An Actively Balanced GaAs HBT-Schottky Mixer for 3-V Wireless Applications

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***Abstract*— Here we present a novel low-voltage active mixer topology which enables 3-V double-balanced active mixer operation from wide-bandgap GaAs-based heterojunction bipolar transistors (HBT's). The compact mixer design integrates directly coupled active radio frequency (RF) and local oscillator (LO) transformer baluns with a Schottky-diode ring-quad to form a double-balanced mixer which operates from dc to 5 GHz. Biased with a low 3-V supply and operated as a down-converter with a fixed LO at 800 MHz and 0 dBm, the mixer achieves 9.4-dB conversion gain (CG) at 1 GHz with positive CG out to 4 GHz and an IP3 of −5 dBm. The LO-IF isolation is >20 dB while the 2-2 spur suppression is >20 dB over a broad 1–5-GHz RF input band. The novel $2.1 \cdot V_{\rm BE}$ supply design topology allows 3-V operation from the high turn-on voltage GaAs HBT's, making them suitable for portable wireless applications, and can enable 1.5-V operation for Si, Si-Ge, and InP BJT/HBT technologies.**

I. Introduction

In the past few years, the commercialization of GaAs heterojunciton bipolar transistor (HBT) technology has resulted in low-cost high-performance IC's for wireless applications including 3-V high PAE amplifiers [1]. Compact low-cost low dc power and high linearity LNA design solutions have also been demonstrated using GaAs HBT's [2], [3]. These LNA and PA designs typically employ common-emitter topologies and, therefore, can easily obtain reliable low 2–3-V single-supply operation inspite of the high 1.4–1.45-V base-emitter turn-on voltage characteristics of GaAs HBT's. However, for the active double-balanced Gilbert-cell mixer typically used for the RF down-conversion and modulator applications, the high turn-on voltage of GaAs HBT's can present a challenging design problem, especially for supply voltages lower than 2.5 times the HBT base-emitter turn-on voltage $(V_{\rm BE})$. Si-bipolar techniques for reducing the operating voltage of the active Gilbert-cell mixer involve folded current source topologies [4] and ac capacitor-coupled approaches [5]. These approaches can result in as low as $2.1 \cdot V_{\rm BE}$ voltage supply operation, or ≈1.5 V for the Si-BJT implementation, but may suffer from linearity performance degradation or size and cost increase due to the integration of large on-chip coupling capacitors as well as limited frequency capability.

Recently, a novel compact actively balanced GaAs HBT-Schottky mixer topology has been reported which can accommodate low $2.1 \cdot V_{\rm BE}$ supply voltage operation as well as multi-decade RF performance using 2-μm GaAs HBT's [6]. However, this previous work only reported 5-V performance results and dc 2-GHz operation. In this letter, we present the first 3-V design results of this novel active balanced mixer topology which employs higher speed 1-μm GaAs HBT's and achieves dc 5-GHz performance.

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II. Low 3-V GaAs HBT Active Balanced Schotty Mixer

Fig. 1 gives the detailed schematic of the novel active mixer design. The mixer integrates compact radio frequency (RF) and local oscillator (LO) active balun transformers which are directly coupled to four 7 × 7 μm^2 Schottky diodes forming a ring-quad-mixer. Active IF-combiner taps are a novel part of the active transformer design and provide broadband amplitude and phase balance performance from dc to 5 GHz. Typical amplitude and phase balance of <1 dB and <6 degrees were achieved over a dc to 5 GHz band [6] using a 2-μm GaAs HBT-based active transformer design. In this work, the active transformers employ 1-μm GaAs HBT which obtain f_T's and $f_{\max}$'s of 43 and 65 GHz, respectively, and possess 1.4–1.45-V turn-on voltages [7]. The use of the faster 1-μm HBT's is expected to extend the amplitude and phase balance to higher frequencies. The key feature of the novel active balanced mixer topology is that it only requires an ≈$2.1 \cdot V_{\rm BE}$ diode drop, or ≈3-V supply using GaAs HBT's. This topology can also enable reliable 1.5-V multi-decade double-balanced active mixer performance using lower bandgap Si and InP-based HBT and bipolar transistor junction (BJT) technologies.

Fig. 2 gives a microphotograph of the fabricated GaAs HBT-Schottky active double-balanced mixer. The mixer is symmetrically layed-out with the compact active RF and LO baluns constructed on either side of the Schottky-diode ring-quad devices. The total chip size including a supply bypass capacitor is 1.3 × 0.9 mm^2. A smaller area can be obtained by integrating the supply bypass capacitors off-chip.

III. Measured Performance

The double-balanced mixer was operated as a down-converter and characterized for 3- and 3.3-V supply bias conditions. Fig. 3 gives the conversion gain and two-tone IP3 performance over a swept RF input frequency from 1 to 5 GHz using a fixed LO at 800-MHz and 0-dBm power. At 3 V, the monolithic microwave integrated circuit (MMIC)

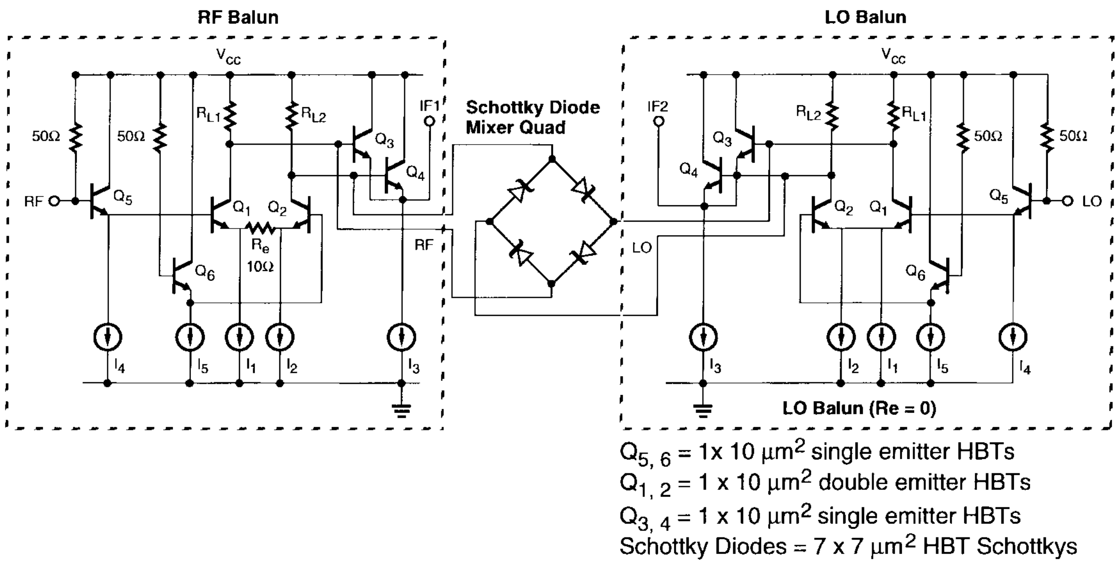

Fig. 1. Schematic of the 3-V direct-coupled HBT-Schottky active mixer design.

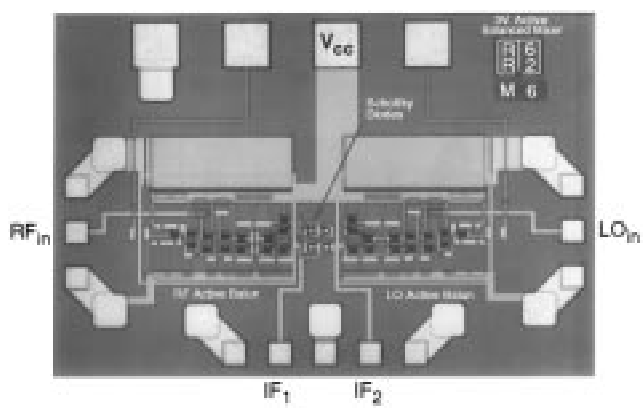

Fig. 2. Microphotograph of the active balanced mixer MMIC. The chip size is 1.3 $\times$ 0.9 mm^2.

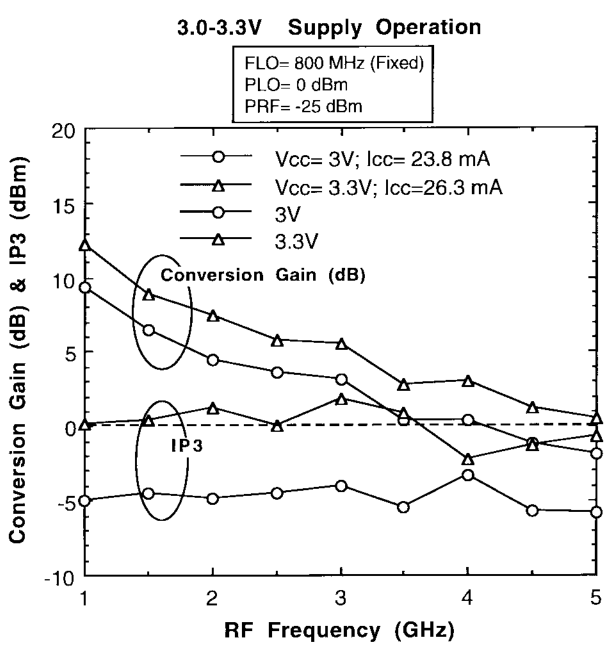

Fig. 3. Conversion gain and two-tone IP3 performance over a swept RF input frequency from 1 to 5 GHz for 3- and 3.3-V bias operation.

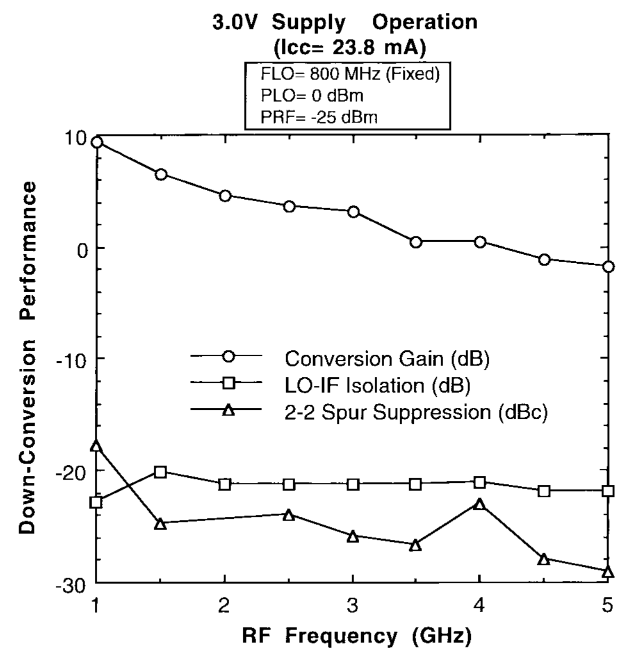

Fig. 4. Conversion gain, LO-IF isolation, and 2-2 spur suppression at 3-V bias.

draws 23.8 mA and achieves 9.4-dB gain at 1 GHz with positive conversion gain up to 4 GHz. The corresponding IP3 is between -5 and -6 dBm. At 3.3-V bias, the MMIC draws 26.3 mA and achieves 12-dB conversion gain at 1 GHz and positive conversion gain beyond 5 GHz. The corresponding average IP3 is about 0 dBm across the band. The broadband multidecade performance is attributed to the novel direct-coupled active-balanced design topology while the upper frequency capability is directly attributed to the speed of the 1-μm GaAs HBT's.

Fig. 4 gives the conversion gain, LO-IF isolation, and 2-2 spur suppression at the 3 V bias. Under this low supply bias condition and with -25 dBm RF input power, the LO-IF isolation is better than -20 dB while the 2-2 spur suppression is typically 24 dBc over the broad 1–5 GHz multi-octave bandwidth. The direct-coupled nature of the active balance mixer topology allows similar performance down to dc, however, no measurements were taken below 1 GHz. The reasonable LO-IF isolation and 2-2 spur suppression over this multi-octave bandwidth is directly related to the excellent dc beta and threshold matching of the HBT's, as well as its high-frequency performance capability. These features make GaAs HBT feasible for applications covering dc to 5.7 GHz which include the Industrial-Scientific-Medical (ISM) frequency allocated bands.

IV. Conclusion

Here we presented a $2.1 \cdot V_{\mathrm{BE}}$ active double-balanced mixer design topology suitable for low-voltage battery wireless applications. This topology enables 3-V operation and dc 5-GHz double-balanced performance using wide-bandgap GaAs HBT's with base-emitter turn-on voltages of ≈1.4–1.45 V. The low $2.1 \cdot V_{\mathrm{BE}}$ of this new active mixer topology can enable 1.5-V operation using lower-bandgap Si, Si-Ge, and InP-based HBT and BJT device technologies without limiting the bandwidth capability. The unique topology presented here offers a potential compact low cost solution for commercial RF down-converter and modulator applications spanning baseband up through 5.7 GHz and operating from 3-V battery supplies and lower.

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