Broadband Gilbert Micromixer With an LO Marchand Balun and a TIA Output Buffer

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Abstract — **A single-ended wideband downconversion Gilbert micromixer is demonstrated in this paper using 0.35-um SiGe BiCMOS technology. Because of the wideband matching property of the micromixer, it can perform broad frequency translation. The TIA is utilized in the IF stage while a broadband Marchand balun is employed not only to generate differential LO signals but also to reserve the wideband operation of the mixer. This single-ended wideband mixer has the conversion gain of 15 dB, IP_{1dB} of -17 dBm, and IIP_3 of -6.5 dBm and works from 3.5 to 14.5 GHz. The input return loss is below -14 dB and the chip size is 1×1 mm^2.**

Index Terms — **Micromixer, Marchand balun, TIA, SiGe BiCMOS, wideband, downconverter, single-ended.**

I. INTRODUCTION

The era of the wireless applications with high data rate transmission and multiple functions is coming, for examples, the IEEE 802.11a/b/g combo system [1], Ultra-Wideband (UWB) system [2] and WiMAX system. The range of carrier frequencies and their bandwidth constantly increase. The obligation of the complicated data processing belongs to the baseband design, while the radio frequency integrated circuit design takes responsibility for the wide range frequency and broad bandwidth operation.

Nevertheless, the design of the high frequency and wideband RF circuits is a big challenge in the overall solution implementation. For an active mixer, the transistors have natural instinct to perform wide range and broad bandwidth frequency translation. Due to the matching networks, narrow-band passive components and loading effects, the mixer's wideband ability deteriorates.

For the wideband circuit design, the wideband matching is a vital issue. The common employed mixer is a Gilbert mixer using the emitter-coupled differential input stage. Due to the high input impedance of the common-emitter-configured transistors, the reactive or resistive matching is needed at the input port. For the reactive matching, the matching bandwidth relates to the orders of the passive matching network. Increasing the order of the matching network can increase the operation bandwidth but also takes more area. Although the resistive matching can perform wideband matching, it also introduces loss. The variant of the Gilbert mixer, so called micromixer, has the properties of the wideband input matching and single-ended input [4]. Those properties facilitate the realization of the wideband and single-ended mixer. In this paper, the mixer core is made up of the micromixer.

High impedance resistors or active PMOS loads are usually employed to obtain high conversion gain. In addition, the PMOS current mirror is used to combine effectively the differential current output signals of the mixer to establish a single-ended output. However, the high impedance causes low-frequency pole at the output stage, which reduces the IF bandwidth. Hence, the transimpedance amplifier is utilized at the output stage to reduce the output impedance and extend the bandwidth in this paper [5] [6].

For the balanced structure, the Gilbert switch quad demands the differential LO signals. To form a single-ended mixer, a single-to-differential LO balun is adopted. Because it is difficult to achieve truly differential signals by an active balun in addition to more power consumption at high frequencies, a passive balun is taken into consideration. The Marchand balun is a very wideband passive balun and is widely used for broad band applications [7].

A single-ended wideband Gilbert downconverter is fabricated in the 0.35-um SiGe BiCMOS technology and demonstrated in this paper. It is composed of a micromixer, an LO Marchand balun and a TIA output amplifier. This mixer has the conversion gain of 15 dB and the IF bandwidth of 400 MHz and works from 3.5 to 14.5 GHz.

II. CIRCUIT DESIGN

The entire schematic of the single-ended and wideband downconverter is shown in Fig. 1. This downconverter is formed by the micromixer, the Marchand balun and the TIA output buffer. Each element has the broad band property.

The micromixer can be considered as the combination of two single-balanced mixers. One mixer is formed by the common-emitter-configured input stage, Q_2, and the switch quad, Q_7 and Q_8; the other counterpart is composed of the common-base-configured transistor, Q_3, and the switch quad, Q_5 and Q_6. The different configurations of the input stages provide the equal magnitude and opposite phase transconductance gain. The combination of both single-balanced mixers forms a double-balanced structure to obtain a desired translated signal and to reduce even order distortion. The current mirror pair, Q_1 and Q_2, keeps the dc balance of the mixer. Moreover, the diode-type transistor, Q_1, reduces the

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input impedance of Q_2 and enhances the speed of the common-emitter-configured input stage. The input impedance is controlled by the transistors, Q_1 and Q_3, and the resistors, r_1 and r_3. The impedance is denoted as

$$R_{in} = \left(r_1 + \frac{1}{g_{m1}}\right) \| \left(r_3 + \frac{1}{g_{m3}}\right) = 50\Omega \qquad (1)$$

It is easy to achieve wideband matching, so this micromixer can act as a wideband mixer.

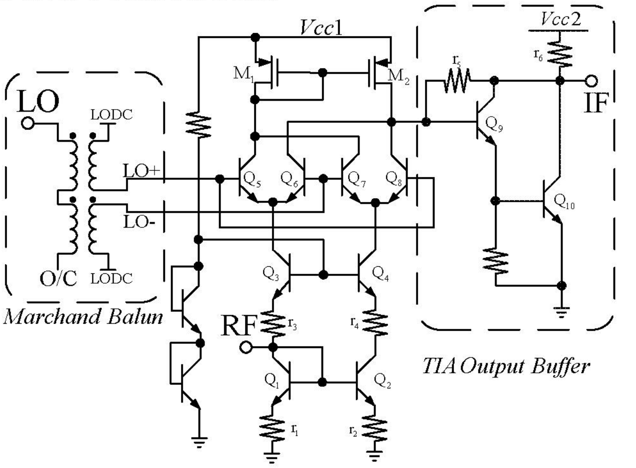


Fig. 1. Schematic of the micromixer with an LO Marchand balun and a TIA output buffer.

To establish a single-ended output, the PMOS current mirror is applied to combine the differential output current signals of the mixer. Furthermore, a TIA amplifier is used in this mixer. As shown in Fig. 2, the RF input stage is viewed as a transconductance amplifier while the IF output stage is a transimpedance amplifier. The TIA output buffer employs a resistive feedback to enlarge the output bandwidth. In addition, a Darlington pair is also utilized to enhance the speed of transistors. Therefore, this output stage of the mixer has the single-ended and wideband properties. The frequency translation is performed by the current switch quad Gilbert mixer core. The mixer functions as a Cherry-Hooper amplifier with current switching between the transconductance stage and the transresistance stage [5].

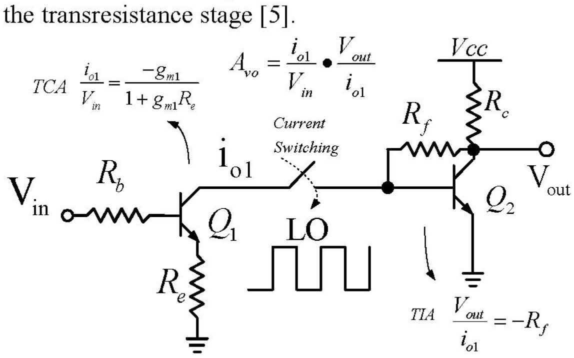


Fig. 2. Cherry Hooper technique employed in the micromixer.

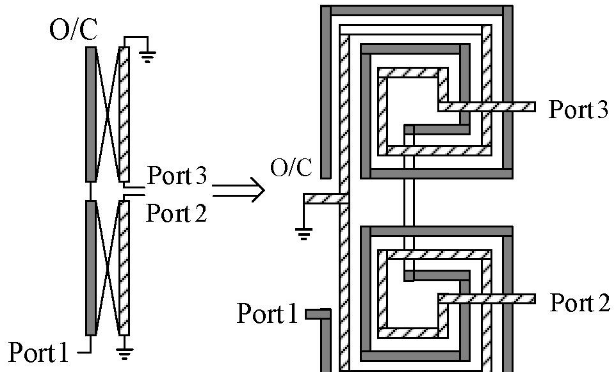


Fig. 3. Layout of the lumped Marchand balun.

For the balanced structure, the LO switch quad is driven by the differential signals. A wideband single-to-differential balun is demanded in order to offer differential LO signals and to reserve the mixer wideband operation. The broadband Marchand balun is a 3-port passive element and formed by two section quarter wavelength couple lines. In order to reduce the layout area of the couple lines, an interleave transformer is employed as a quarter wavelength couple line, as shown in Fig. 3 [7]. The two ground terminals of the Marchand balun in Fig. 3 are tied together. The transmission coefficients form the port 1 to the port 2 and the port 3 are denoted as

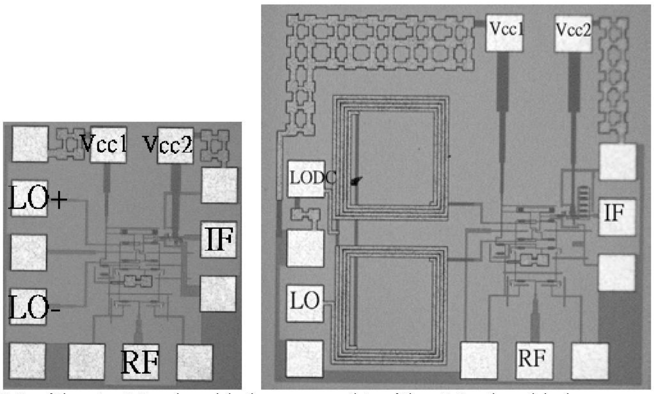
$$S_{21} = \frac{2jC\sqrt{1-C^2}}{1+C^2}$$
$$S_{31} = \frac{-2jC\sqrt{1-C^2}}{1+C^2} = -S_{21} \qquad (2)$$

with the coupling coefficient, C [8]. Clearly, this balun has the wideband single-to-differential operation when the port 1 is used as an input port. Besides, the LO bias of the switch quad is fed from the common ac ground and is isolated from the port 1. The common ac ground has a by-pass capacitor to ground to facilitate the dc LO bias. The ac signal and dc bias are hence separated by a Marchand balun.

These three components (the micromixer, the TIA amplifier, and the Marchand balun) form a single-ended and wideband downconverter. Because of the single-ended property and the wideband matching and operation, this Marchand micromixer has the wide range of usage.

III. Measurement Results

Two wideband micromixers are fabricated in the 0.35-um SiGe BiCMOS technology. Both mixers have identical active circuitry except the LO Marchand balun. Figure 4 illustrates two die photos of implemented mixers. The left photo is a micromixer without a Marchand balun and its chip size is about 0.75×0.75 mm^2. The chip size of the right chip with a integrated Marchand balun is about 1×1 mm^2. The measurement results of the micromixer without the Marchand balun gives excellent agreement with the wideband operation of the micromixer. Then, the Marchand mixer also performs wideband mixing.



(a) without a Marchand balun (b) with a Marchand balun

Fig. 4. The die photos of the micromixers (a) without a Marchand balun and (b) with a Marchand balun.

The wideband property of the micromixer is shown in Fig. 5. For the micromixer without an LO Marchand balun, an external single-to-differential balun is employed to generate differential LO signals. Five external baluns in different frequency range (0.002-to-2 GHz, 2-to-4 GHz, 4-to-8 GHz, 8-to-12.4 GHz, and 12.4-to-18 GHz baluns) are employed to perform the measurements in each band. Obviously, the mixer has the broad band property. Its input return loss is below -14 dB at overall operating frequencies. The conversion gain is about 15 dB.

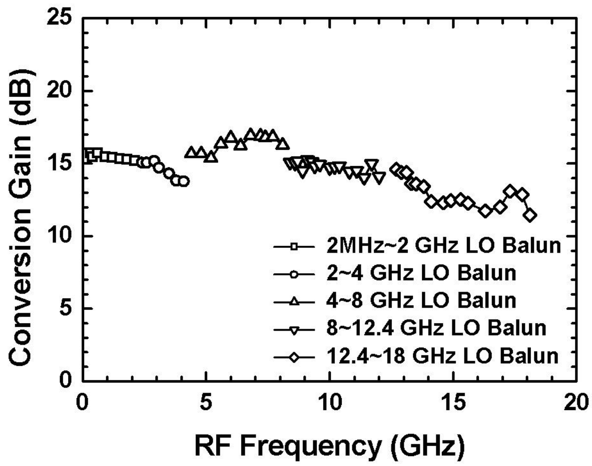


Fig. 5. The conversion gain of the micromixer without a Marchand balun.

The mixer without the Marchand balun is measured with a fixed 6 GHz LO signal. The experiment result is depicted in Fig. 6. The 3-dB IF bandwidth is about 400 MHz.

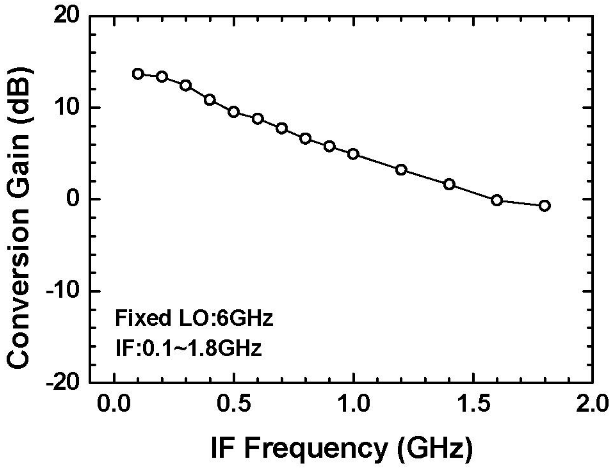


Fig. 6. The conversion gain of the micromixer without a Marchand balun.

To form a single-ended mixer, a Marchand balun is utilized at the LO port. This Marchand balun has several gigahertz bandwidth and is compatible with the wideband property of the micromixer. The conversion gain of the micromixer with the LO Marchand balun is measured with a fixed 100 MHz IF and figure 7 displays the experiment result. This Marchand mixer can operate from 3.5 to 14.5 GHz with 11 GHz 3-dB bandwidth. The conversion gain in the 3-dB bandwidth is about 15 dB and is the same as that of the mixer without the Marchand balun.

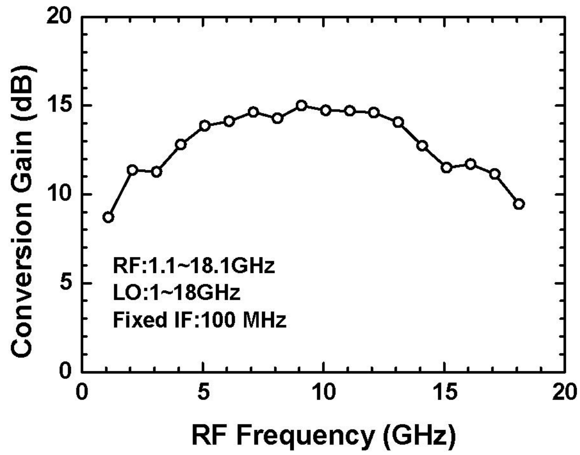


Fig. 7. The conversion gain of the micromixer with the integrated Marchand balun.

The 1-dB gain compression point, P_{1dB}, and the third-order intercept point, IP_3, of the micromixer with the integrated Marchand balun are measured at 10 GHz, as shown in Fig. 8. The IP_{1dB} is about -17 dBm while the IIP_3 is about -6.5 dBm. Both mixers work with 5 V supply and have the same core power consumption of about 60 mW. The additional Marchand balun does not consume any dc power.

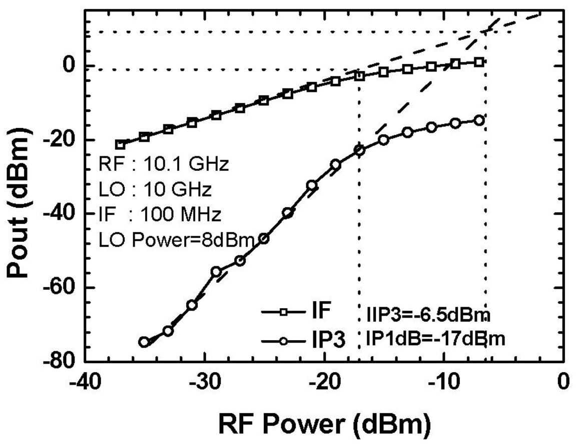


Fig. 8. The P_{1dB} and IP_3 of the micromixer with the integrated Marchand balun.

IV. Conclusion

A single-ended wideband Gilbert mixer is demonstrated in this paper and implemented in the 0.35-um SiGe BiCOMS technology. The mixer core is formed by a micromixer. The micromixer can execute wide range frequency translation thanks to its wideband matching property. The wideband TIA amplifier is utilized at the output stage to increase the IF bandwidth, while a broadband Marchand balun is employed not only to generate differential LO signals but also to reserve the wideband operation of the mixer. This single-ended wideband mixer has the conversion gain of 15 dB, IP_{1dB} of -17 dBm, and IIP_3 of -6.5 dBm and works from 3.5 to 14.5 GHz with 400 MHz IF bandwidth. Its input return loss is below -14 dB and its chip size is 1×1 mm^2.

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