A Novel 12-24 GHz Broadband HBT Distributed Active Balanced Mixer

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ABSTRACT

Here we present a novel HBT distributed active balanced Schottky mixer design that demonstrates octave-band balanced frequency performance in a compact 3x3.9 mm2 MMIC while operating with a reduced LO power of +9 dBm. The MMIC mixer features a unique HBT distributed active balun design which employs a novel HBT active IF center-tap combiner that provides gain and also functions as an active load termination for the distributed LO and RF baluns. High performance vertical Schottky diodes made from the existing HBT epitaxy comprise the active mixer device. The HBT active balanced Schottky mixer achieves 8-12 dB conversion loss over a simultaneously swept 12-24 GHz RF and LO octave input band. An LO-IF isolation ≥ 20 dB, LO-RF isolation ≥ 30 dB, and 2-2 spur suppression of 24-30 dBc were also achieved across the band and are attributed to the excellent bipolar threshold and beta matching properties of the high speed 1μm GaAs HBTs (fT's=43 GHz). The new HBT distributed active balanced mixer design has potential use in wideband mixer applications such as direct-conversion receivers.

Introduction

Broadband distributed active balanced mixer approaches are attractive for consolidating balun, amplifier, and mixer functions into a miniature MMIC chip, as well as being capable of providing wider (multi-octave) bandwidth performance and lower LO drive requirements compared to conventional passive balanced mixers. Previous work on distributed baluns for broadband mixers have relied on CG-CS FET and dual-gate FET topologies [1], distributed FET amplifiers which utilize the gate termination as the non-inverting output [2], and more recently, a transversal active FET filter/mixer type approach[3]. In order to realize a monolithic mixer, these FET active baluns will typically be integrated with the *generic* planar FET Schottky diodes of the given FET technology for providing the nonlinear device mixing element.

However, it has been previously shown that Schottky diodes and Schottky-based mixers constructed from the vertical epitaxy layers of MBE grown GaAs HBTs possess better device and circuit performance characteristics than planar FET-based Schottky diode devices and mixers [4]. While this suggests that the vertical MBE-based HBT technology is better suited for fabricating high performance Schottky-based mixers, there has been no prior report on HBT distributed active balanced mixers.

In this work, we developed an HBT single-ended-to-differential distributed amplifier topology to provide broadband RF and LO balun functions and is unlike those demonstrated with FET technologies [1], [2], [3]. Although an HBT distributed differential amplifier has already been previously demonstrated for wideband optical modulator applications[5], our work is believed to be the first application of an HBT distributed differential amplifier-type topology for broadband actively balanced Schottky mixer applications. In addition, our balanced mixer features a novel HBT active IF center-tap combiner which functions as the active load terminations of the distributed network in addition to providing IF combining, amplification, and LO and RF cancellation at the IF output.

1 μm GaAs HBT-Schottky Technology

The HBT-Schottky mixer was fabricated using a 1 μm emitter width Self-Aligned Base Ohmic Metal (SABM) HBT device process illustrated in Fig. 1. The HBT MBE profile is similar to that described for our 2-μm SABM GaAs HBT process [4], except for the use of a thinner base structure in order to obtain higher device gain to support the broadband distributed active balun design. The resulting fabricated 1 μm GaAs HBTs with the thin base material obtain a typical f_T and f_{max} of 43 GHz and 65 GHz, respectively, while achieving high uniform dc betas > 200. The excellent device beta and threshold match are critical to the balance performance of the distributed differential active balun designs.

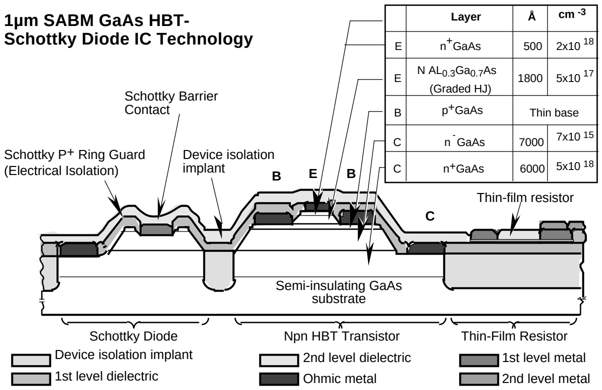

Fig. 1 Cross section of the integrated 1 μm GaAs HBT-Schottky IC technology.

Utilizing the same HBT MBE material, low parasitic vertical Schottky diodes are also fabricated with little additional processing steps, see Fig. 1. The Schottky diode structure is made by wet-chemical etching the emitter and base material away to get to the n^- collector material. A p^+ guard-ring made from the base material is left which surrounds the Schottky diode. This p^+ guardring electrically isolates the Schottky diode and reduces the reverse bias leakage current. The etch continues into the n^- collector region. The Schottky contact is made by evaporating Ti/Pt/Au. The resulting Schottky diodes have ideality factors of nearly 1.0 and a cut-off frequency as high as 1 THz.

HBT Distributed Active Balanced Schottky Mixer Design

Fig. 2 shows a block diagram of the HBT distributed active balanced Schottky diode mixer which includes a vertical Schottky diode ring-quad. The mixer integrates broadband 9-25 GHz RF and LO HBT distributed active baluns as well as HBT active IF center-tap combiners. Fig. 3 gives a detailed schematic of the HBT distributed active balun. Each of the four sections consists of an emitter coupled differential amplifier-type topology which provides the 0 and 180° complementary outputs that AC/DC drive the Schottky mixer. Contrary to its topological representation as a diff-amp, Q_1 functions as an inverting common-emitter amp while Q_2 functions as a non-inverting common-base amplifier whose base is AC grounded thru a capacitor. The input transmission line is terminated with a simple R-C network, while the complementary output lines are terminated with an R-C network which is in parallel with the base of an HBT transistor comprising the active IF combiner.

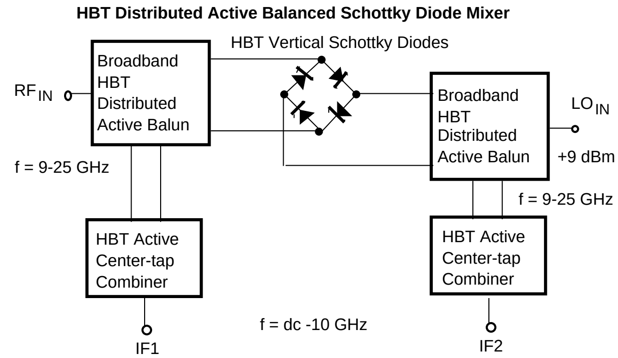

Fig. 2 Block diagram of the HBT distributed active balanced Schottky diode mixer.

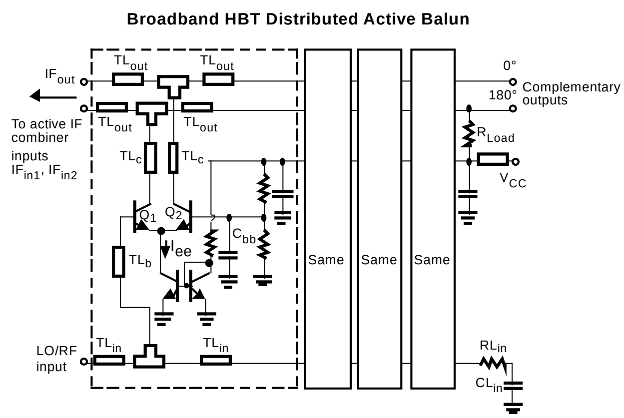

Fig. 3 Schematic of the HBT distributed active balun

<u>A unique feature of this work is the employment and operation of the HBT active IF center-tap combiner circuit</u> given in Fig. 4. The two in-phase IF signals presented at the input ports IF_{in1} and IF_{in2}, pass through the emitter followers Q_A and Q_D, respectively, which are amplified by common-base HBTs Q_B and Q_C and combined at their collectors through a common output load resistance, R_{IF}. Likewise, the out-of-phase complementary RF/LO signal presented at the combiner input ports is canceled at the combined IF output. The LO and RF suppression at the IF output will depend on the threshold and beta matching characteristics of the HBTs comprising the active circuits. HBTs are therefore <u>preferred</u> over a FET implementation using this topology. An attractive feature of this IF center tap combiner is that it is active and can be designed for high IF gain and dc IF output which is useful for direct-conversion receiver applications.

<u>Proper active balanced mixer operation:</u> Since the active baluns are directly coupled (i.e. no dc blocking capacitors) to the schottky diode ring-quad, the value of the load resistor must be

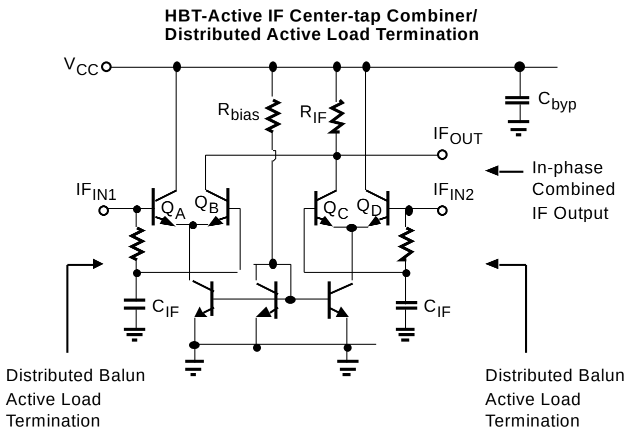

Fig. 4 Schematic of the HBT active IF center-tap combiner circuit

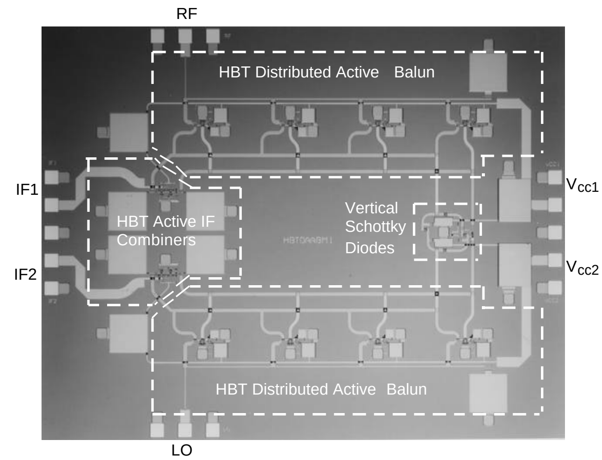

Fig. 5 Microphotograph of the fabricated HBT distributed active balanced Schottky mixer MMIC. The chip size is 3x3.9 mm^2

chosen such that the Schottky diode is properly "switched on" to achieve linear mixer action:

$$I_{Schottky} = \frac{N \cdot I_{ee}}{2} - \frac{V_{Schottky}}{R_{Load}} > 0$$

where N is the number of distributed sections, I_{ee} is the source current of each distributed section, $V_{schottky}$ is the turn-on voltage of the schottky diode, and R_{load} is the load resistor at the output of the distributed active baluns. The higher $I_{schottky}$, the better the mixer linearity and conversion gain.

Fig. 5 shows a microphotograph of the fabricated HBT distributed active balanced Schottky mixer MMIC. The RF and LO distributed active baluns are symmetrically layed out about the Schottky diode ring quad. Each RF/LO balun has its own active HBT IF center tap output. The total chip size is 3x3.9 mm^2 and is self-biased through 4.5 V while consuming ≈ 140 mA.

Measured Performance

Fig. 6 gives the broadband conversion loss, LO-IF isolation and 2-2 spur suppression of the active mixer for swept RF and LO from 5-25 GHz, an RF power of -10 dBm, an LO power of +9 dBm, and a fixed IF=200 MHz. The conversion loss is between 8-12 dB over a 12-24 GHz octave frequency band. The corresponding LO-IF isolation is > 20 dB while the 2-2 spur suppression is 24-30 dB and is typical of conventional passively balanced mixers. The good isolation and spur suppression of the mixer is an indication of the balanced device matching property of the HBTs comprising the active balun and IF center tap combiner circuits.

Fig. 7 gives the measured conversion loss as a function of LO power. The conversion loss reaches a minimum of 8 dB at an LO drive of +9 dBm which is ≈3-4 dBm lower than that required for conventional passive balanced mixers, and is due to the broadband gain provided by the LO active balun.

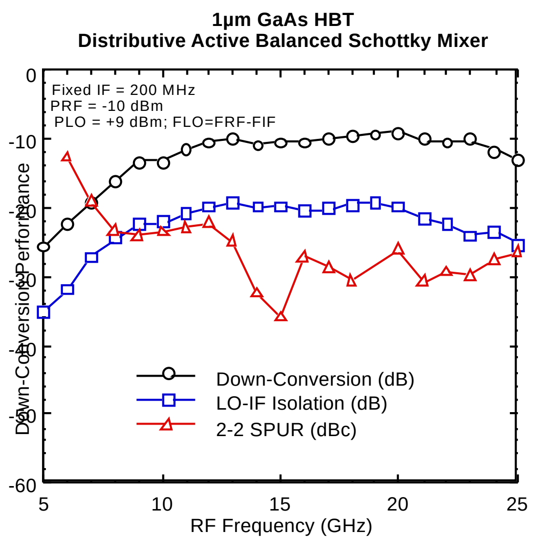

Fig. 6 Measured broadband conversion loss, LO-IF isolation and 2-2 spur suppression of the active mixer

Fig. 8 gives the measured conversion loss as a function of dc supply bias voltage. At a Vcc = 3.5V, 4.0V, and 4.5V, the total chip current is 89 mA, 114 mA, and 140 mA, respectively, and includes both RF and LO active baluns and their respective active IF center-tap combiners. The higher the dc voltage and bias of the active baluns, the higher the ac/dc $I_{schottky}$ current which is switched through Schottky diodes when an LO signal is applied. This will improve the conversion gain and linearity of the mixer. Because of time and resource restriction, the linearity performance has not yet been evaluated.

Fig. 9 gives the measured LO-RF isolation swept across the broad band with an LO input power of +9 dBm. The isolation is ≈30 dB or better across the octave band. High LO-RF isolation is a

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key mixer performance parameter for direct-conversion applications, since it is related to the amount of dc offset produced by the LO self mixing at the RF port. Because of the unilateral characteristics of three terminal devices, an active balun approach can offer enhanced LO-RF port isolation. It is left to future design work to investigate the potential improvement of this key performance parameter.

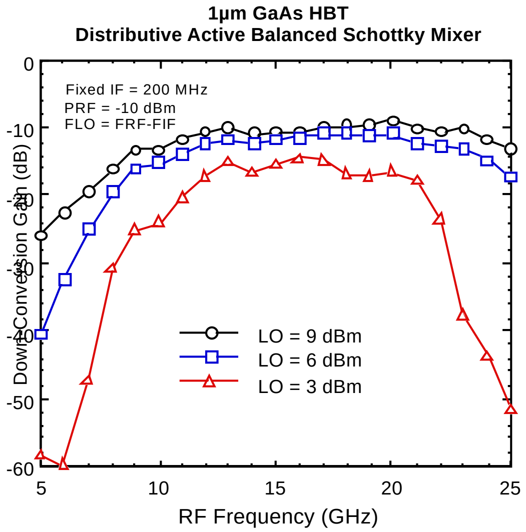

Fig. 7 Measured conversion loss for LO powers of +3, +6, and + 9 dBm

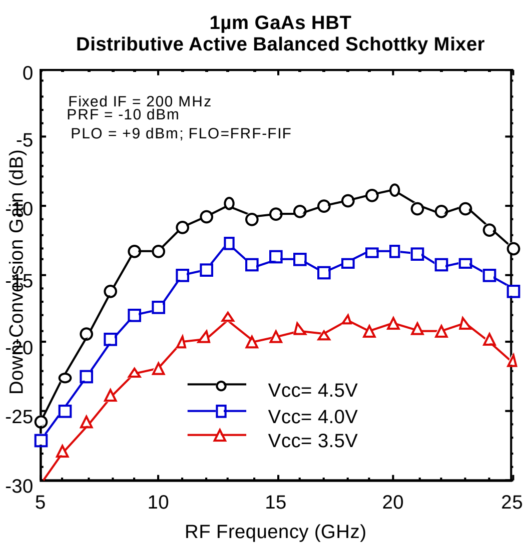

Fig. 8 Measured conversion loss for supply biases of 4.5V, 4.0V, and 3.5V

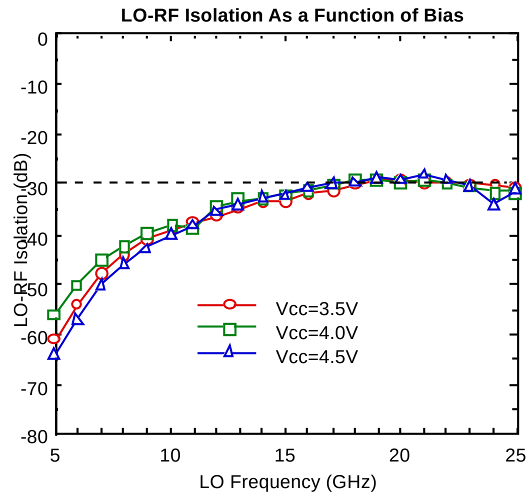

Fig. 9 Measured LO-RF isolation swept across the broadband with an LO input power of +9 dBm

Conclusion

The new HBT distributed active balanced mixer design topology presented here combines the best performance attributes of HBTs and Schottky diodes and has potential use in wideband mixer applications such as direct-conversion receivers. Future demonstration of this approach using InP based HBT technology which possesses higher f_{max} and lower turn-on voltage InGaAs Schottky diodes will result in substantially improved BW, higher conversion gain, and lower LO power requirement, while consuming less dc power.

Acknowledgment

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