A Fully Integrated 5.2 GHz GaInP/GaAs HBT Upconversion Micromixer with Output LC Current Combiner and Oscillator

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Abstract — **A 5.2 GHz upconversion micromixer with output LC current combiner and integrated oscillator is demonstrated in 2 μm GaInP/GaAs HBT technology in this paper. Micromixer has a single-ended input and a passive LC current combiner is used to convert mixer differential output into a single-ended output. A cross-coupled LC oscillator with oscillation frequency of 4.3 GHz and a cascode buffer amplifier are also integrated in the same chip. The die size is 1 mm^2. The fully integrated upconversion micromixer has conversion gain of -2.5 dB, OP_{1dB} of -12.5 dBm and 40 dB RF-IF isolation when input IF=0.9 GHz and thus output RF=5.2 GHz. The IF input return loss is better than 25 dB for frequencies up to 6 GHz while RF output return loss is better than 12 dB for frequencies from 5.15 GHz to 5.35 GHz.**

I. INTRODUCTION

A fully integrated 5.2 GHz upconverter with a single-ended input and a single-ended output as illustrated in figure 1 is demonstrated here in 2 μm GaInP/GaAs HBT technology. The upconverter has a Gilbert mixer core pumped by an integrated cross-coupled LC oscillator with a cascade buffer amplifier. The Gibert micromixer [1] used in this paper has intrinsically a single-ended input and a passive LC current combiner [2]-[4] is used to convert mixer differential output into a single-ended output. The upconverter with a single-ended input and a single ended output also facilitates on-wafer rf measurement.

A double balanced Gilbert mixer has been widely used in analog and rf society to implement mixer integrated circuits because of the excellent port-to-port isolation. The separate feeding ports for IF (RF) and LO in a Gilbert upconversion (downconversion) mixer provides good isolation between IF (RF) port and LO port. Excellent IF-RF (RF-IF) and LO-RF (LO-IF) port-to-port isolation can be achieved only if a Gilbert upconversion (downconversion) mixer is fed with balanced IF (RF) / LO signals and output RF (IF) signals are taken differentially. A single balanced mixer can be used as a downconversion mixer to reduce power consumption because the subsequent low pass filter can tolerate the bad LO-IF isolation of a single balanced mixer. However, it is difficult to separate two closely-spaced LO and RF frequencies by the subsequent off-chip passive band pass filter for an upconversion mixer and a double balanced Gilbert topology is thus needed to provide high LO-RF isolation. In other words, good common mode rejection is needed to preserve the good isolation properties of a double balanced mixer if balanced signals are absent. However, the common mode rejection provided by the biased current source in a conventional Gilbert mixer deteriorates rapidly at high frequencies [5].

The micromixer proposed by Gilbert is the ideal circuit for mixer at rf frequencies because the intrinsic single-to-differential input stage of a Gilbert micromixer renders high speed response and eliminates the need for common mode rejection. A passive LC current combiner can double the current gain and preserve the perfect port-to-to isolation properties by converting mixer differential output into a single-ended output. A cross-coupled LC oscillator with a balanced cross-coupled cascode buffer amplifier is used here to provide balanced signals to the LO port of the mixer. Thus, a truly balanced operation of a Gilbert micromixer with a single-ended input and a single-ended output is achieved in this paper.

The fully integrated GaInP/GaAs HBT upconversion micromixer demonstrated in this paper has conversion gain of -2.5 dB, OP_{1dB} of -12.5 dBm and 40 dB RF-IF isolation when input IF=0.9 GHz and thus output RF=5.2 GHz. The oscillation frequency of the integrated oscillator is 4.3 GHz. The IF input return loss is better than 25 dB for frequencies up to 6 GHz while RF output return loss is better than 12 dB for frequencies from 5.15 GHz to 5.35 GHz. The die size is 1 mm^2.

II. CIRCUIT DESIGN

The circuit schematic of a GaInP/GaAs downconversion micromixer is illustrated in figure 1 and the photo of the fabricated circuit is illustrated in figure 2. The die size is 1 mm^2. The single-to-differential input stage is not only used to turn an unbalanced signal into balanced signals but also facilitates wideband impedance matching. The common-base-biased Q_3 and common-emitter-biased Q_2 provides

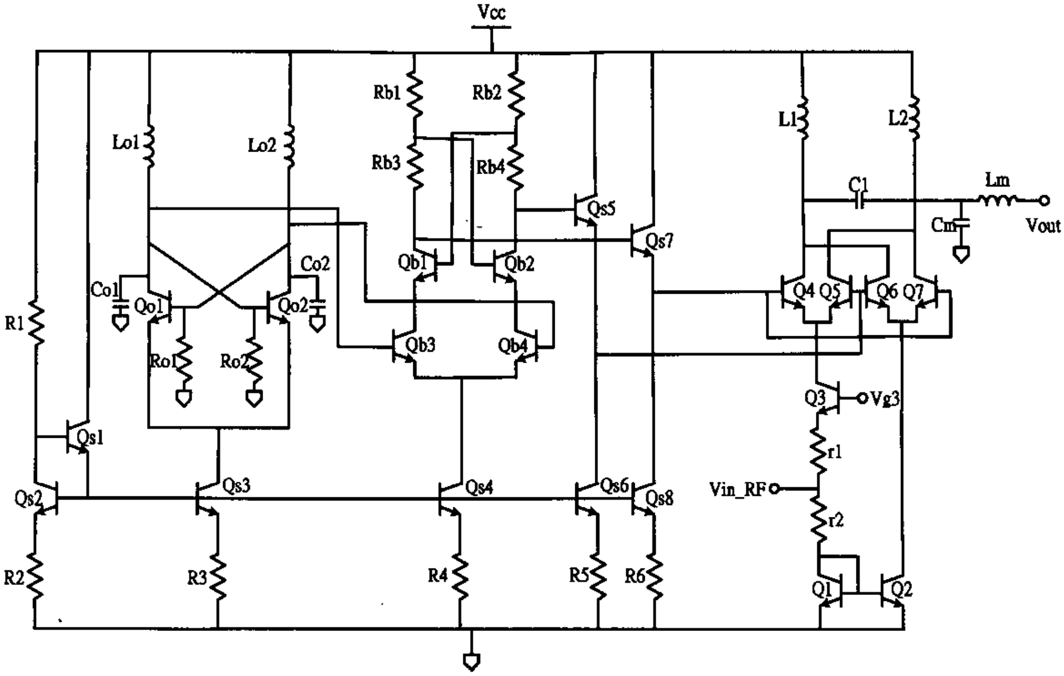

Fig. 1 Schematic of an upconversion micromixer with integrated output LC current combiner and oscillator.

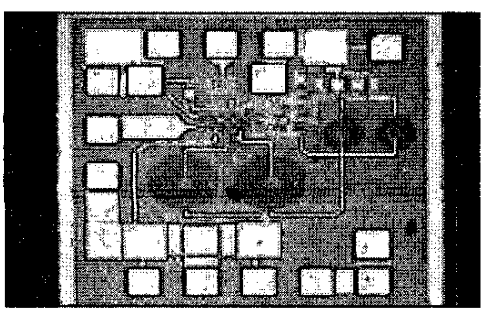

Fig. 2 Photo of the upconversion micromixer with integrated output LC current combiner and oscillator

equal but out of phase transconductance gain when Q_1 and Q_2 are connected as a current mirror. The common-base-configured 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-source-configured Q_2.

A balanced cross-coupled LC oscillator with a balanced cross-coupled cascode buffer amplifier is used to provide balanced signals to the LO port of a micromixer and preserve good isolation properties. The cross-coupled cascode buffer amplifier in figure 1 [6] has high speed response with good reverse isolation and thus prevents the local oscillator frequency pulling caused by the impedance mismatches at mixer LO port. The cross-coupled cascode buffer amplifier also reduces the equivalent input capacitance and allows the output of previous oscillator stage to bias at less current.

The Gilbert mixer core formed by Q_4, Q_5, Q_6 and Q_7 commutates the balanced IF currents to generate RF collector output currents. The operational principle of the passive current combiner is illustrated in figure 3. The current combiner doubles the output current at the resonant frequency, $\omega_0 = \sqrt{\frac{1}{2L_1C_1}}$. A passive current combiner has a desired band pass response for upconversion mixer application and the size of LC current combiner at 5 GHz is reasonably small to be incorporated in the integrated circuit. On the other hand, despite of the small size of an active current mirror, the speed response of an active transistor current mirror combiner is limited by low frequency pole caused by the high output resistance of a transistor. The active current mirror can be used in the low IF downconversion mixer application. Thus, an integrated passive LC current combiner at 5.2 GHz is designed in this paper. A subsequent L matching network transform the high output resistance of combined current source to 50 Ω at 5.2 GHz. Both high pass LC current combiner and low pass L matching network form a desired band pass filter at 5.2 GHz for upconverter application.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

On-wafer measurements are performed because the fabricated circuit in figure 2 has a GSG single-ended IF input, a GSG single-ended RF output and an integrated oscillator. The measured oscillation frequency of the integrated cross-coupled LC oscillator is 4.3 GHz. Power performance is illustrated in figure 3 and the conversion gain is -2.5 dB and OP_{1dB} is -12.5 dBm when input IF=0.9 GHz and thus output RF=5.2 GHz.

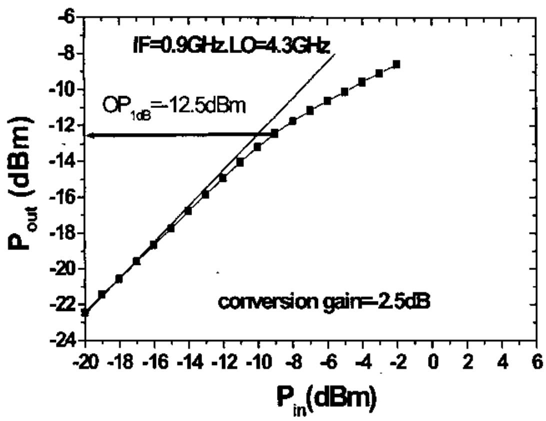

Fig. 3 Power measurement of the upconversion micromixer with integrated output LC current combiner and oscillator

A micromixer has a broad input matching bandwidth and the IF input return loss is better than 25 dB for frequencies up to 6 GHz as illustrated in figure 4. The RF output has a limited matching bandwidth because of the high pass LC passive current combiner and subsequent low pass L matching network. Figure 5 illustrates that the RF output return loss is better than 12 dB for frequencies from 5.15 GHz to 5.35 GHz.

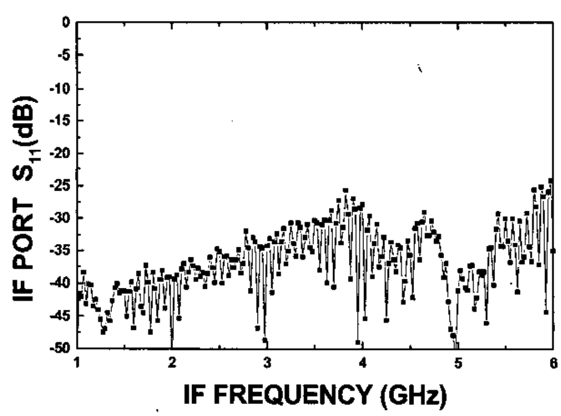

Fig. 4 IF port input return loss of the upconversion micromixer with integrated output LC current combiner and oscillator

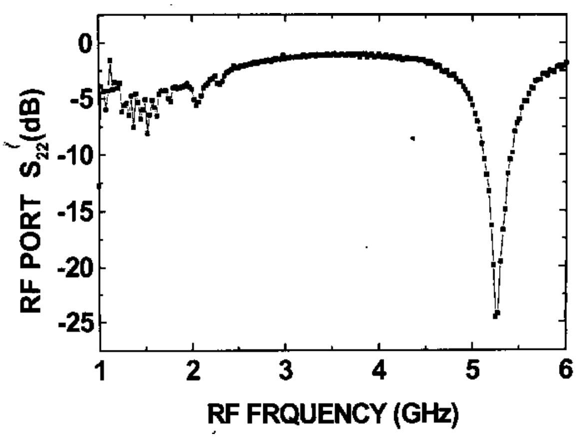

Fig. 5 RF port output return loss of the upconversion micromixer with integrated output LC current combiner and oscillator

IF-RF isolation measurement results as a function of IF frequencies when IF=-20 dBm is also illustrated in figure 6 and isolation is better than 30 dB for IF frequency up to 2 GHz. 40 dB and better IF-RF isolation occurs around IF=0.9 GHz and the high isolation property should come from a truly balanced operation of a Gilbert micromixer with output LC current combiner. Finally, the measured conversion gain as a function of IF frequencies is illustrated in figure 7 and the conversion gain peaks around 0.9 GHz as expected because of the effectiveness of the LC current combiner.

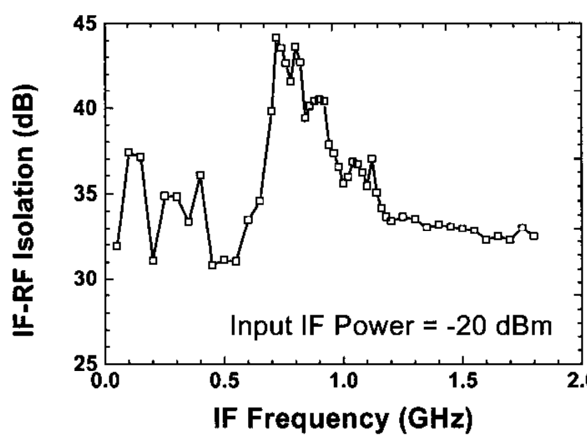

Fig. 6 IF-RF isolation of the upconversion micromixer with integrated output LC current combiner and oscillator

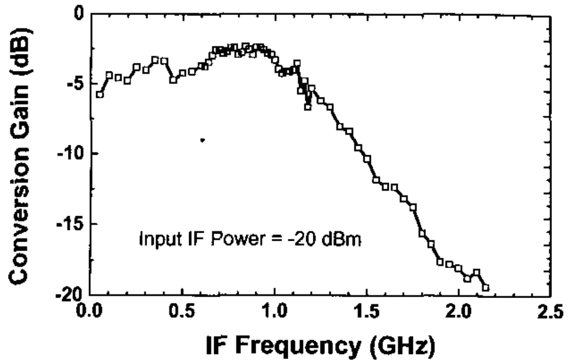

Fig. 7 Conversion gain as a function of IF frequencies of the upconversion micromixer with integrated output LC current combiner and oscillator

IV. CONCLUSION

A truly balanced operation of a Gilbert micromixer with a single-ended input and a single-ended output is achieved in this paper. The micromixer has single-to-differential input stage and a passive LC current combiner is used to convert mixer differential output into a single-ended output. A cross-coupled LC oscillator with a balanced cross-coupled cascode buffer amplifier is used here to provide balanced signals to the LO port of the mixer. The fully integrated GaInP/GaAs HBT upconversion micromixer has conversion gain of -2.5 dB, OP_{1dB} of -12.5 dBm and 40 dB RF-IF isolation when input IF=0.9 GHz and thus output RF=5.2 GHz. The IF input return loss is better than 25 dB for frequencies up to 6 GHz while RF output return loss is better than 12 dB for frequencies from 5.15 GHz to 5.35 GHz.

ACKNOWLEDGEMENT

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