A 5.7 GHz 0.35 μm SiGe HBT Upconversion Micromixer with a Matched Single-ended Passive Current Combiner Output

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***Abstract* — This paper demonstrates a small compact 5.7 GHz upconversion Gilbert micromixer using 0.35 μm SiGe HBT technology. A micromixer has a broadband matched single-ended input port. A passive LC current combiner is used to convert micromixer differential output into a single-ended output and doubles the output current for single-ended-input and single-ended-output applications. Thus, a truly balanced operation of a Gilbert upconversion mixer with a single-ended input and a single-ended output is achieved in this paper. The fully matched upconversion micromixer has conversion gain of –4 dB, OP_{1dB} of –9.5 dBm and OIP_3 of –1.5 dBm when input IF=0.3 GHz, LO=5.4 GHz and output RF=5.7 GHz. The IF input return loss is better than 18 dB for frequencies up to 20 GHz while RF output return loss is 25 dB at 5.7GHz. The supply voltage is 3.3V and the current consumption is 4.6 mA. The die size is 0.9× 0.9 mm^2 with 3 integrated on-chip inductors.**

I. INTRODUCTION

A fully matched and truly balanced Gilbert upconversion micromixer with a single-ended input and a single-ended output is demonstrated at 5.7 GHz in this paper by using a 0.35 μm SiGe HBT technology. The circuit schematic is illustrated in figure 1. A Gilbert micromixer [1] is used to transform the unbalanced single-ended input signal to the balanced differential signal. In addition, an LC output current combiner combines the differential output into a single-ended output.

A double balanced Gilbert mixer has been widely used in RF IC design because of the excellent port-to-port isolation property. The excellent performance in IF (RF) and LO port isolation is fundamentally achieved by separating IF (RF) and LO feeding ports in a Gilbert upconversion (downconversion) mixer. If the IF (RF) and LO signals that feed the Gilbert upconversion (downconversion) mixer are balanced, the IF-RF (RF-IF) and LO-RF (LO-IF) port-to-port isolation will be very high. Of course, the fact should be observed if the output signals are taken differentially. The transistor Q_1 and Q_2 basically form a current mirror and can be operated at very high frequencies. The common-base-biased transistor Q_3 and common-emitter-biased transistor Q_2 provide 180 degree out of phase transconductance gain when Q_1 and Q_2 are connected as a current mirror [2]. Thus, the input stage in a micromixer can easily generate balanced RF signals and achieve broadband input impedance matching simultaneously. On the other hand, a traditional Gilbert mixer has an emitter coupled pair input stage and needs a current source to increase the common mode rejection ratio. Unfortunately, the common mode rejection provided by the biased current source in a conventional Gilbert mixer deteriorates rapidly at high frequencies and thus reduces the port-to-port isolation.

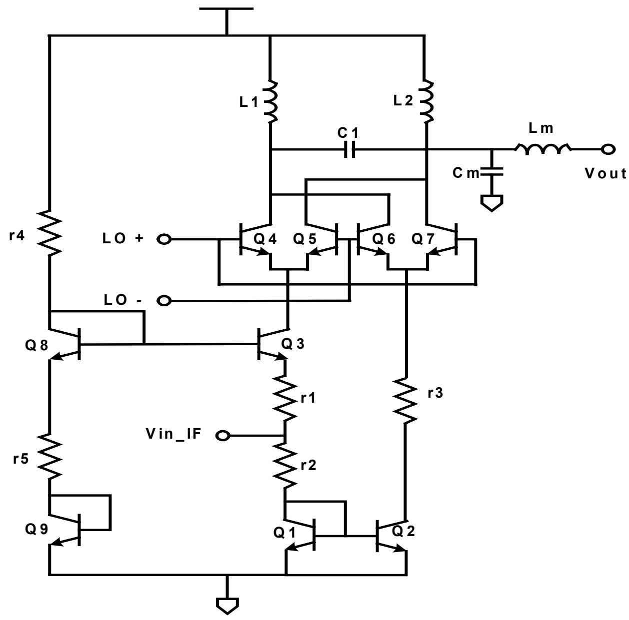

Figure 1 Schematic of an upconversion micromixer with an integrated LC current combiner and a low-pass LC matching output

The upconversion mixer consists of a passive LC current combiner as the output stage. A LC current combiner is capable of doubling the output current and converts the differential output into a single-ended output. The LO input signal is generated by a broadband 180^o coupler to maintain balanced LO signals. A low-pass LC network is used here for impedance matching. Thus, a truly balanced operation of a Gilbert upconversion micromixer with a single-ended input and a single-ended output is achieved in this paper.

The fully integrated SiGe HBT upconversion micromixer with a single-ended passive combiner output has conversion gain of –4 dB, OP_{1dB} of -9.5 dBm, and OIP_3 of –1.5 dBm when input IF=0.3 GHz, LO=5.4 GHz and RF=5.7 GHz. The IF input return loss is better than 18 dB for frequencies up to 20 GHz while RF output return loss is 25 dB at 5.7 GHz RF output frequency. The supply voltage is 3.3V and the current consumption is 4.6 mA.

II. CIRCUIT DESIGN

The photograph of the fabricated circuit is illustrated in figure 2. The die size is 0.9 × 0.9 mm^2 and contains three on-chip inductors. The SiGe HBT device used in this work has BVceo=3.8V, and peak F_t around 49 GHz. The transistor emitter length is 9.9 μm with a non-self-aligned single-poly-emitter 0.35 μm SiGe HBT technology.

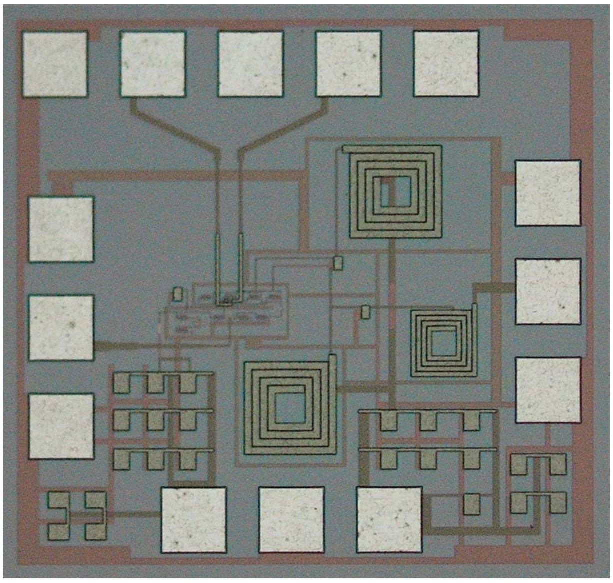

Figure 2 Photograph of the upconversion micromixer with an integrated output LC current combiner.

The common-base-biased transistor Q_3 and common-emitter-biased transistor Q_2 provide 180 degree out of phase transconductance gain when Q_1 and Q_2 are connected as a current mirror. The common-base-configured transistor Q_3 possesses good frequency response while the speed of common-emitter-configured Q_2 is improved drastically by adding a low impedance diode-connected Q_1 at the input of common-emitter-configured Q_2. The input resistance equals to $(\frac{1}{g_{m3}}+r1)\left\|(r2+\frac{1}{g_{m2}})\right.$. This configuration achieves broadband impedance matching.

The Gilbert mixer core consists of transistors Q_4, Q_5, Q_6 and Q_7. The current combiner doubles the output current at the resonant frequency, $\omega_0=\sqrt{\frac{1}{2L_1C_1}}$. A passive LC current combiner is used as loads instead of using a pair of active loads or resistors as combining circuitry. It is because the active current combiner limits the output signal swing and its performance unfortunately degrades very seriously for high frequency applications. Thus, an integrated passive LC current combiner at 5.7 GHz is designed in this paper. The design flow of a current combiner is described in three steps as follows:

Step 1: Decide the value of resonant frequency of the LC passive combiner.

Step 2: Choose the inductance as large as possible but we should be careful with the Q value of inductors. Then the capacitance is determined.

Step 3: Design a proper LC low-pass filter that transforms output impedance to 50 Ω. At the mean time, the previous choosing inductor of the current combiner would have influence on the impedance transformation. In this procedure, we must check the inductance and redesign current combiner if necessary. There are three rectangular on chip inductors (two 2.4 nH and one 0.6 nH) in the die photograph of figure 2.

A low-pass LC network consisting of inductor L_m and capacitor C_m is used to improve the output matching as illustrated in figure 1. According to the design flow, the LC current combiner and the LC low pass network are designed to form a band-pass matching network and the designed center frequency is located at 5.7 GHz.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

Figure 2 illustrates the fabricated 5.7GHz upconversion micromixer. The single-ended input and single-ended output configuration is convenient for on-wafer measurements. As shown in the photograph, The GSG IF input port is on the left side of the chip while GSG RF output port is on the right side. The GSGSG LO differential input pad is on the top side while the DC pads are on the bottom side. There are many small rectangular capacitors around the bottom side of the chip. These are bypassing or DC chocking capacitors. Because of the foundry process fabrication limitations, they should be implemented as capacitor arrays instead of one larger capacitor.

Figure 3 shows the measured conversion gain as a function of LO power. The peak conversion gain is -4 dB when LO power is 3 dBm as illustrated in figure 3. Figure 3 shows that conversion gain increases monotonically from -6 dB to -4 dB when LO power changes from -10 dBm to 3 dBm. This is because the bipolar type LO mixer core of a Gilbert upconversion mixer can commutate IF currents if the differential voltage twist on the LO stage is several times of thermal voltage (say 0.1 V). In other words, a mixer core implemented with bipolar type technology needs a small power local oscillator and has a wide range of LO power for optimum conversion gain.

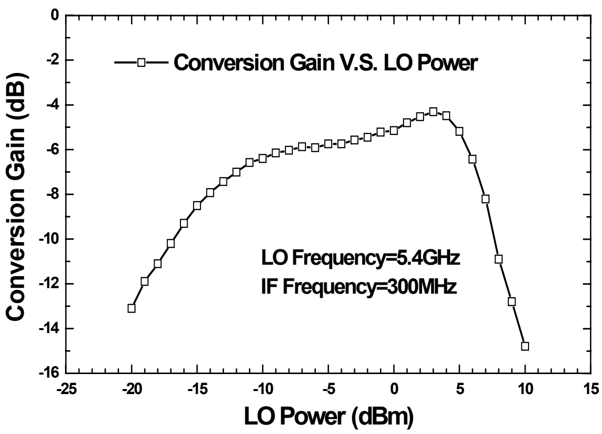

Figure 3 Conversion gain vs. LO power measurement of the upconversion micromixer with an integrated output LC current combiner

Figure 4 shows that the RF output return loss is 25 dB at 5.7 GHz. Figure 4 also indicates that the LC current combiner functions very well. In our design, the operating output frequency is 5.7 GHz and the measurement results show that the output return loss has a notch exactly at 5.7 GHz. The exact output matching directly comes from the LC current combiner and LC low-pass filter. On the other hand, a micromixer has a wide bandwidth impedance matching and the IF input return loss is better than 18 dB for frequencies up to 20 GHz as shown in figure 5. We can assure that the input resistive matching indeed works perfectly based on the experimental data.

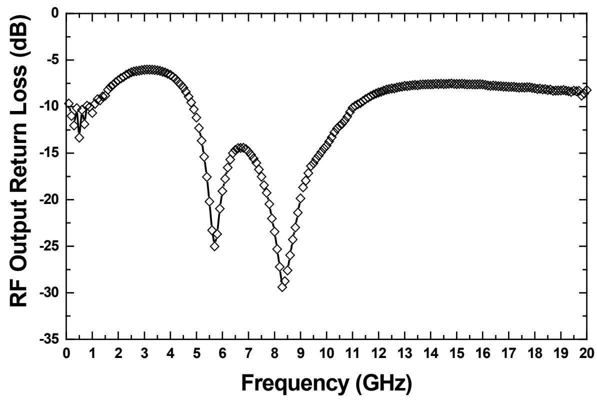

Figure 4 RF port output return loss of the upconversion micromixer with an integrated output LC current combiner

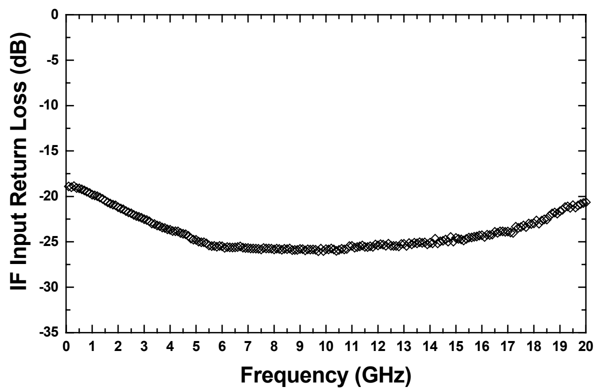

Figure 5 IF port input return loss of the upconversion micromixer with an integrated output LC current combiner

The measured conversion gain as a function of IF frequency is illustrated in figure 6 and the conversion gain peaks around 0.3 GHz as expected because of the effectiveness of the LC current combiner. The LC current combiner filters signal around 5.7 GHz and the output signal current is doubled around 5.7 GHz. The LC current combiner is compact and very useful in an upconversion mixer design. As illustrated in figure 4 and figure 6, the output return loss and conversion gain vs. IF frequency measurement results support the effectiveness of our LC current combiner design.

Power performance of the fabricated upconverter is shown in the figure 7. Experimental result shows that the OP_{1dB} is –9.5 dBm and the OIP_3 is –1.5dBm.

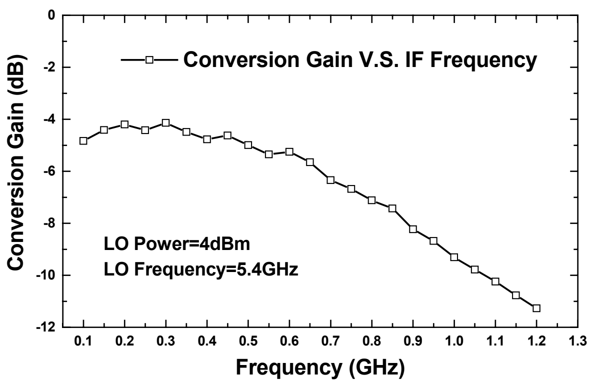

Figure 6 Conversion gain as a function of IF frequencies of the upconversion micromixer with an integrated output LC current combiner

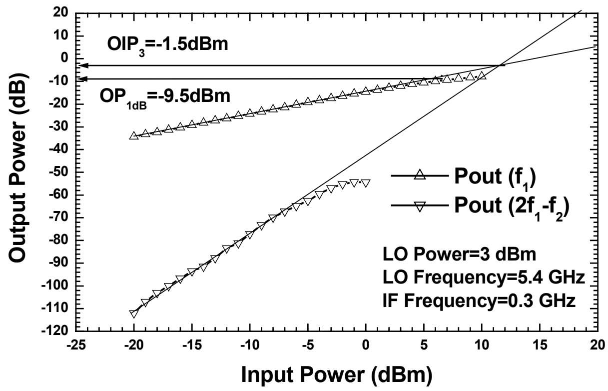

Figure 7 Power Performance of the upconversion micromixer with an integrated output LC current combiner

IV. Conclusion

An upconversion micromixer is demonstrated in this paper. It has a single-to-differential input stage with a passive LC current combiner converting mixer differential output into a single-ended output. The fully matched and fully integrated SiGe HBT upconverter has conversion gain of –4 dB, OP_{1dB} of -9.5 dBm, and OIP_3 of –1.5dBm when input IF=0.3 GHz and the output RF frequency equal to 5.7 GHz. The IF input return loss is better than 18 dB for frequencies up to 20 GHz while RF output return loss is 25 dB at 5.7 GHz output frequency. The die size is 0.9×0.9 mm^2 with three on-chip rectangular inductors. The supply voltage is 3.3V and the current consumption is only 4.6 mA.

Acknowledgement

This work was supported by the National Science Council of Republic of China under contract NSC 93-2219-E-009-026, by the Ministry of Education under contract 89-E-FA06-2-4 and by Ministry of Economic Affairs under contract number 92-EC-17-A-05-S1-020.

References

[1] B. Gilbert, "The MICROMIXER: A highly linear variant of the Gilbert mixer using a bisymmetric Class-AB input stage," *IEEE J. Solid-State Circuits*, Vol. 32, pp. 1412-1423, Sept. 1997.

[2] J. Durec, "An integrated silicon bipolar receiver subsystem for 900 MHz ISM band applications," *IEEE J. of Solid-State Circuits*, Vol. 33, No. 9, pp. 1352-1372, Sept. 1998.