A Novel 20 to 40 GHz Monolithic InGaP/GaAs HBT Double Balanced Mixer

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***Abstract* — This paper reports on a 20 to 40 GHz monolithic double-balanced mixer implemented using InGaP/GaAs HBT process The compact MMIC mixer makes use of a Gilbert-cell multiplier with broadband input matching networks to widen the bandwidth up to 20 GHz. Operated as a down-converter mixer, a measured conversion gain of 16 dB was achieved given an RF signal at 30 GHz, LO drive of 5 dBm and a down-converted baseband signal at 10 MHz. The mixer IP3 occurs at an output power of 4 dBm while the IP2 occurs at an output power of 11 dBm. The developed mixer presents an attractive building block for future high data rate systems employing direct-digital modulators/demodulators.**

I. Introduction

The use of direct down conversion techniques is a promising approach for highly integrated wireless receivers due to their potential for low power fully monolithic operation and extremely broad bandwidth [1]. However, the direct down-conversion from RF to the baseband entails several well-known drawbacks that should be taken into consideration when designing the mixer. These include, second order distortion and LO self-mixing. Direct-coupled balanced mixers are attractive for applications involving direct digital modulation/demodulation, as well as wide band reception and detection of high date rate digital signals. In these applications, direct coupled analog mixers, which posses excellent balance and high conversion gain over a multi-decade bandwidth, are typically preferred over RF diode balanced mixers that have substantial conversion loss [2].

In this paper a novel broadband monolithic direct conversion mixer is presented. The mixer makes use of *Gilbert* cell multiplier, and it integrates a direct-coupled baseband differential amplifier at its output. A simplified block diagram of the proposed 20-40 GHz *Gilbert* cell based direct conversion mixer is illustrated in Fig. 1, where the matching networks and baluns are also shown.

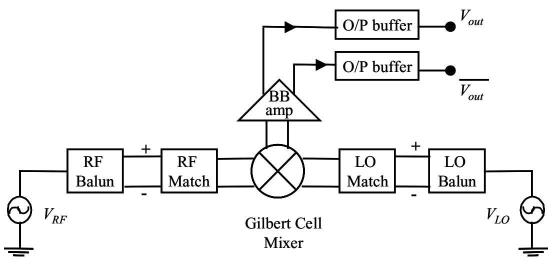

Fig. 1 block diagram of the 20 to 40 GHz Direct conversion mixer.

II. Mixer Design

A schematic of the proposed mixer circuit is shown in Fig. 2. As can be seen, the mixer integrates several passive and active components. First, a newly developed broadband monolithic passive balun [3] is used to provide the differential RF and LO signals required at the *Gilbert* cell inputs. The balun is implemented using a multi-layer dielectric structure, and achieves better than 3.5° and 0.8 dB of phase and amplitude imbalance over a frequency band from 15 to 45 GHz Next, a *Gilbert* cell multiplier is used to obtain the mixing action required while achieving conversion gain and intrinsic port-to-port isolation together with excellent intermodulation distortion suppression. Consequently, Gilbert cell multipliers are considered as strong candidates for direct conversion mixers. As can be noticed from Fig. 2 a departure from the conventional *Gilbert* cell design was done by eliminating the customary constant current source, and hence reducing the number of active devices and the supply voltages used. Without this source, the differential RF input transistors (Q_1 and Q_2) serve a dual role: one is establishing the DC operating current and the other is the RF switching portion of the mixer [4]. However, this arrangement will come at the expense of increasing the common mode gain. Therefore, the RF balun must be designed to efficiently provide the RF differential signals requited at the Gilbert cell input with minimum phase and amplitude mismatch. A compact balanced wideband matching networks is used. It consists of a resistor in series with an inductor, which are used to match the balun output impendence to the RF, and LO inputs of the *Gilbert* cell over a wide frequency band from 20 to 40 GHz.

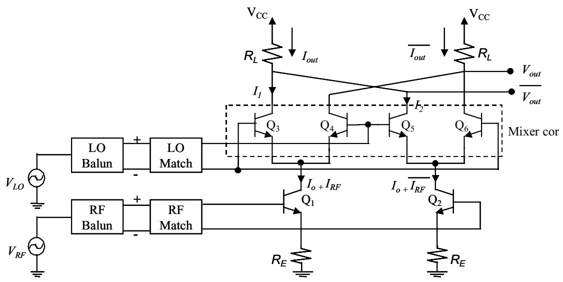

Fig. 2 Double balanced mixer schematic

The mixer integrates at its output a direct-coupled baseband differential amplifier and an output buffer stage. A detailed schematic of the output differential amplifier and the buffer stage is shown in Fig. 3. As can be seen the down converted baseband signal is directly fed to the bases of the differential amplifier. Since the mixer is designed to be used with high data rate direct digital demodulators. The amplifier was designed to offer a uniform differential gain of 13 dB over a wideband from DC up to 1 GHz. Also the high common mode rejection ratio (CMRR) offered by the amplifier will help eliminate the common mode signal that might result due to possible mismatch in the differential signal fed by the balun to the Gilbert cell. Finally, a buffer stage is used to connect the high impedance output of the differential amplifier to the output load impedance (Z_{load} = 50 Ω). The buffer stage is composed of a simple transistor connected in an emitter follower configuration. To match the low output impedance of the emitter follower to the output load (Z_{load}), a series resistor (R_{buffer}) is connected to the emitters of the buffer transistors as shown in Fig. 3.

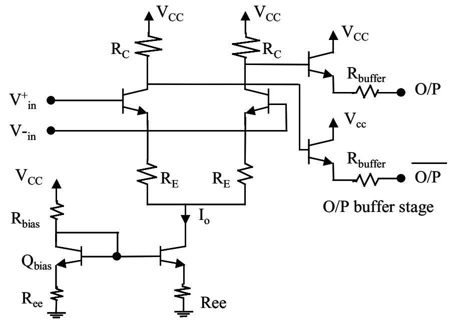

Fig. 3 Detailed schematic of the output differential amplifier and buffer stage

The mixer was implemented and fabricated using the NORTEL InGaP/GaAs HBT process. Generally, HBT's are characterized by their high transconductance, large current drive, and low *1/f* noise and hence they have strong potential for these types of circuits. The transistors were laid out such that an array of four HBT transistors of size 2x5 μm^2, were cascaded to form one transistor that is used in the differential pair of the *Gilbert* cell and the output amplifier. The substrate thickness was 200 μm and the mixer circuit was implemented monolithically using a CPW based structure. A photograph of the fabricated MMIC mixer chip is shown in Fig. 4. The mixer along with the probe pads measures 3.5x1.5 mm^2.

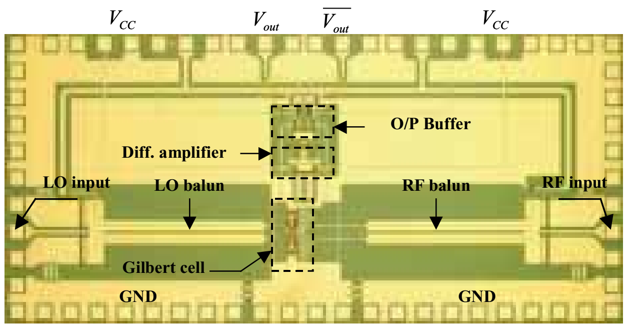

Fig. 4 Photograph of the fabricated MMIC direct conversion mixer chip (3.5x1.5 mm2)

III. Experimental Results

The measured return losses looking at the RF, LO and IF ports of the direct conversion mixer are all shown in Fig. 5, As can be noticed from the figures a return loss better than 10 dB over the frequency band from 20 to 40 GHz has been achieved for both the RF and LO ports of the mixer, which demonstrates the broadband performance of the designed matching networks. The match at the baseband output port is also better than 10 dB from DC up to 5 GHz.

The measured and simulated conversion gain plotted as a function of the input RF power is shown in Fig 6. As noticed from the figure, a measured conversion gain of 16 dB is achieved for a 30 GHz input signal down-converted to the baseband using 5 dBm of LO power. The 1 dB gain compression point occurs at –15 dBm of input RF power. The difference between the measured and simulated conversion gain results from the variation between the fabricated transistor parameters and the model used in the simulation.

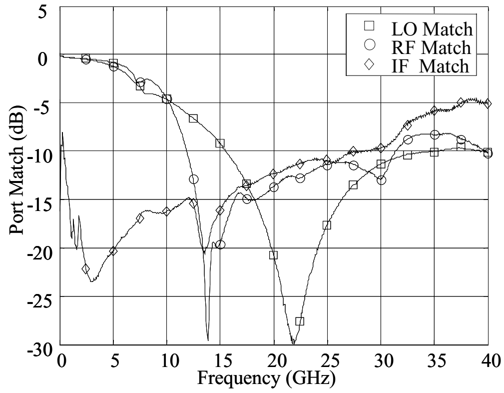

Fig. 5 Measured return loss for the RF, LO and IF ports of the mixer

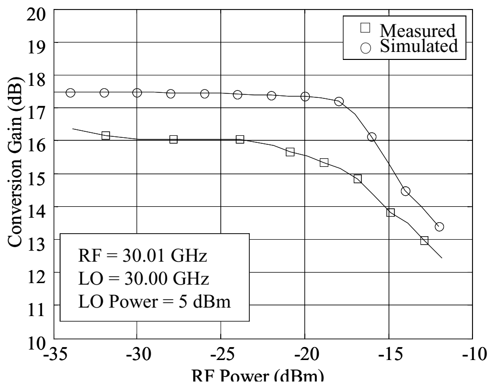

Fig. 6 Measured and simulated conversion gain Vs input RF Power

To examine the mixer intermodualtion distortion performance, two closely spaced RF signals at 29.999 GHz and 30.001 GHz ($\Delta f = 2$ MHz) having the same power are fed to the RF port of the mixer, and a 30 GHz LO signal at 5 dBm inputted to the LO port. A plot of the linear output power and its second and third intermodualtion products versus the RF input power is shown in Fig. 7. It can be noticed from the figure that the measured third order intercept point (IP3) occurs at 4 dBm of output power. The second order intermodulation level, which is vital in the case of direct conversion mixers, is low in the actual input region with the second order intercept point (IP2) occurring at 11 dBm of output power.

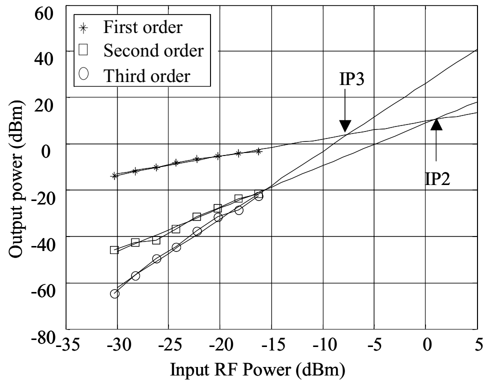

Fig. 7 Mixer measured intermodulation distortion

IV. Conclusion

A novel broadband monolithic direct conversion mixer has been designed, simulated and measured. The newly developed mixer achieved port matching better than 10 dB for both the RF and LO ports over a wide frequency band from 20 to 40 GHz. A conversion gain of 16 dB given 5 dBm of LO with a second order intercept point occurring at 11 dBm of output power was also measured. The new mixer is an attractive building block for future high data rate systems employing direct digital modulation and demodulation, millimeter wave digital radio, and fiber optic communications.

References

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