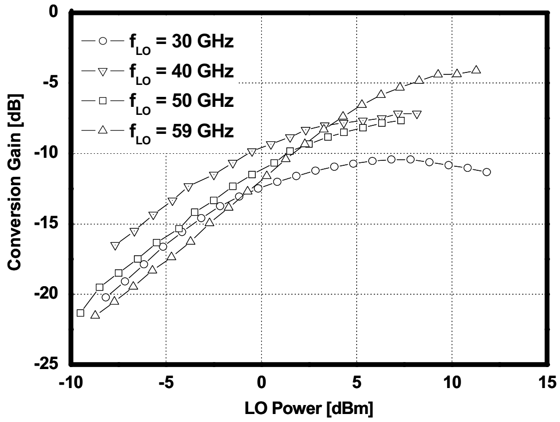


Fig. 4. Measured conversion gain versus LO power of the Gilbert cell up-convert mixer with IF power, and IF frequency of -20 dBm, and 1 GHz, respectively.

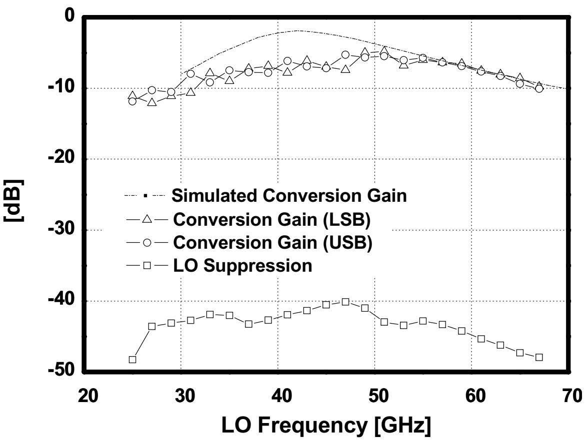


Fig. 5. Simulated and measured conversion gain and LO suppression of the Gilbert cell up-convert mixer with LO power, IF power, and IF frequency of 5 dBm, -20 dBm, and 1 GHz, respectively.

IV. Measurement Results

The IF input signal of the up-converter is fed through an off-chip hybrid rat-race hybrid. The center frequency of the rat-race hybrid is designed at 1-GHz with 3-dB bandwidth of 300 MHz. The measured conversion gain versus LO power of the Gilbert cell up-convert mixer in different LO frequencies is presented in Fig. 4. With LO input power, IF input power, and IF input frequency of 5 dBm, -20 dBm, and 1 GHz, respectively, the simulated and measured conversion losses are shown in Fig. 5. The measured conversion losses of upper- and lower-sideband signals are 7 ± 1.5 dB from 35 GHz to 65 GHz. An LO suppression of more than 40 dB is achieved over this frequency range. The discrepancy between the simulation and measurement may be due to the uncertainty of the models in millimeter-wave range.

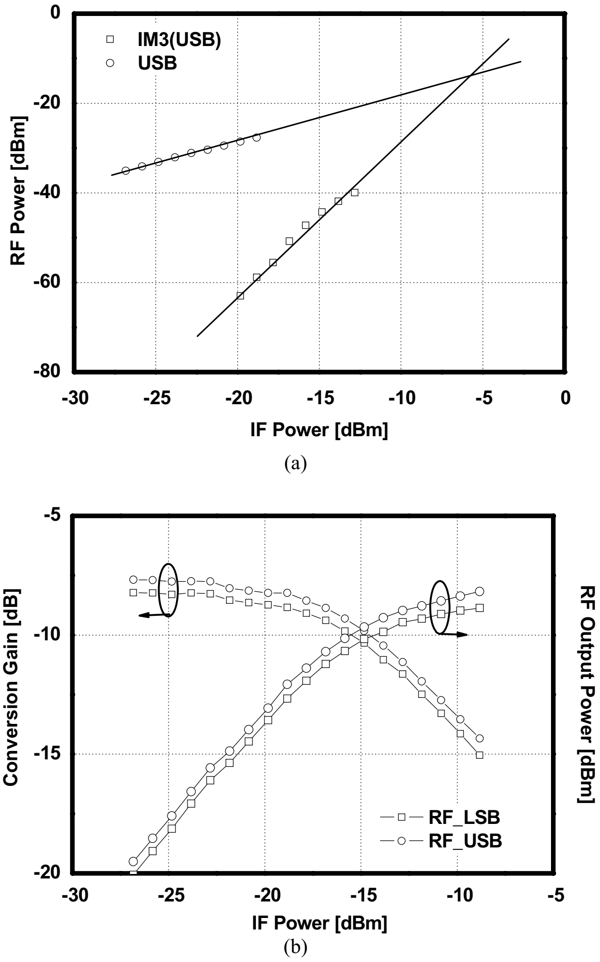


Fig. 6. Measured (a) third-order intermodulation intercept point (b) 1-dB compression point of the Gilbert cell up-convert mixer with LO frequency, LO power, IF frequency of 40 GHz, 5 dBm, and 1 GHz ± 100 kHz, respectively.

The measured conversion gain swept with LO pumped power is saturated at -7 dBm, where the LO and IF input power are 5 dBm and -20 dBm, respectively. The output third-order intermodulation intercept point (OIP3) and output 1-dB compression point (OP_{1dB}) is -16 and -25 dBm at 40 GHz, respectively, as shown in Fig. 6(a) and (b). The collector bias is 4 V while the base bias is optimized to be 3 and 2 V for the switching stage and the gain stage, respectively. The total dc power consumption is 14 mW. Table I summarizes the recently reported MMW up-conversion mixers. This Gilbert cell MMW up-converter demonstrated the most compact chip area and the highest operation frequency among up-conversion mixers using silicon-based technology.

TABLE I

COMPARISON OF RECENTLY REPORTED MMW UP-CONVERSION MIXERS

Ref.	Technology	Type	Topology	Bandwidth (GHz)	Conversion Gain (dB)	P_{LO} (dBm)	LO Isolation (dB)	Power Consumption (mW)	Die Size (mm^2)
[3]	0.15μm InGaP/InGaAs pHEMT	Passive	Single-balanced gate mixer	50-70	-14 ± 1	0	> 15	N/A	1.67 × 1.34
[5]	GaAs MESFET	Passive	Antiparallel diode pair	62-66	-9 ± 1	7	>9.8	N/A	N/A
[9]	0.2μm InP pHEMT f_T=135 GHz, f_{max} = 200 GHz	Active	Single-transistor	64.5	1	-1.7	> 30	N/A	3.7 × 1.4
[2]	0.14μm pHEMT f_T=95 GHz, f_{max} = 180 GHz	Passive	Double-balanced resistive mixer	30-50	-6 ~ -12	1.5	> 30	N/A	2 × 1.5
[6]	0.18μm pHEMT	Passive/SHP	Antiparallel diode pair	43-46	-10	12	8-20	N/A	1.7 × 1.7
[4]	0.25μm 3-D Si BJT	Active	Base active mixer	12-27	2.5 ± 2.5	0	30	9.8	1.4 × 0.7
[7]	0.3μm GaAs MESFET	Passive/SHP	Antiparallel diode pair	21.6 -30.8	-12.9 ± 1.1	8	> 50	N/A	1.8 × 1.3
This work	0.18μm SiGe BiCMOS f_T=120 GHz, f_{max}= 130 GHz	Active	Gilbert cell with integrated passive broadband balun	35-65	-7 ± 1.5	5	> 40	14	0.6 × 0.45

V. CONCLUSION

A compact Gilbert cell up-conversion mixer in 0.18-μm SiGe BiCMOS technology is presented in this paper. The mixer consists of broadband and compact Machand-type transformers and meandered thin-film microstrip lines to reduce the chip size. From 35 GHz to 65 GHz, the MMIC achieves a flat conversion loss with less than 3 dB variation. With the total chip area of 0.28 mm^2, which is the most compact MMW up-converter ever reported, it can be easily integrated into single-chip transmitters.

ACKNOWLEDGEMENT

This work is supported by NTU-TSMC Joint-Development Project and National Science Council of Taiwan, R. O. C. (Project no. NSC 93-2752-E-002-002-PAE, NSC 93-2219-E-002-024, and NSC 93-2213-E-002-033). The authors would like to thank Chun-Hsien Lien for the chip testing and the Chip Implementation Center for providing design software.

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