A 1.9GHz Double-Balanced Subharmonic Mixer for Direct Conversion Receivers

Kiran Nimmagadda and Gabriel M. Rebeiz
Radiation Lab, EECS Department, The University of Michigan, Ann Arbor, MI 48109-2122
kirann@umich.edu, rebeiz@umich.edu

Abstract—**This paper presents a 1.9 GHz Double-Balanced Subharmonic Mixer for wireless communications applications. The mixer is fabricated in a 0.35μm BiCMOS process. The conversion gain of the subharmonic mixer at an RF input of 1.6-1.9 GHz with an LO input at 750-900 MHz is 9.5-7.5 dB. The mixer has a measured IIP3 of -3 dBm and an input 1 dB compression point of -10 dBm at 1.9 GHz. The measured SSB noise figure is 9.5-10.5 dB at 1.9 GHz. The mixer core consumes 8 mA of current and the LO buffers consume 7 mA of current from a 3 V power supply. The application areas are in direct conversion transceivers for wireless systems.**

I. Introduction

There is currently a great amount of activity in realizing low-cost Si-based transceivers for wireless communications. A double balanced Gilbert cell mixer is routinely used in most transceivers today where high LO (local oscillator) to RF isolation and high LO/RF suppression at the IF port is needed. For direct conversion transceiver applications, the Gilbert cell mixer suffers from LO self mixing problem due to LO leakage to the RF port, thus creating a variable DC offset at the IF output. One solution is to use an LO frequency doubler in front of the double-balanced mixer [1]. Another solution is to use a subharmonic mixer as presented in [2]. The implementation in [2] uses three levels of transistors and a quadrature LO to perform subharmonic mixing. In this paper, a modified form of the Gilbert cell mixer called the subharmonic double balanced mixer (SDBM) is presented. The SDBM has *two levels* of transistors and requires an LO signal at half the frequency of the RF signal. The basic operation, design, measurement results and applications of a 1.9 GHz design using a 0.35μm BiCMOS technology are presented in this paper.

II. Circuit Topology

A simplified schematic of the double-balanced Gilbert cell mixer is shown in Fig. 1. A modification made in this circuit is the reversal of the traditional RF and LO ports, the reason for which will become apparent once the SDBM circuit is described. In this double-balanced mixer topology, it is observed that the currents I_1 and I_2 switch at the rate of the LO frequency and are 180° out of phase. These currents are fed to the RF section, and the mixing between the RF and LO frequencies occurs in the current domain.

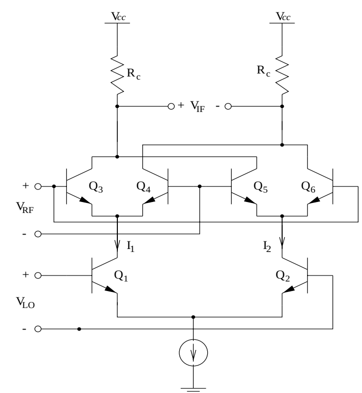

Fig. 1. Simplified schematic of the double-balanced Gilbert cell mixer.

For a subharmonic mixer, the mixing needs to occur between the RF frequency and *twice* the LO frequency. So, if one can generate I_1 and I_2 which switch at twice the LO frequency and which are 180° out of phase, subharmonic double balanced mixing is possible. The novel circuit topology shown in Fig. 2 implements this function precisely. It should be noted that there are two LO ports with each port driven by a differential (0-180°) voltage, and the LO input at one port is 90° out of phase with the LO input at the other port.

The frequency doubling operation can be better understood by taking a closer look at the collector currents in the transistors in the LO section of the mixer (Fig. 3). Notice the 0, 180, 90, 270° phase of the four collector currents i_c(Q1), i_c(Q2), i_c(Q3) and i_c(Q4) respectively. The current I_1, which is the sum of the collector currents in Q1 and Q2, is switching at twice the LO frequency. In a similar fashion, the current I_2, which is the sum of the collector currents in Q3 and Q4, is also switching at twice the LO frequency. The LO signal, applied differentially to the bases of Q3 and Q4, is 90° out of phase with the the LO signal applied to Q1 and Q2. As a result, the current I_2 is 180° out of phase

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

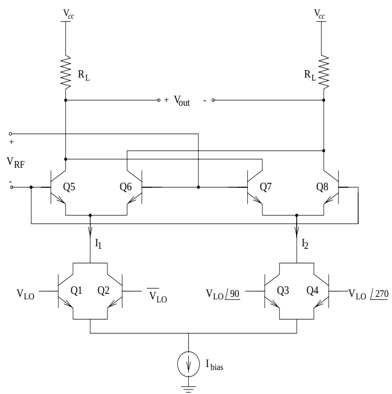

Fig. 2. Simplified schematic of the novel Subharmonic Double-Balanced Mixer (SDBM).

with respect to current I_1 due to the frequency doubling effect. With I_1 and I_2 going into the RF section 180° out of phase, double balanced mixing occurs and with I_1 and I_2 switching at twice the LO frequency, and subharmonic double balanced mixing is achieved.

The circuit uses only two levels of transistors and therefore can be driven using low voltage power supplies (down to 1-1.5 V). Also, it can be implemented using CMOS transistors for low power operation.

III. Circuit Design

A 1.9 GHz SDBM design which includes the mixer core, a polyphase filter for quadrature LO generation and LO buffers was designed using the Conexant 0.35μm BiCMOS process. The overall schematic of the design is shown in Fig. 4. The RF input is at 1.9 GHz and the LO input is at 900 MHz resulting in an IF output at 100 MHz.

A simplified schematic of the first stage of the LO buffer, polyphase filter and the second stage of LO buffers is shown in Fig. 5. The outputs of the polyphase filter are amplified by differential amplifier limiting stages before being fed to the two LO ports of the mixer. The LO drive at the mixer was chosen to optimize the dynamic range and is around 500 mV_{pk}.

The polyphase filter outputs have phase and amplitude variation with LO input frequency. Nevertheless, the two differential LO quadrature signals maintain a 90° phase difference over a wide bandwidth.

A simplified schematic of the subharmonic double balanced mixer core is shown in Fig. 6. Inductive degeneration in the RF section is used to improve the linearity of the mixer and to also improve the input matching. There is a limit to which the RF section can be degenerated, since beyond a 2 nH inductance, the mixer gain degrades

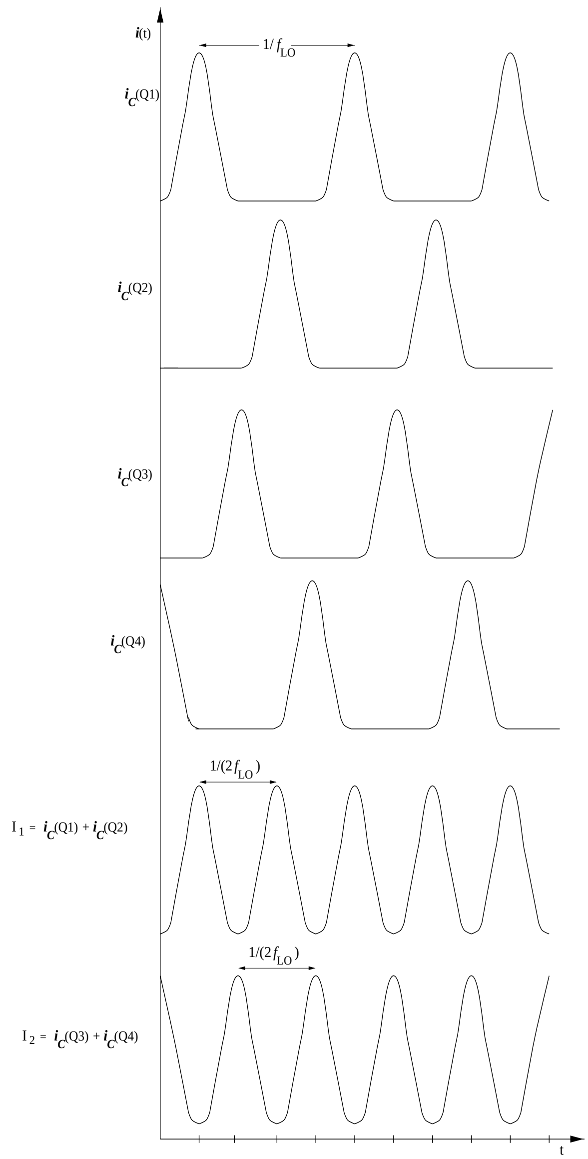

Fig. 3. Collector currents in LO section, which show the frequency doubling.

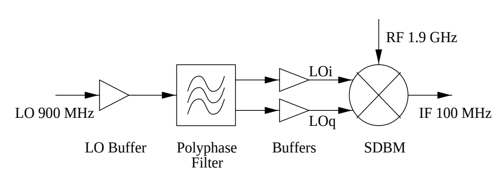

Fig. 4. Schematic of the 1.9 GHz Subharmonic Double-Balanced Mixer (SDBM) circuit

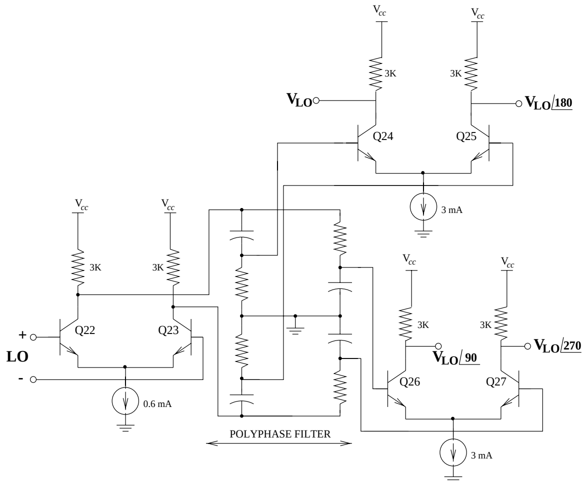

Fig. 5. LO buffer and polyphase filter circuit

severely with increasing degeneration inductance. An external matching network is assumed to provide a 50 Ω input impedance at the RF port of the mixer.

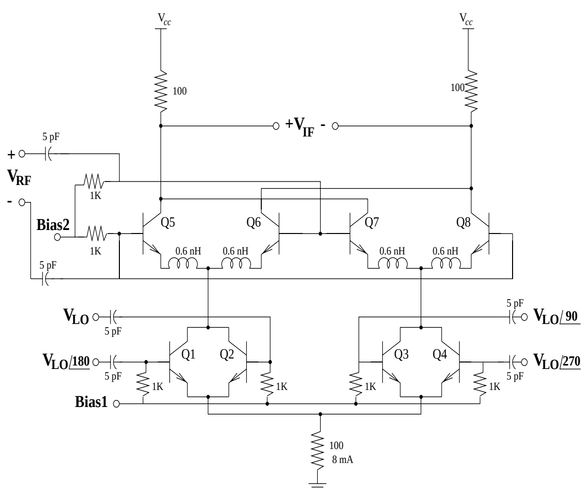

Fig. 6. Subharmonic Double-Balanced Mixer (SDBM) schematic

In order to keep the design simple, 100 Ω resistive loads are used at the collectors of Q5/Q6 and Q7/Q8. Also, for low-voltage operation with V_{cc}=3 V, a 100 Ω resistor is used for biasing instead of an active current source. The DC voltage at node Bias1 is designed to be a PTAT (proportional to absolute temperature) voltage so as to keep the input impedance of the RF port stable with respect to temperature variations [1]. This bias voltage is derived from a basic PTAT current source and sets the current flowing through the mixer core at 8mA.

IV. Measurement Results

The fabricated die was mounted on a test board and the layout is shown in Fig. 7. The RF and LO differential ports on the die are probed using a differential probe which includes a balun to convert from differential mode to single ended coaxial mode. DC block capacitors are also integrated into the probe [3]. The IF, VCC and GND pads on the die were wire-bonded to coplanar striplines on the test board.

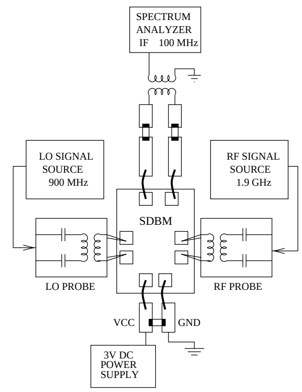

Fig. 7. Layout of the test board for measurements

Fig. 8 shows a photomicrograph of the chip under test.

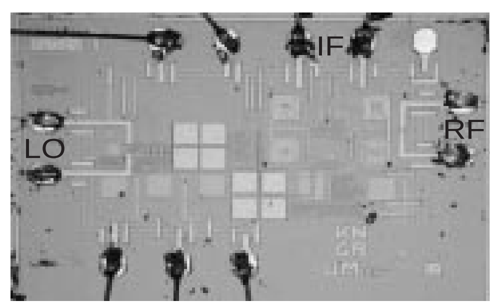

Fig. 8. Photomicrograph of the SDBM chip

Fig. 9 shows the mixer power gain versus RF input freqeuncy with the LO input frequency at 900 MHz and, an LO input power of 0 dBm into the mismatched LO port (LO port was not externally matched). The RF probe effects have been normalized out of the measurements. A two tone test was performed to measure the input third order intermodulation point (IIP3) of the mixer. The two tones were at 1.89 GHz and 1.91 GHz resulting in fundamental tones at 90 MHz and 110 MHz, and third order intermods at 70 MHz and 130 MHz at the IF output. Fig. 10 shows the fundamental and intermod powers with respect to the two tone

TABLE I

SUMMARY OF MEASUREMENT RESULTS

Supply Voltage	3 V
Mixer Core Current	8 mA
LO Frequency	900 MHz
RF Frequency	1.9 GHz
Conversion Gain	7.5 dB
IIP3	-3 dBm
Input P_{-1dB}	-8 dBm
SSB Noise Figure	10 dB

input powers. Extrapolation of the two curves results in an IIP3 of -3 dBm. Fig. 11 shows a plot of the mixer gain at 1.9 GHz as the LO input power at 900 MHz is varied from -20 dBm to 0 dBm. The mixer has a measured double sideband noise figure of 7 dB $\pm$ 0.5 dB at an RF frequency of 1.9 GHz with the LO input power level of 0 dBm at 900 MHz. This translates to a single sideband noise figure of 10 dB $\pm$ 0.5 dB. The mixer operates well down to an input LO power (mismatched) of -12 dBm. The measured DC differential output level at the IF port with an LO input of 0 dBm and a mismatched RF port is about 10 μV. However, we need to do more measurements to accurately determine this value. The measurement results are summarised in Table I.

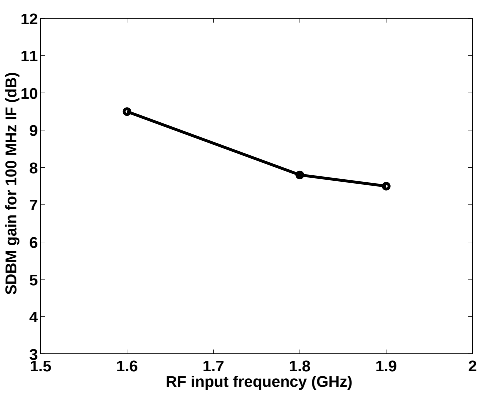

Fig. 9. SDBM measured gain versus the RF input frequency

V. CONCLUSION

This paper presented a novel double-balanced subharmonic mixer with an RF input at 1.6-1.9 GHz, an LO input at 750-900 MHz and an IF at 100 MHz. The mixer core consumes 8 mA of current, and has a measured power gain of 7.5 dB, an IIP3 of -3 dBm, a P_{1dB} of -8 dBm and a single sideband noise figure of 10dB at 1.9 GHz. The circuit is very compact and requires a two-level transistor topology,

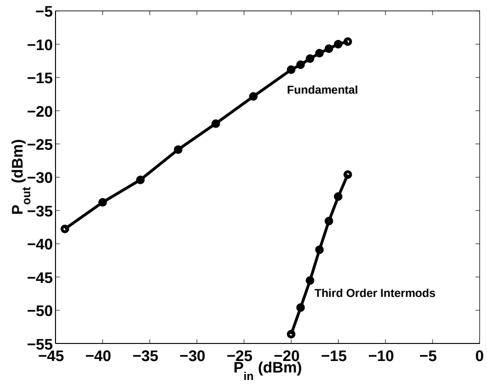

Fig. 10. Measured SDBM harmonic signature at 1.9 GHz RF input

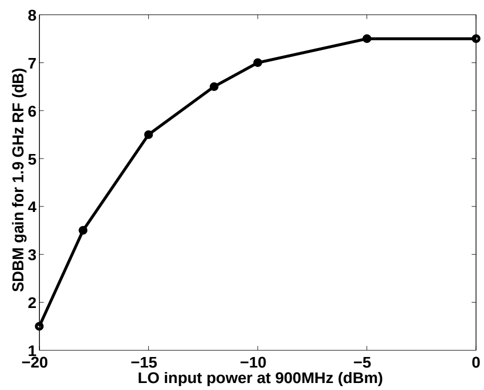

Fig. 11. Measured SDBM gain at 1.9 GHz RF input versus the LO input power at 900 MHz

and therefore can operate at very low power supply voltages (down to 1-1.5 V).

VI. ACKNOWLEDGEMENTS

The authors would like to thank the RFIC design group at Conexant, Newport Beach, CA for fabricating the circuit, with special thanks to Madhukar Reddy for his help at Conexant. This work is supported by the US-Army Low Power Electronics MURI Program at the University of Michigan.

REFERENCES

[1] R. G. Meyer, W. D. Mack and J. J. E. M. Hageraats, “A 2.5-GHz BiCMOS Transceiver for Wireless LAN’s”, *IEEE J. Solid-State Circuits*, vol. 32, pp. 2097-2104, Dec. 1997.

[2] L. Sheng, J. C. Jensen and L. E. Larson, “A wide-bandwidth Si/SiGe HBT direct conversion sub-harmonic mixer/downconverter”, *IEEE J. of Solid-State Circuits*, vol. 35, pp. 1329 -1337, Sept. 2000.

[3] GGB Industries Inc, Picoprobe differential probes, http://www.picoprobe.com/diffprb.html