A High 2LO-to-RF Isolation GaInP/GaAs HBT Sub-Harmonic Gilbert Mixer Using Three-Level Topology

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***Abstract* — A 5.2 GHz three-level sub-harmonic downconversion Gilbert mixer using GaInP/GaAs HBT (Heterojunction Bipolar Transistor) technology is demonstrated in this paper. The LO frequency is half of the RF frequency for the three-level sub-harmonic mixer architecture; therefore, the RF frequency is 5.2004 GHz and LO frequency is 2.6 GHz. The conversion gain is 14.5 dB, IP_{1dB} is –18 dBm, IIP_2 is 13 dBm and the IIP_3 is –5 dBm when the LO power equals to –8 dBm. The 2LO-to-RF leakage is about –83 dBm. The RF input return loss is better than –18 dB from DC to 6GHz.**

***Index Terms* — GaInP/GaAs HBT, Sub-harmonic mixer, Gilbert mixer, Self-mixing, 2LO-to-RF Isolation**

I. Introduction

A three-level sub-harmonic downconversion Gilbert mixer [1][2] using GaInP/GaAs HBT technology to reduce the LO self-mixing problem is demonstrated for the first time to the best of our knowledge. The LO leakage from the LO port to the RF port is always a problem in a RF receiver design. The LO leakage can cause the DC offset problem; however, the sub-harmonic mixer architecture can effectively solve this issue Ideally, there is no second-order distortion for a fully balanced sub-harmonic mixer. The even-order harmonics can be eliminated by the double-balanced architecture; therefore, the 2LO leakage, which is the second-order harmonic of the LO signal, is minimized. There is a fact that the frequencies of the remaining odd harmonics of the LO signal in a sub-harmonic mixer are 3LO, 5LO, 7LO, etc., and thus the frequencies of 2LO harmonics are impossible to exist in the sub-harmonic mixer. Consequently, the DC offset problem is solved by preventing the self-mixing with a fully balanced sub-harmonic mixer. In practice, the 2LO leakage can still be induced by the mismatches in the circuit implementation, the imperfection of the LO signals.

The self-mixing effect resulting from the 2LO leakage is more pronounced through the substrate coupling. The isolation property can be improved using the deep N-well in CMOS technology [3] and the deep trench isolation in the SiGe bipolar technology [4]. Compared with silicon substrate, the GaInP/GaAs HBT technology possesses a semi-insulating substrate. Therefore, the high frequency 2LO signal can not leak to the RF port through the GaAs semi-insulating substrate and a high 2LO-to-RF isolation is achieved in this paper. One of the reasonable specifications to estimate the self-mixing effect is the 2LO-to-RF isolation [2].

The three-level sub-harmonic Gilbert mixer architecture is used in this work. The main principle is that the RF signal can be mixed down by using the stacked Gilbert-cell stages with the quadrature LO signals. The Stacked-LO stage of the mixer consists of two cascode Gilbert cells. The DC current consumption of the three-level mixer is less than the total DC current of two cascaded Gilbert mixers because the DC current is reused.

II. Circuit Design

The circuit topology is shown in Fig. 1. The three-level sub-harmonic Gilbert mixer has two LO ports and one RF port. The lower LO Gilbert cell consists of transistors (Q_3 to Q_6) with I+ and I- LO input signals and the upper LO Gilbert cell consists of transistors (Q_7 to Q_{10}) with Q+ and Q- LO input signals in the sub-harmonic mixer. The LO frequency is set to be half of the RF signal due to the sub-harmonic architecture. If the RF input signal is defined as $\cos\omega_{RF}t$, the LO signals of the I-phase as $\cos\omega_{LO}t$, and LO signals of the Q-phase as $\sin\omega_{LO}t$, then the IF output signals can be determined from the following equations:

$$\cos\omega_{RF}t\cdot\cos\omega_{LO}t\cdot\sin\omega_{LO}t=\frac{1}{2}\cos\omega_{RF}t\cdot\sin 2\omega_{LO}t \quad (1)$$

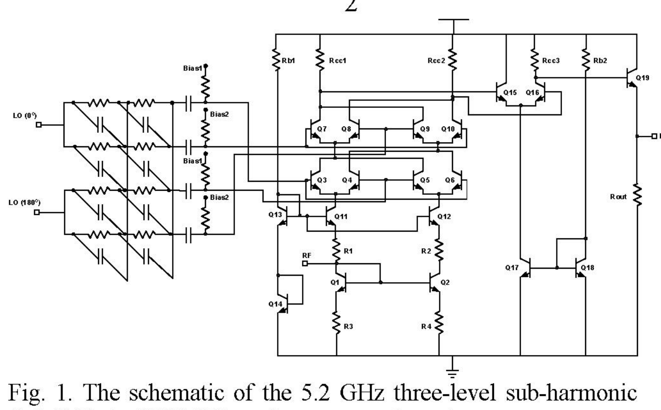

Fig. 1. The schematic of the 5.2 GHz three-level sub-harmonic GaInP/GaAs HBT Gilbert downconversion mixer.

Hence, the downconverted IF output frequency of the three-level Gilbert mixer is the difference between the RF frequency and the two times of the LO frequency. The three-level sub-harmonic Gilbert mixer requires quadrature LO signals and thus a two-section passive polyphase filter is employed to generate the balanced quadrature LO signals [5]. Because the GaInP/GaAs HBT technology provides the thin film resistor and the semi-insulating substrate, the values of the resistors and the capacitors used in the polyphase filter are closer to the designed values when compared with the CMOS technologies. Thus, the quadrature signals are more balanced in both magnitude and phase using GaInP/GaAs HBT technology. The LO stages are stacked and biased at different dc levels. Therefore, the four output nodes of the passive polyphase filter are connected with four DC blocking capacitors to bias the upper and lower level LO stages as shown in Fig. 1. The value of the DC blocking capacitor is 2 pF.

The common-emitter-configured Q_2 and common-base-configured Q_{11} and the resistors R_1 to R_4 form the single-to-differential input stage when Q_1 and Q_2 are connected as a current mirror [6], [7]. The common-base-configured transistor Q_{11} possesses good frequency response and the low input impedance for the wideband impedance matching. The speed of the common-emitter-configured Q_2 is improved significantly by the low impedance diode-connected Q_1 and the low input impedance common-base-configured Q_{12} at the input and output of the common-emitter-configured Q_2, respectively. The RF input impedance matching is achieved by the method of resistive matching; hence, the chip area is saved. Similarly, an output buffer consisting of an asymmetric differential amplifier to improve the frequency response and a common-collector output stage is used to combine the IF output differential signals and to perform the impedance matching at the output port.

III. Experimental Result And Discussion

The die photo of the fabricated GaInP/GaAs HBT three-level sub-harmonic Gilbert mixer is shown in Fig. 2. The 2um GaInP/GaAs HBT technology has f_T of 40 GHz and BV_{CEO} of 13 V. The emitter areas of the transistors used here are 2um X 6um for the mixer core and 3um X 9um for the output buffer. All of the transistors have single emitter, single base, and single collector. As shown in Fig. 2, the LO GSGSG differential input pad is on the left, IF GSG output pad is on the right, RF GSG input pad is on the bottom, and the DC pad is on the top. The DC power supply is 3.3 V and the current consumption is 4 mA. The total size is 1.5 mm X 1 mm including probe pads.

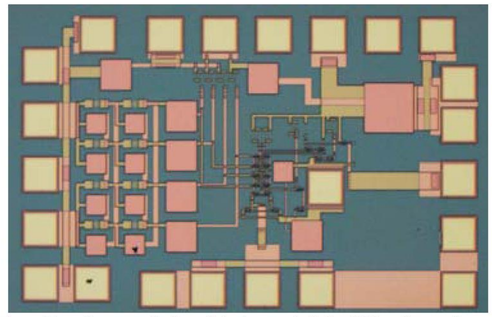

Fig. 2. The die photo of the fabricated 5.2 GHz three-level sub-harmonic GaInP/GaAs HBT Gilbert downconversion mixer.

An off-chip phase trimming technique is applied in the measurement setup to maintain the differential LO signals as balance as possible. A 180 degrees hybrid and a pair of phase shifters are used to keep the phase accuracy; therefore, the performance of the port-to-port isolation in a fully balanced Gilbert mixer is maintained without any degradation caused by the measurement setup. As shown in Fig. 3, the measured LO-to-IF isolation is better than -40 dB for frequencies between 2.5992GHz and 2.6012 GHz while the measured LO-to-RF isolation is better than -50 dB. All the good isolation performances not only result from the accuracy of on-chip resistors and capacitors but also result from the carefully phase trimming of the LO input signal. The measured result of the 2LO-to-RF leakage power is shown in Fig. 3, and the measurement data indicates that the leakage power is less than –83 dBm when the LO input power equals to –8 dBm and the LO frequency is 2.6 GHz. The experimental result proves that the three-level sub-harmonic topology helps to reduce the 2LO-to-RF leakages effectively. As shown in the table 1, the experimental data of the 2LO-to-RF isolation in our work is better than the existing research results.

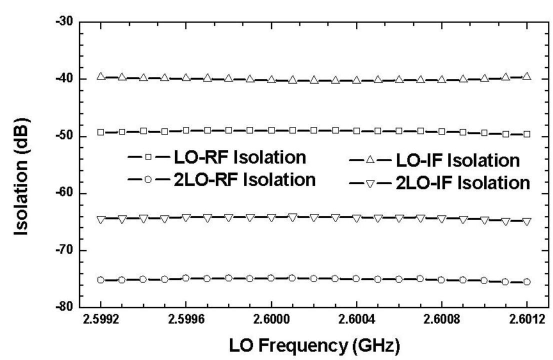

Fig. 3. The measured port-to-port isolation of the 5.2 GHz three-level sub-harmonic GaInP/GaAs HBT Gilbert downconversion mixer.

TABLE I
THE COMPARISON OF THE 2LO-TO-RF ISOLATION

	2LO-to-RF Isolation(dB)	RF frequency (G Hz)	Technology
This Work	75	5.2	2um GaInP/GaAs HBT
Ref[2]	70	2	0.5um SiGe HBT
Ref[8]	35	5-6	SiGe BiCMOS
Ref[9]	37	38	GaAs HEMT

Figure 4 shows the measured conversion gain as a function of the LO power and Fig. 5 shows the measurement result of the input and output return loss. The conversion gain is 14.5 dB when LO power is larger than −10 dBm. As shown in Fig. 5, the RF input return loss is better than −18 dB from DC to 6GHz resulting from the single-to-differential wideband input stage. The measured IP_{1dB} ,IIP_2 and IIP_3 of the 5.2 GHz GaInP/GaAs HBT three-level sub-harmonic downconversion Gilbert mixer are shown in the Fig. 6. The measured IP_{1dB} is −18 dBm, IIP_2 is 13 dBm and the IIP_3 is −5 dBm.

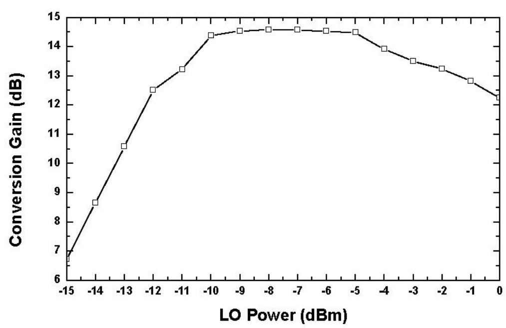

Fig. 4. The measured conversion gain as a function of the LO power of the 5.2 GHz three-level sub-harmonic GaInP/GaAs HBT Gilbert downconversion mixer.

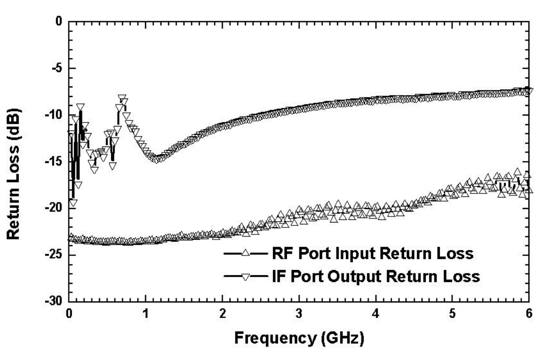

Fig. 5. The measured return loss of the 5.2 GHz three-level sub-harmonic GaInP/GaAs HBT Gilbert downconversion mixer.

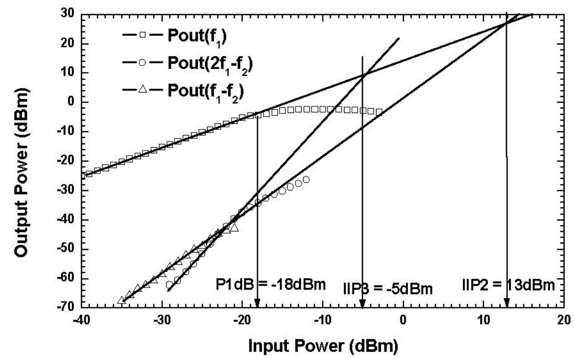

Fig. 6. The measured IP_{1dB} and IIP_3 of the 5.2 GHz three-level sub-harmonic GaInP/GaAs HBT Gilbert downconversion mixer.

IV. CONCLUSION

A 5.2GHz three-level sub-harmonic downconversion Gilbert mixer is demonstrated in this letter using the GaInP/GaAs HBT technology. The conversion gain is 14.5 dB, with IP_{1dB} = −18 dBm, IIP_2 =13 dBm and IIP_3 = −5 dBm when the LO power equals to −8 dBm. The low leakage power of the 2LO frequency measured at the RF port attributed to the topology of the double-balanced sub-harmonic Gilbert mixer. The 2LO-to-RF leakage is about −83 dBm when LO input power is −8 dBm and the LO frequency is around 2.6 GHz.

ACKNOWLEDGEMENT

This work is supported by National Science Council of Taiwan, Republic of China under contract numbers NSC 94-2752-E-009-001-PAE, NSC 94-2219-E-009-014 and by the Ministry of Economic Affairs of Taiwan, Republic of China under contract number 94-EC-17-A-05-S1-020. The authors also thank to the Chip Implementation Center (CIC) for its support.

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