A Novel HBT Active Transformer Balanced Schottky Diode Mixer

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ABSTRACT

This paper describes a unique HBT active transformer balun which has been monolithically integrated with a GaAs Schottky diode ring quad to construct a double balanced mixer which can operate from dc to > 2 GHz. The HBT active balun transformer achieves < ± 0.5 dB gain balance and < ± 3° phase balance from dc-5 GHz and provides an in-phase combined IF center-tap output. The HBT actively balanced Schottky mixer achieves positive conversion gain from dc - 2 GHz, and excellent LO-IF and LO-RF isolation in excess of 28 dB across the band. Two-tone input IP3's of -6 dBm and -14 dBm were obtained with an LO drive of +15 dBm and +6 dBm, respectively. The unique HBT active transformer balanced Schottky mixer topology can achieve multi-decade balanced performance, whereas, the passive transformer-balun approach is limited to an octave in frequency bandwidth. Furthermore, the HBT active balanced mixer topology is capable of operating from a minimum voltage supply of ≈ 2 Vbe which is lower than that achieved with conventional active Gilbert cell-based mixers (3 Vbe) making it potentially attractive for low voltage battery powered applications.

Introduction

Balanced mixers which can obtain high linearity performance from baseband to a few GHz and operate from a low voltage supply are attractive for wireless communication systems. Conventional Schottky balanced mixers require little or no dc power and achieve high IP3, but normally integrate expensive and cumbersome discrete passive transformers in a hybrid and are often limited to an octave in frequency bandwidth. The Gilbert cell mixer is an active balanced topology which can provide conversion gain from baseband to microwave frequencies, but requires at least 3 Vbe (base-emitter diode drop) of rail-to-rail supply voltage to operate with reasonable linearity. Other low voltage operated Gilbert cell mixer topologies have relied on folded current source techniques, however, this usually compromises mixer linearity also. Other active balanced approaches such as MMIC MESFET active baluns have been developed for microwave/millimeter-wave mixer applications[1], but its topology constrains it from operating down to baseband and results in a large consumption of area at frequencies below 2 GHz.

In this paper, we present an HBT active transformer balun which is employed with a GaAs Schottky diode ring quad to realize a multi-decade double balanced mixer with conversion gain from dc-2 GHz, excellent isolation performance, and good linearity (IP3). This novel HBT actively balanced mixer approach provides an alternate topology for achieving a miniature, low cost, high performance mixer MMIC for applications requiring baseband to microwave frequency operation. For the first time, this new actively balanced mixer design is revealed along with its first measured RF performance.

HBT Active Balanced Schottky Diode Mixer Design

Fig. 1a shows the conceptual schematic of a balun represented by a conventional passive transformer with an IF center-tap. The main function of the transformer in the Schottky mixer application is to divide a single-ended LO (RF) input signal into two out-of-phase complementary signals for driving two vertices of a Schottky diode ring quad. In addition, the in-phase IF output is taken at the center-tap of the balanced

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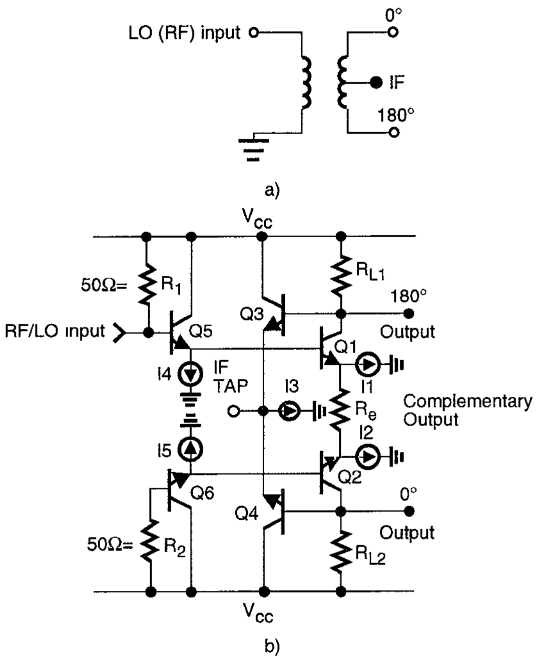

Fig. 1 Schematic of a) conceptual ideal transformer, b) the newly developed HBT active balun transformer with IF center tap.

outputs. The HBT active transformer balun developed in this work replaces these function while providing gain over a multi-decade frequency band.

A detailed schematic of the HBT active balun is presented in Fig. 1b. The HBT active balun has a singled ended input, a 180° differential complementary output, and an in-phase IF center-tap combiner. The active balun consists of a single-ended 50 Ω RF/LO input follower comprised of resistor R1 (50Ω), a 2x10μm^2 single-emitter HBT Q5, and a current source I4 (3.3 mA). The follower drives a differential amplifier comprised of 2x10μm^2 double-emitter HBTs Q1 and Q2, load resistors RL1 and RL2, emitter degeneration resistor Re, and current sources I1 and I2 which sink 6.6 mA each. The outputs of the collectors of Q1 and Q2 provide the balanced anti-phase complementary outputs. The other input to the differential amp is loaded by an identical follower stage comprised of resistor R2 (50Ω), HBT Q6, and current source I5 in order to provide balanced operation. Because the active balun uses a differential amp to drive the Schottky quad, techniques such as inverse Tanh predistortion or simple emitter degeneration may be used to enhance its linear operation. In our case, an emitter degeneration resistor Re is used which can be adjusted to increase the linear input power range of the differential amp, as well as adjust the conversion gain-bandwidth performance of the mixer. The values of the load resistors RL1 and RL2 are chosen such that the product RL*I is greater than the turn-on voltage of the Schottky diodes. In this manner, the balun can be driven by a large LO source such that the complementary outputs have enough voltage swing to switch the diodes on and off under large signal operation. Because both LO and RF active baluns are directly coupled to the Schottky diode ring quad, the voltage product (RL*I) must be the same for both RF and LO active baluns so that the diodes of the ring quad are biased with zero voltage bias with the absence of RF and LO signals. This design constraint must be maintained in order to preserve the dc balance of the Schottky diodes as well as the active baluns. The IF center-tap is comprised of 2x10μm^2 single-emitter HBT followers Q3 and Q4, and a current source I3 (6.6 mA). These transistors combine in-phase IF signals at the emitters of Q3 and Q4.

One noteworthy advantage of the HBT active balun transformer circuit is that it is unilateral where the reverse isolation of the HBT devices provide additional port-to-port isolation which is not present in conventional passive baluns. Yet another advantage of the HBT active balanced topology is that it can operate from less than a 2 Vbe diode drop supply voltage, where the minimum supply voltage can be expressed as Vsupply(min.)≈ 1•Vbe (Vce of Q1 and Q2) + Vshottky (required drop across RL1 and RL2) + Vcesat (Vce of the I1 and I2 current source transistors) ≈ 1.9 Vbe. In comparison, the conventional Gilbert cell mixer normally requires ≈ 3 Vbe supply voltage for linear operation including 2•Vbe for the stacked transistors of the Gilbert cell, Vcesat of the current source bias, and the headroom across the output load resistors. Additionally, the active balun is self-biased through a single supply voltage and incorporates PTAT current sources.

Fig. 2 illustrates the amplitude and phase balance of the HBT active balun. An amplitude balance of < ± 0.5 dB and phase balance of < ± 3° is achieved over a dc-5 GHz bandwidth. The excellent amplitude and phase balance is due to the beta (< 5%) and Vbe (< 1mV) uniformity of the GaAs HBTs while the direct-coupled nature of the mixer topology allows operation from microwave frequencies down to dc.

Fig. 3 gives the schematic of the full HBT double balanced Schottky mixer. Four 15x15μm^2 area GaAs HBT

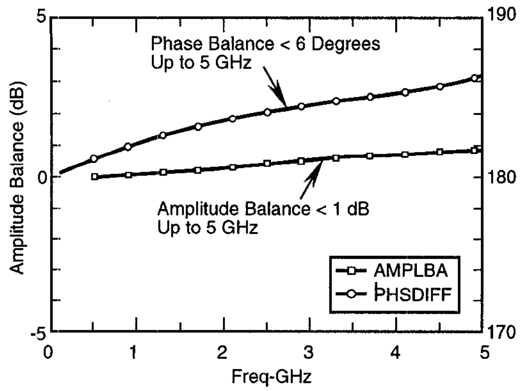

Fig. 2 Amplitude and phase balance performance of the HBT active balun transformer.

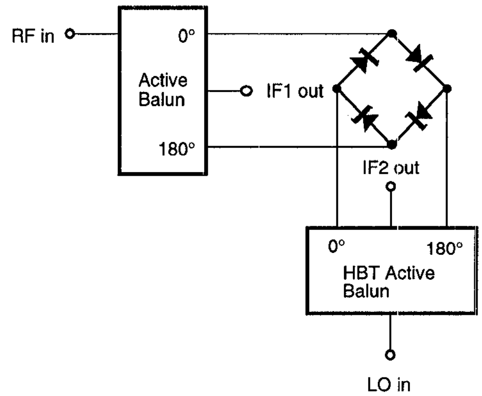

Fig. 3 Schematic of the HBT actively double-balanced Schottky mixer with IF center-taps.

Schottky diodes in a ring-quad configuration are driven by the RF and LO HBT active balun transformers. A description of the GaAs HBT Schottky diode characteristics and its MMIC mixer performance has been previously described in detail elsewhere [2],[3],[4]. For this first prototype demonstration, the mixer is generously biased at a Vcc= +5V and consumes ≈ 53 mA. Lower voltage and current operation can be achieved with this topology as described above. Fig. 4 illustrates the compact integrated implementation of the HBT actively balanced Schottky mixer. Note that there are two IF outputs IF1 and IF2. These outputs are complementary and can be directly fed into an op-amp/filter for combining these signals. The total chip size is only 1.3x0.9 mm^2 including the two active balun transformers.

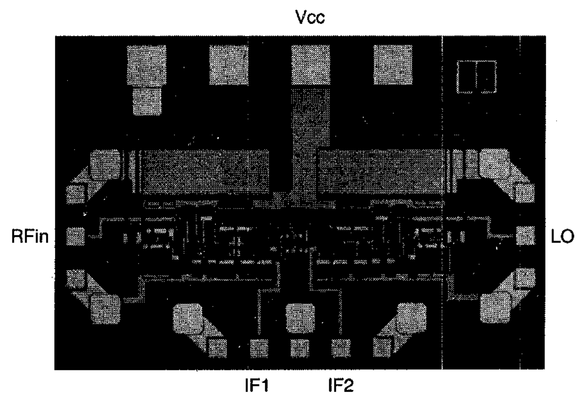

Fig. 4 Photograph of the dc-2 GHz HBT actively balanced Schottky mixer MMIC. The chip size is 1.3x0.9 mm^2.

Measured Performance

The measured down conversion gain performance for various LO drive levels is given in Fig. 5. The RF and LO track with a fixed difference (IF) frequency of 200 MHz. For fixed LO frequency operation, the CG roll-off is expected to be half that shown in Fig. 5. At an LO drive of + 6 dBm and an RF input of 1 GHz, a conversion gain of 6.5 dB is achieved. As the RF (and LO) increase to 2 GHz the CG rolls off to 1 dB. Similar up-conversion gain performance was also observed (Fif=Frf+FLo). Fig. 6 shows the LO-IF isolation for the various LO drive levels. At a PLo=+6 dBm, the LO-IF isolation is > 28 dB across the 1-2 GHz band. The LO-RF and IF-RF isolation is also given in Fig. 7. This shows LO-RF and IF-RF isolations of > 27 dB and > 20 dB across the 1-2 GHz band, respectively. The excellent port-to-port isolation performance is indicative of the excellent phase and amplitude balance of the active HBT transformers which are ultimately dependent on the dc beta and Vbe match of the HBTs. The IF output power compression characteristics were also measured versus RF input power and is illustrated in Fig. 8. As the input power is

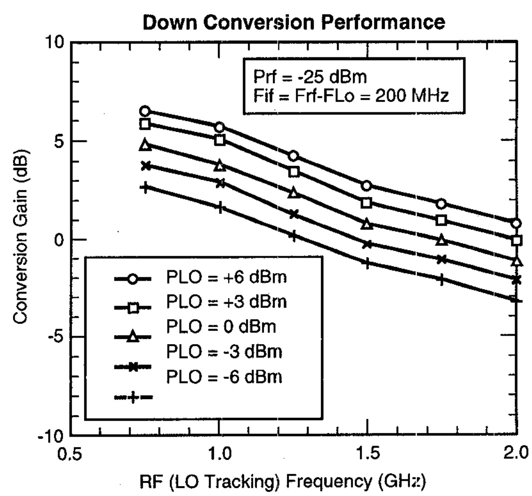

Fig. 5 Measured down-conversion gain for various LO drive levels.

increased, the up- and down- converted IF outputs gradually compress at an input power of -15 dBm. Finally, Fig. 9 illustrates a two-tone IP3 measurement of the mixer. From this figure, an output IP3 of 0 dBm is achieved with an 800 MHz LO drive of +15 dBm and the RF input tones at 1 and 1.005 GHz. The conversion gain

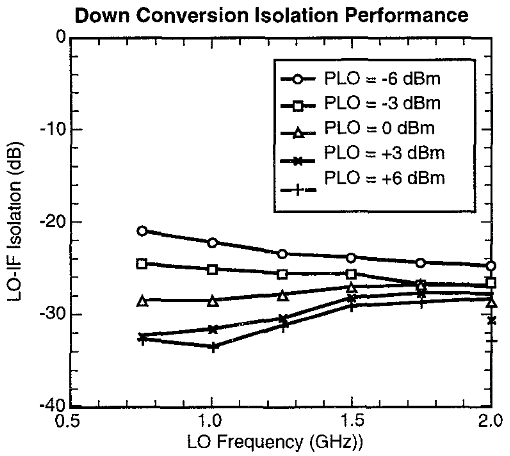

Fig. 6 LO-IF isolation for various LO drive levels.

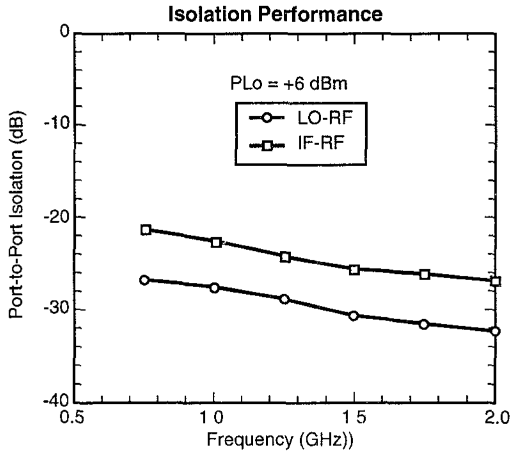

Fig. 7 LO-RF and IF-RF isolation performance.

is 6 dB and the associated input IP3 is - 6 dBm. At a slightly lower LO drive level of +6 dBm, the input IP3 was measured to be -14 dBm.

Conclusion

A novel HBT active balun transformer has been integrated with GaAs Schottky diodes to realize a miniature double-balanced Schottky mixer MMIC which achieves positive conversion gain and multi-decade bandwidth performance from baseband to microwave frequencies. The HBT active balanced topology is useful for mixer applications where low voltage operation and broadband balanced performance is required.

References

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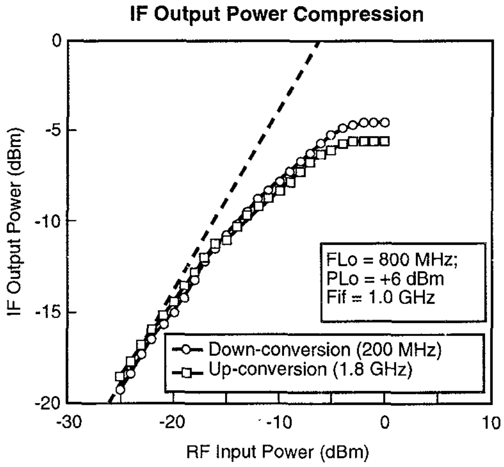

Fig. 8 IF output power compression characteristics versus RF input power.

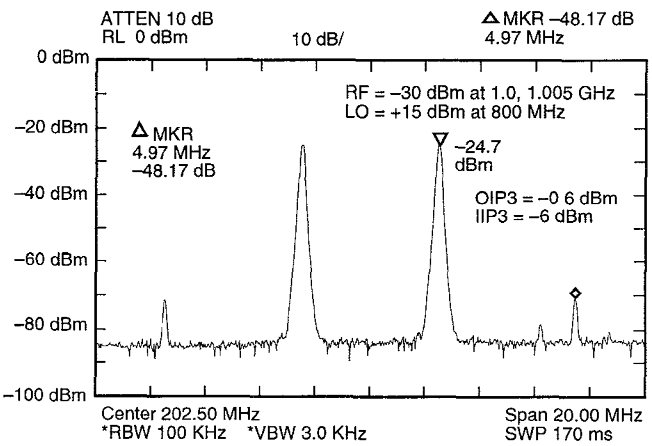

Fig. 9 Frequency spectrum of the two-tone IP3 measurement of the mixer.