A Passive X-Band Double Balanced Mixer Utilizing Diode Connected SiGe HBTs

Michaelsen, Rasmus Schandorph; Johansen, Tom Keinicke; Tamborg, Kjeld; Zhurbenko, Vitaliy

Published in: Proceedings of the 8th European Microwave Integrated Circuits Conference

Publication date: 2013

A Passive X-Band Double Balanced Mixer
Utilizing Diode Connected SiGe HBTs

Rasmus Michaelsen\textsuperscript{1,2}, Tom Johansen\textsuperscript{1}, Kjeld Tamborg\textsuperscript{2}, Vitaliy Zhurbenko\textsuperscript{1}
\textsuperscript{1}Technical University of Denmark, Department of Electrical Engineering
2800 Kongens Lyngby, Denmark
Email: rsmi@elektro.dtu.dk
\textsuperscript{2}Weibel Scientific A/S
3450 Allerød, Denmark

Abstract—In this paper, a passive double balanced mixer in SiGe HBT technology is presented. Due to lack of suitable passive mixing elements in the technology, the mixing elements are formed by diode connected HBTs. The mixer is optimized for use in doppler radars and is highly linear with 1 dB compression point above 12 dBm. The conversion gain at the center frequency of 8.5 GHz is -9.8 dB with an LO drive level of 15 dBm. The mixer is very broadband with 3 dB bandwidth from 7-12 GHz covering the entire X-band. The LO-IF and RF-IF isolation is better than 46 dB and 36 dB, respectively, in the entire band of operation.

Index Terms—Mixer, double balanced, MMIC, passive devices.

I. INTRODUCTION

Direct conversion receivers are used in Doppler radars for speed monitoring, vital signs detection, and measurements of ballistic targets. They can also be configured to implement a simple image rejection system. The key element in a direct conversion receiver is the mixer.

Mixers for direct conversion applications suffer from low frequency, 1/f, noise and leakage due to LO and RF being at the same frequency. Two fundamental types of direct conversion mixers exists, active and passive. Active mixers have the advantage of providing a conversion gain, whereas passive mixers have the advantage of higher linearity and less noise. Therefore, passive mixers provide a larger dynamic range, but at the cost of loss in the signal path.

In this paper a direct conversion mixer operating at X-band which has characteristics optimized for doppler radar applications, to be used for vital signs detection. These characteristics include, state-of-the-art linearity, reasonable conversion loss, and noise performance. To meet these requirements a double balanced passive mixer architecture is chosen. As the SiGe HBT process used for implementation do not offer suitable diodes for mixing, we use diode connected HBTs as in [1].

II. DESIGN

This section describes the design of the proposed double balanced ring diode mixer. The double balanced structure has the advantage of inherent isolation between all ports, good linearity and broadband operation [2]. These are all wanted characteristics for mixers to be used in doppler radars. The drawbacks are increased circuit complexity, higher LO-power requirement, and higher conversion loss. Diodes are desired for the implementation of low-noise mixers in direct conversion receivers. In many SiGe technologies there are no diodes available. Using the base-emitter junction of the high-speed HBTs available as a pn-junction diode [1], it is possible to have diodes in a SiGe technology. The design description is divided into three parts covering the design of the balun, the IF extraction and the mixer core. Figure 1 shows the complete mixer schematic, divided into corresponding parts.

A. Marchand balun

The balun of the double balanced mixer is implemented in a form of a lumped element Marchand balun. The Marchand balun is chosen due to its broadband properties. The lumped element implementation allows compact size and straightforward design for good phase and magnitude balance [3], [4]. The lumped element implementation uses offset broadside coupled spiral inductors together with capacitors to realize the coupled transmission lines, normally used in Marchand baluns. The schematic for the balun can be viewed as the part of Figure 1 labelled ‘LO balun w. IF ground’.

For any balun, perfect phase and magnitude match is obtained if [5]

\[ T_{\text{even}} = 0, \]  

where \( T_{\text{even}} \) is the even mode transmission coefficient. In [4] it is shown that this corresponds to the requirement that

\[ C_m = 2C_c \left( \frac{1}{k} - 1 \right), \]  

where \( C_c \) and \( k \) are the capacitive and inductive coupling respectively. Thus it is possible to obtain good phase and magnitude match by careful selection of \( C_m \), even though the coupling between the inductances is not as required for the standard Marchand balun.

The S-parameters for the balun alone is shown in Figure 2, where simulation results are compared to measurements. It is observed that there is good agreement, in general, between the simulation and experimental results, except for the \( S_{11} \) curve where an additional resonance behavior is observed in the experimental results. At the design frequency a loss of 2.5 dB was measured. The rather high loss is mainly due...
to the low Q-factor of the inductors. As desired the balun is broadband with a measured 3 dB bandwidth of 6.4 GHz. Figures 3 and 4 shows the phase and magnitude imbalance, respectively. Excellent magnitude and phase imbalance of 0.11 dB and 0.7°, respectively, are achieved at the design frequency. A magnitude imbalance better than 0.4 dB and a phase imbalance better than 5°, achieved over the entire bandwidth, which makes this balun suitable for a double balanced mixer application.

**B. IF extraction**

To get an output signal from the mixer it is necessary to have a circuit which allows to extract the IF signal, without disturbing the LO and RF baluns. The IF extraction is achieved by making a low frequency ground at either the LO or RF port and extract the signal from the other. It is desirable not to have any large signal leaking out of the IF port as this might saturate or cause other unwanted effects in the low frequency circuitry following the mixer. For this reason it is chosen to use the balun at the LO port to make the low frequency ground connection and the balun at the RF port to extract the IF signal, as the LO-signal can be several magnitudes larger than the RF signal.

Due to the low IF frequency of the mixer together with the grounded parts of the Marchand balun, the IF extraction is quite simple and follows the idea from [6]. The schematic for the IF extraction is the part of Figure 1 labelled ‘RF balun w. IF extraction’. The low frequency grounding is ensured by the Marchand balun as the inductors \( L_s \) are seen as a
short. To avoid this short in the RF balun it is blocked by large capacitors which creates an open for the IF signal and a short for the RF signal. It is important to make the IF extraction symmetric as any asymmetry will affect the balun performance. To ensure the symmetry the capacitor $C_{IF}$ is split into three parallel 2 pF capacitors placed after both of the two inductors and in the middle where the IF signal is combined. The small influence on the balun performance from the 2 pF capacitors, can be compensated by slightly changing $C_s^2$ for matching and $C_m^2$ for balance.

C. Mixer core

The mixer core consists of the mixing elements and a matching circuit. Each mixing element consists of a diode connected HBTs. There are two possible ways to make the diode, either use the base-emitter or the base-collector pn-junction. The base-emitter junction is the preferred diode junction due to the heavier doping of the n-region of the emitter compared to the collector. Simulations also shows that this gives the best behavior having a 3 dB difference between the two diode connections. To get the double balanced properties the ring mixer structure is used [2].

Using Harmonic Balance simulations the optimum load conditions are found to be $58+j106\,\Omega$ and $50+j122\,\Omega$ for the LO and the RF ports, respectively. With a conversion gain of $-8.7\,\text{dB}$, 1 dB compression point of 8 dB and IIP2 of 53 dBm. As a $50\,\Omega$ match is required it is relatively simple to tune out the reactive part using single series inductors, $L_{RF}$ and $L_{LO}$. In Figure 1 the schematic of the mixer core is labelled 'Mixer core w. matching'.

The mixer has been manufactured using a $0.25\mu m$ SiGe process. The die size is $2200\mu m \times 800\mu m$. A microphotograph of the full mixer is shown in Figure 5.

III. EXPERIMENTAL RESULTS

In this section, the experimental results are discussed. The measurements are made on-wafer using a probe station and simple calibration is used to remove losses in cables and probes. The IF-frequency for all measurements is 100 MHz. The mixer conversion loss and single sideband noise figure is shown in Figure 6 as a function of frequency, with a fixed LO power of 15 dBm. At the design frequency of 8.5 GHz the conversion loss is 9.8 dB. The noise figure follows the conversion loss as is expected. Due to measurement inaccuracy the noise figure is at some points lower than the conversion loss. The 3 dB bandwidth covers more than the entire X-band or more precisely the range from 7 GHz to 12 GHz, thus showing the benefit of using a broadband balun design together with the double balanced topology.

In Figure 7 the conversion loss and noise figure is plotted versus the LO power level, at the design frequency of 8.5 GHz. It is seen that the mixer is not fully saturated at an LO power of 15 dBm which was the limit of the measurement equipment used.

To measure the linearity the IF power is measured as a function of the RF power, which is plotted in Figure 8. Due to equipment limitations the measurement was not made with a RF power above 12 dBm. At this point there is a compression of 0.8 dB measured. The 1 dB compression point must therefore be well above 12 dBm. This proves that the design gives a high linearity as required.

The LO-IF and RF-IF isolation at the design frequency are 55 dB and 40 dB, respectively. In Figure 9 the isolation is plotted versus frequency. In the entire band of operation the LO-IF and RF-IF isolation is better than 46 dB and 36 dB, respectively. A comparison between this work and passive mixers recently reported in the open literature is presented.
in Table I.

IV. CONCLUSION

The design of a passive double balanced mixer in a 0.25 μm SiGe HBT technology has been presented. The mixer is a direct conversion mixer suitable for use in doppler radars for vital signs detection. The passive mixing element consists of diode-connected HBTs, using the base-emitter pn-junction to realize the mixing diodes. Lumped element Marchand baluns were implemented using offset broadside coupled spiral inductors and capacitors. This gives the possibility of an elegant IF-extraction together with wide bandwidth and good balance.

The broadband mixer has a 3 dB bandwidth from 7 - 12 GHz, covering the entire X-band, with a conversion loss of 9.8 dB at the design frequency. It requires a relatively high LO level of 15 dBm for best performance, but has a high linearity with a 1 dB compression point over 12 dB. Good isolation between LO-IF and RF-IF ports of 55 dB and 40 dB, respectively, is ensured due to the good balance of the Marchand baluns.

V. ACKNOWLEDGMENT

The authors would like to thank the H.C. Ørsted Foundation for financial support to cover the cost of chip fabrication.

REFERENCES


