10-GHz 0.35-μm SiGe BiCMOS Bottom-LO-Sub-Harmonic Gilbert Mixer With Lumped-Element Rat-Races

Sheng-Che Tseng, Chinchun Meng, and Guo-Wei Huang*

Department of Communication Engineering, National Chiao Tung University, Hsinchu, 300 Taiwan, R.O.C.

*National Nano Device Laboratories, Hsinchu, 300 Taiwan, R.O.C.

***Abstract* — In this paper, a single-ended downconversion sub-harmonic mixer is implemented using 0.35-μm SiGe BiCMOS technology. Two lumped-element rat-races are applied to generate differential LO and RF signals. This single-ended rat-race mixer has the conversion gain of 25 dB and high port-to-port isolations at 10 GHz. The input return loss is about -10 dB and the compact chip size is 0.8 mm × 0.9 mm. The total current consumption is about 16 mA at 3.3 V.**

***Index Terms* — Direct-conversion, lumped-element, rat-race, SiGe, sub-harmonic.**

I. INTRODUCTION

Direct-conversion is the main stream in the transceiver architecture design. Due to no demand of image rejection in a direct-conversion transceiver, many bulky and expensive off-chip components, such as image-reject and channel-select filters, are eliminated [1]. Therefore, the direct-conversion structure can be utilized not only for the manufacturing cost reduction but also for the high integration.

In a direct-conversion structure, the LO frequency of the fundamental mixer is too close to the RF one so that the LO radiation and self-mixing caused by the LO leakage can influence the transceiver performance. However, a harmonic mixer conquers these problems because of the large difference between the RF and LO frequencies. The sub-harmonic mixer works with the second harmonic of the LO signal, so the LO frequency is set to be half of the RF frequency. Then, the mixer is free of LO self-mixing and its LO leakage radiation is easily lowered by a well-designed antenna.

The traditional harmonic mixer is composed of diodes and uses the nonlinear property of diodes. Such passive mixers can not provide conversion gain. There are three distinct sub-harmonic active mixers based on the double-balanced structure. The first one is a two-level stacked-lo structure. The two-level stacked-lo structure performs twice mixing with quadrature LO signals and had been implemented in the SiGe HBT technology [2][3]. The other two types are one-level structures and their operation is based on the second harmonic generated by the transistor nonlinearity. Goldfarb et al presented the top-lo-configuration using the SiGe BiCMOS technology [4], while Zhang et al offered the bottom-lo-configuration using CMOS technology [5].

Sub-harmonic active mixers need balanced differential input signals and balanced quadrature LO signals in order to perform harmonic mixing perfectly. External baluns or hybrids are commonly used to generate the desired signals. However, those components should be integrated in chips to reduce the magnitude and phase mismatches of cables or baluns for high frequency applications. The most commonly used 180^{o} hybrid is a rat-race coupler. For integration, the lumped-element techniques are applied in rat-race couplers for size reduction [6][7][8].

In this paper, a 10GHz sub-harmonic mixer with rat-race couplers is demonstrated using 0.35-μm SiGe BiCMOS process. The mixer core is a bottom-lo-configuration harmonic mixer. Two lumped-element rat-race couplers and one two-section polyphase generator are embedded to generate truly differential and quadrature signals, respectively.

II. CIRCUIT DESIGN

An HBT transistor is a nonlinear device. When an emitter-coupled pair with collectors tightening together is fed with a differential sinusoidal signal, this emitter-coupled pair doubles input signal frequency and also eliminates the fundamental tone. Thus, it can be used to effectively double the LO frequency. The mixer core in this paper is designed based on this principle.

Figure 1 depicts the bottom-lo-configuration sub-harmonic mixer. The LO emitter-coupled pairs are under the RF input stage. These emitter-coupled pairs can not only effectively double the LO frequency but also the phase. Here, the differential quadrature LO signals generated by a two-section poly phase circuit and a 5-GHz rat-race coupler are

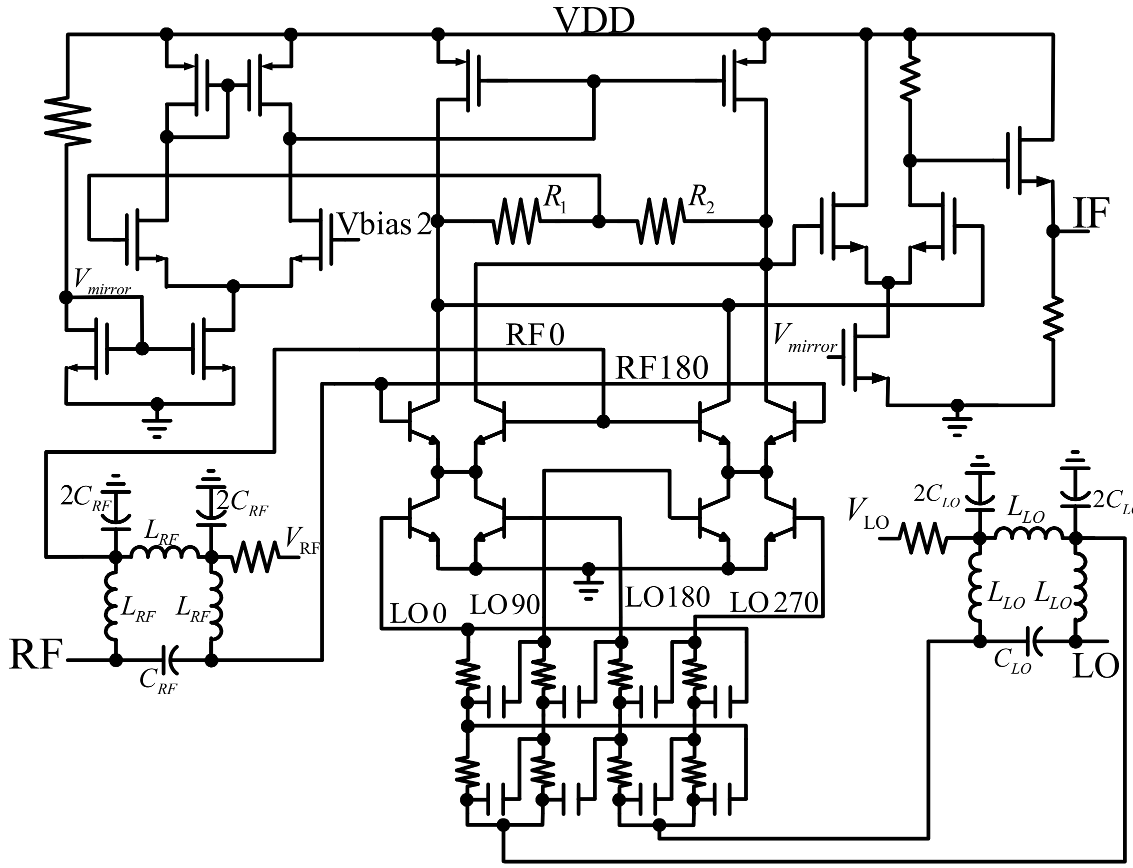
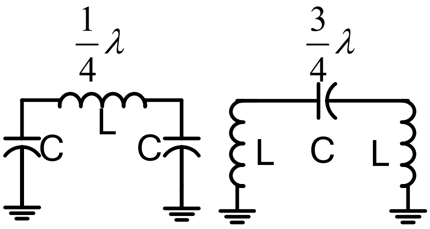


Fig. 1. Schematic of the sub-harmonic mixer with LO and RF rat-races.

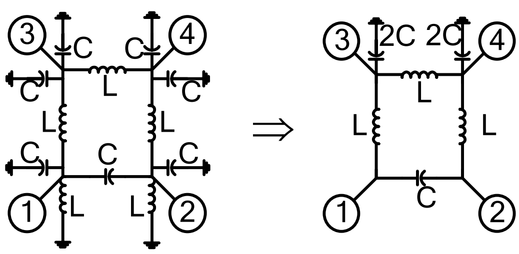
employed to pump the mixer LO port. The LO differential quadrature signals hence function as the 2×LO differential signals.

Two rat-race couplers are employed at RF and LO stages. For size reduction, the lumped-element technique is utilized. Simplified lumped-element rat-race is designed based on quarter and three-quarter wavelength 'pi' networks as shown in Fig. 2. The adjacent shunt capacitor and inductor can cancel each other while two neighboring shunt capacitors are combined in order to reduce the number of lumped elements.

Differential active PMOS loads replace resistive loads in order to improve the conversion gain without reducing the voltage swing headroom. The drawback is the bias stability between PMOS and NMOS transistors. Therefore, the common mode feedback (CMFB) technique is adopted to adjust the current of active PMOS loads and to guarantee NMOS and PMOS in saturation region [9]. Here, the resistors, R_1 and R_2, server as the CMFB sensing resistors with high resistance to preserve high gain performance.



(a) 'pi' lumped elements



$$\omega L = \frac{1}{\omega C} = \sqrt{2} Z_0$$

(b) Simplified lumped-element rat-race

Fig. 2. Simplified lumped-element rat-race with two 'pi' networks.

III. MEASUREMENT RESULTS

A high frequency sub-harmonic mixer is fabricated on the 0.35-µm SiGe BiCMOS technology. Figure 3 illustrates the die photos of the implemented mixer with two integrated rat-race couplers. The entire chip size of the mixer is only about 0.8 mm × 0.9 mm. The input return loss is about -10 dB and the total current consumption is about 16 mA at 3.3 V supply.

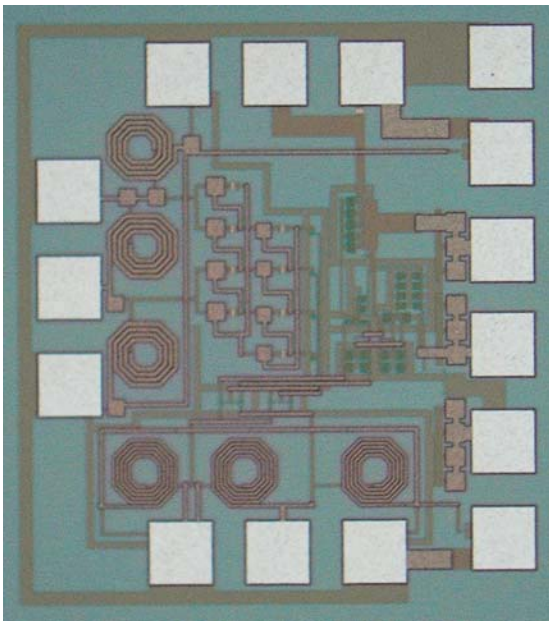


Fig. 3. Die photo of the rat-race sub-harmonic mixer.

The wideband property of the sub-harmonic mixer is shown in Fig. 4. The conversion gain is about 25 dB with the fixed IF frequency of 50 MHz.

This rat-race mixer is measured with a fixed 5 GHz LO signal. The experiment result is depicted in Fig. 5. Due to high impedance of PMOS loads, the frequency response is slow. The input 1-dB compression point, IP_{1dB}, is about -30 dBm, because of the high gain of the output buffer.

This rat-race sub-harmonic mixer has the -49-dB LO-to-RF isolation, -90-dB 2×LO-to-RF isolation, -53-dB LO-to-IF isolation, -78-dB 2×LO-to-IF isolation and -44-dB RF-to-IF isolation. High port-to-port isolations are achieved thanks to truly balanced quadrature LO and differential RF signals.

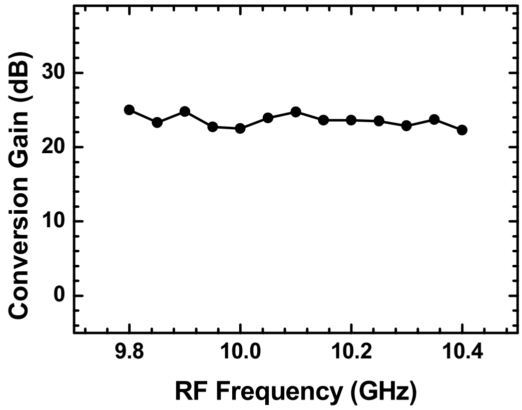


Fig. 4. Conversion gain of the rat-race sub-harmonic mixer with the fixed IF frequency of 50 MHz.

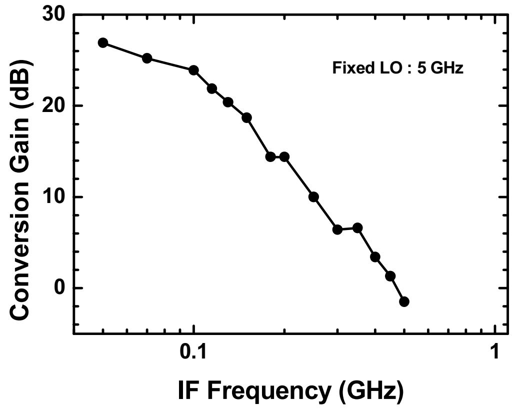


Fig. 5. Conversion gain of the rat-race sub-harmonic mixer with respect to IF frequencies.

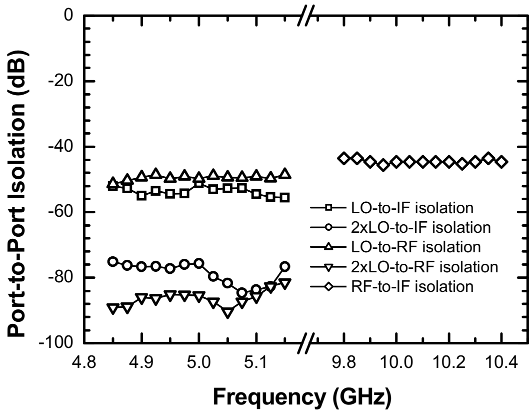


Fig. 6. Port-to-port isolations of the rat-race sub-harmonic mixer.

IV. CONCLUSION

This paper demonstrates a single-ended rat-race downconversion sub-harmonic mixer using standard 0.35-μm SiGe BiCMOS technology. Differential LO and RF signals are generated by integrated lumped-element rat-race couplers. This single-ended rat-race mixer operates at 10 GHz and has 25 dB conversion gain with the IF frequency of 50 MHz. Besides, high port-to-port isolations are archived because of the truly balanced quadrature LO and differential RF signals. The input return loss is about -10 dB and the chip size is 0.8 mm × 0.9 mm. The total power consumption is about 52.8mW.

ACKNOWLEDGEMENT

This work is supported by National Science Council of Taiwan, Republic of China under contract numbers NSC 95-2752-E-009-001-PAE, NSC 95-2221-E-009-043-MY3, by the Ministry of Economic Affairs of Taiwan under contract number 94-EC-17-A-05-S1-020, MoE ATU Program under contract number 95W803, and by the National Chip Implementation Center (CIC).

REFERENCES

[1] A. A. Abidi, "Direct-conversion radio transceivers for digital communications," *IEEE J. Solid-State Circuits*, vol. 30, no. 12, pp.1399-1410, Dec. 1995.

[2] L. Sheng, J.C. Jensen and L.E. Larson, "A wide-bandwidth Si/SiGe HBT direct conversion sub-harmonic mixer/downconverter," *IEEE J. Solid-State Circuits*, vol. 35, no. 9, pp.1329-1337, Sept. 2000.

[3] R. Svitek and S. Raman, "5-6 GHz SiGe active I/Q subharmonic mixers with power supply noise effect characterization," *IEEE Microw. Wireless Compon. Lett.*, vol. 14, no. 7, pp.319-321, July 2004.

[4] M. Goldfarb, E. Balboni and J. Cavey, "Even harmonic double-balanced active mixer for use in direct conversion receivers," *IEEE J. Solid-State Circuits*, vol. 38, no. 10, pp.1762-1766, Oct. 2003.

[5] Z. Zhang, Z. Chen, L. Tsui and J. Lau, "A 930 MHz CMOS DC-offset-free direct-conversion 4-FSK receiver," *ISSCC'2001*, pp.290-291, Feb. 2001.

[6] T. Kawai, Y. Kokubo, and I. Ohta, "Broadband lumped-element 180-degree hybrids utilizing lattice circuits," *in IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 47-50, May 2001.

[7] S. J. Parisi, "180° lumped element hybrid," *in IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1243-1246, June 1989.

[8] I. Sakagami, M. Tahara, Y. Hao, and Y. Iwata, "Simplified lumped-element rat-race for a mobile receiver," *PIMRC 2003*, vol. 3, pp. 2465-2469, Sept. 2003.

[9] Behzad Razavi, *Design of Analog CMOS Integrated Circuits*, McGraw-Hill, chapter 9, 2001