Grenze International Journal of Engineering and Technology, June Issue

Mixer Design for Global Navigation Satellite System

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***Abstract*—Global Navigation Satellite Systems (GNSS) is a satellite navigation system with global coverage. It refers to constellation of satellites that provide precise location and timing data to GNSS receivers via space signals. One of the critical components of the receiver is the mixer. The received Radio frequency (RF) signal after filtering and amplification is given to the mixer. The mixer at receiver downconverts to an Intermediate Frequency (IF) signal. This helps in the frequency band of interest to be moved down the spectrum so that the filter requirements and further processing on the signal become easy. The paper presents the designing of a Double Balanced (DB) mixer and an Inphase Quadrature (I/Q) mixer in 180 nm CMOS technology using Cadence Virtuoso SpectreRF. The mixers are to work in 1.8 V power supply, with 2.4 GHz RF signal and giving IF of 50 MHz. They are intended to have conversion gain > 5 dB, IP3 > -5 dBm, Noise figure< 20 dB.**

***Index Terms*— Down Converting Mixer, Double Balanced Mixers, Inphase-Quadrature mixer, Third Order Intercept Point, 1 dB Compression Point, Conversion Gain.**

I. INTRODUCTION

CMOS technology has been utilized in most of the digital and analog circuits such as microprocessor and data converter. The advancement in transistor scaling, down to nanometer size have significantly reduced the cost per transistor and give greater circuit performances. Focusing on wireless communication applications, Low Power (LP) consumption and Low Voltage (LV) requirement are another design issues, which limits the battery capacity especially for portable devices. In addition, by using LP and LV design technique, the weight and volume of the transceivers can be further reduced [1]. Mixers are the basic element in wireless communication systems. The basic operation of mixer is multiplication. A mixer has two inputs and one output. For a down converting mixer, the inputs are: incoming high frequency RF signal and local oscillator (LO) signal. The output is the intermediate (IF) or baseband signal. The reduced IF signal help to improve selectivity and gain. The figure below shows symbol of mixer with two inputs “input RF” and “LO signal” and output represented by “output F”. After the multiplication, the output contains both sum and difference of input frequencies. For down converting the signal, the designer selects the difference term. A filter is followed by a mixer to remove the unwanted frequency terms.

The mixer can be classified as active or passive mixers. Passive mixers use passive components. Active mixers contain active devices such as MOSFETS that is biased to amplify and perform voltage to current conversion. Gilbert cell mixers are an example of active mixer that is discussed in following section.

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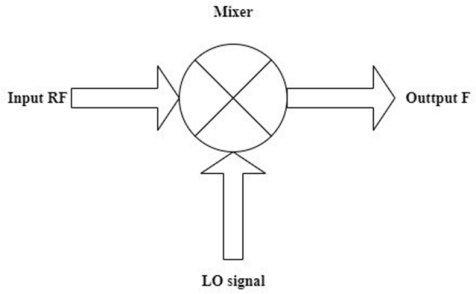

Fig. 1. Symbol of mixer

The different stages of mixers are the transconductance stage, switching stage and the I/V converter stage as shown in figure 2. A few important performance metrics of mixers are as following [2]:

1) **Conversion gain:** The voltage conversion gain is the ratio of output voltage to that of input. It is usually measured in decibels.
2) **Noise Figure:** It is defined as the ratio of signal to noise ratio of input to that of output.
3) **1 dB compression point:** This parameter defines the dynamic operating range of mixers. It is the value of input voltage where the output of the mixer falls by 1dB due to the non-linearity of the transistors. All the transistors must be backed off from this point.
4) **Third order intercept point:** Also called IP3 value, defines the signal handling capability of the mixer. It is the point at which both the fundamental output frequencies as well as the third order output frequency intersect. The point of intersection indicates that both the terms will have same power and can cause false output.

Depending on the way of giving the RF signals, the mixers are classified as Single Balanced (SB) or Double Balanced (DB) mixers. When the RF input is given to a single transistor, it is called Single Balanced mixer. Whereas when the RF input is given after splitting in its phase to two transistors, they are called Double Balanced mixer. This paper focuses on the DB mixer topology as it has better performance metrics than the SB mixer.

II. Proposed Design

B. Double Balanced Mixer

The mixer is based on Gilbert cell design. It comprises of 3 stages: the transconductance stage $M_{1,2}$, Local Oscillator (LO) stage M_{3to6} and load stage $R_{1,2}$ as shown in figure 3. The transistor M_0 is the tail transistor that act as constant current source.

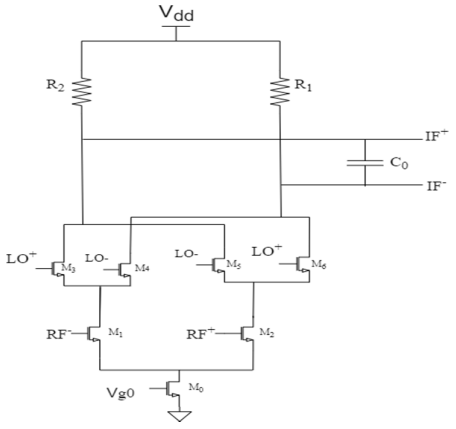

Fig. 2. Schematic of DB mixer

TABLE I. SPECIFICATION OF DB MIXER

Parameter	Values
Supply Voltage	1.8 V
Current	$\leq 3mA$
Output IF load	50 fF
RF frequency	2.4 GHz
LO frequency	2.35 GHz
IF frequency	50 MHz
RF power	-50 dBm
LO power	$\leq 10dBm$
Conversion gain	$\geq 5dB$
1 dB Compression point	$\geq -1dBm$
IIP3	$\geq 0dBm$

TABLE II. COMPONENT VALUES OF DB MIXER

Parameter	Values
Supply Voltage	1.8 V
RF power	-50 dBm
Total current	1.95 mA
DC biasing voltage of $M_{1,2}$	0.86 V
$(W/L)_0$	47/0.18 μm
$(W/L)_{1,2}$	40/0.18 μm
$(W/L)_{3,4,5,6}$	27/0.18 μm
$R_{1,2}$	1 KΩ
C_0	50 fF

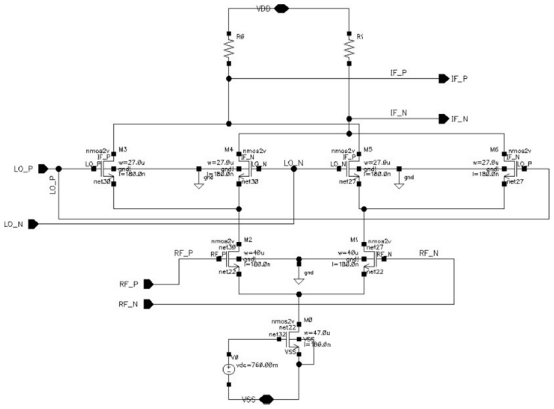

Fig. 3. Schematic of DB mixer in Cadence Virtuoso

$$V_{g0} = V_{th0} + V_{ov0} \quad (1)$$

Taking V_{th0}= 0.5 V and overdrive voltage V_{ov0}= 150 mV, the gate voltage of tail transistor is obtained as V_{g0}= 0.76 V. To make the transconductor stage to saturation, use equation (2).

$$V_{ds1,2} \geq V_{gs1,2} - V_{th1,2} + V_{ov1,2} \quad (2)$$

Substituting for $V_{ds1,2}$, threshold voltage, V_{th} = 0.5 V, and overdrive voltage V_{ov} = 200 mV in equation (2),

$$V_{gs1,2} = 0.86V \quad (3)$$

To bias the LO transistors, again use the equation (2) and substituting V_{ov3to6}=200 mV, $V_{th1,2}$=0.5 V,

$$V_{gs3to6} = 1.5V \quad (4)$$

To find the value of load resistor, substituting A_v= 5dB and g_{m1}=9.48 mS in equation (5),

$$A_v = \frac{2}{\pi} g_m R_L \quad (5)$$

$$R_L = 1K\Omega \quad (6)$$

The total current requirement through the mixer is fixed as 2 mA. To have this current through the tail transistor, the width of M_0 is fixed using the equation (7).

$$I_{ds} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{gs}-V_{th})^2 \quad (7)$$

where, $\mu_n C_{ox}$ is the process transconductance. Substituting values of current, I_{ds} =2 mA, L=180 nm, and threshold voltage as 0.5 V, the width of transistors are obtained as tabulated in table II. Using the component values, the schematic of the DB mixer is as shown in figure 4.

B. Inphase Quadrature (IQ) Mixer

From the developed DB mixer, an I/Q mixer is built. The block diagram of I/Q mixer is as shown in figure 5. It uses two identical mixers. The RF input is applied to both the mixers using a ideal balun. The LO signal is applied to both mixers with a quadrature phase shift. One of the mixer is given without any phase shift of LO and to the other a 90 degree phase shift is given. Thus the system provides an inphase IF output at the output of former mixer and a quadrature IF output at the output of the latter. By combining two DB mixer and feeding signals of opposite phase helps in filtering unwanted signals to greater extent.

The schematic of I/Q mixer is as shown in figure 5 in Cadence Virtuoso. The two mixers shown are the identical DB mixers. The IQ mixer should be developed with minimal gain and phase mismatches between the inphase and quadrature outputs. For minimal phase difference, ideal phase shift is used using simple DC ports with pulse signals. The requirements of the I/Q mixer is as in table III.

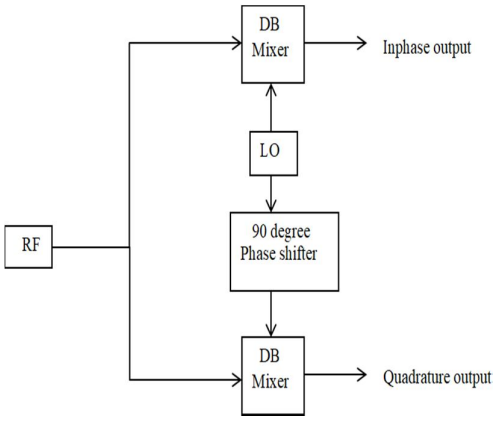

Fig. 4. Schematic of I/Q mixer in Cadence Virtuoso

TABLE III. SPECIFICATION OF IQ MIXER

Parameter	Values
Supply Voltage	1.8 V
Current	$\leq 3mA$
Output IF load	50 fF
RF frequency	2.4 GHz
LO frequency	2.35 GHz
IF frequency	50 MHz
RF power	-50 dBm
LO power	$\leq 10dB$
Conversion gain	$\geq 5dB$
1 dB Compression point	$\geq -1dBm$
Gain and phase mismatch	0 or minimum
IIP3	$\geq 0dBm$

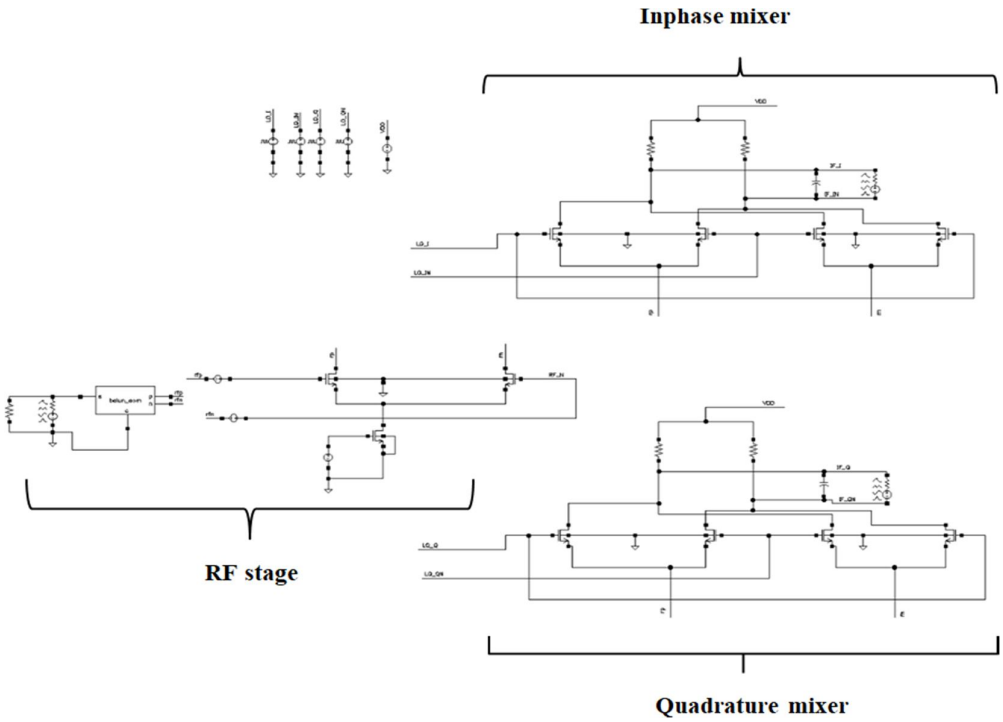

Fig. 5. Schematic of I/Q mixer in Cadence Virtuoso

III. RESULTS

The DB and I/Q mixer are simulated in 180 nm CMOS technology using TSMC library and results validated in Cadence Virtuoso SpectreRF. The performance metrics evaluated are the conversion gain, IP3, 1 dB compression point, and noise figure. Different analysis to find these performance metrics of the DB and I/Q mixer are plotted and shown in the below sections.

C. Double Balanced Mixer

The transient analysis are done and plotted as shown in figure 6 and 7. The gain w.r.t frequency is plotted is as shown in figure 8. The linearity of the mixer is decided by the IP3 and 1 dB compression point (P_{1dB}) values. IIP3 and P_{1dB} are found using harmonic balance (hb) analysis. They are plotted in figures 9 and 10. The noise figure is done using hb and hb-noise analysis. The obtained values after the simulation of the mixer are tabulated in table IV.

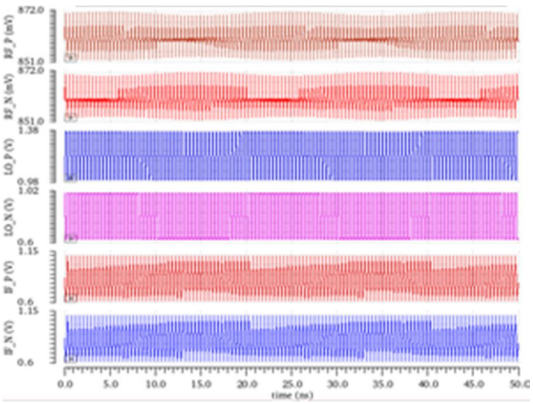

Fig. 6. Transient waveform of DB mixer

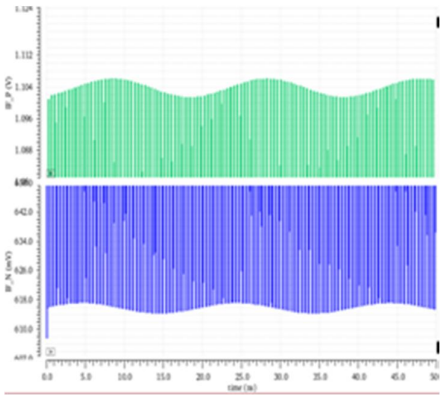

Fig. 7. Input third order intercept point of DB mixer

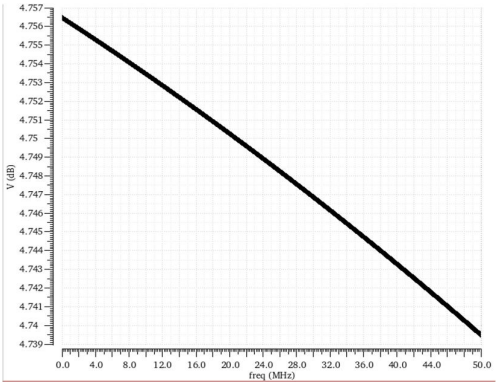

Fig. 8. Gain Vs frequency of DB mixer

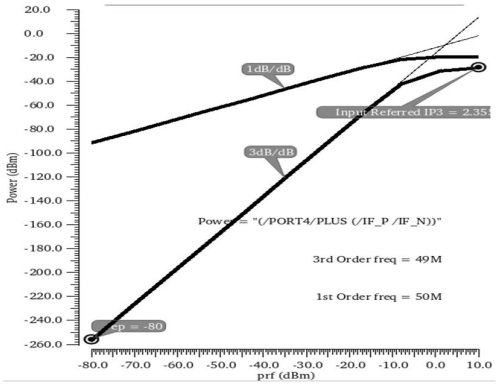

Fig. 9. Input third order intercept point of DB mixer

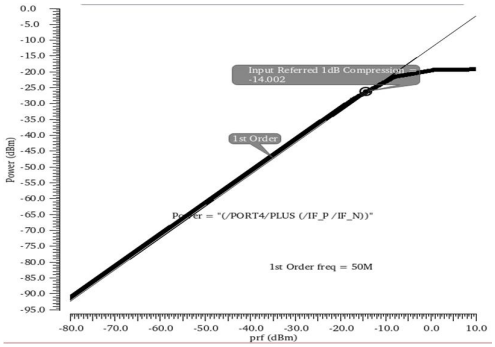

Table IV. PERFORMANCE SUMMARY OF IQ MIXER

Parameter	Values
Supply Voltage	1.8 V
Current	1.9 mA
RF frequency	2.4 GHz
LO frequency	2.35 GHz
IF frequency	50 MHz
RF power	-50 dBm
LO Voltage	520 mV
Conversion gain	4.75 dB
1 dB Compression point	-14 dBm
IIP3	2.25 dBm
NF	23.5 dB

D. IQ Mixer

The transient waveform is shown in figure 11. The IF signal is of 50 MHz. The gain of the inphase and quadrature port are plotted in figure 12. Following the same procedure of the DB mixer, the linearity performance of the I/Q topology is plotted using hb analysis.

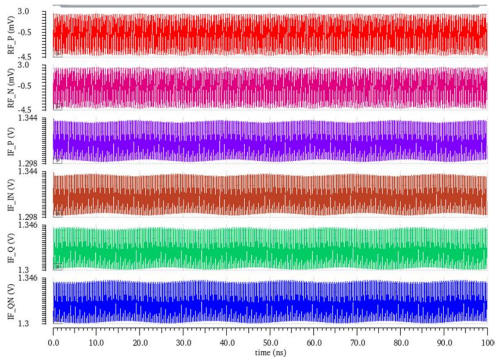

Fig. 11. Transient waveform of DB mixer

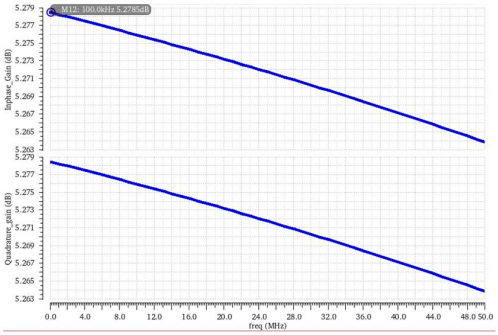

Fig. 12. Transient waveform of mixer

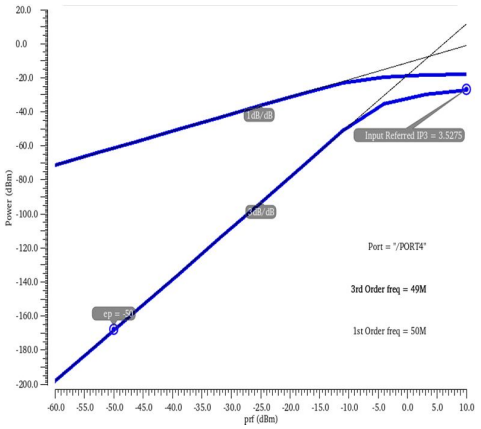

Fig. 13. IIP3 of quadrature port

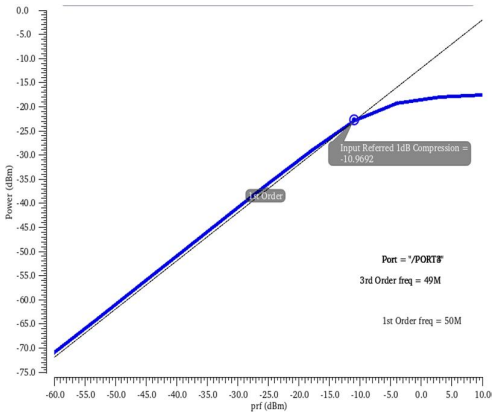

Fig. 14. 1 dB compression point of inphase port

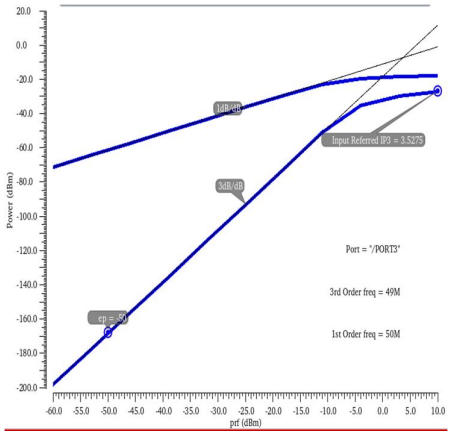

Fig. 15. IIP3 of quadrature port

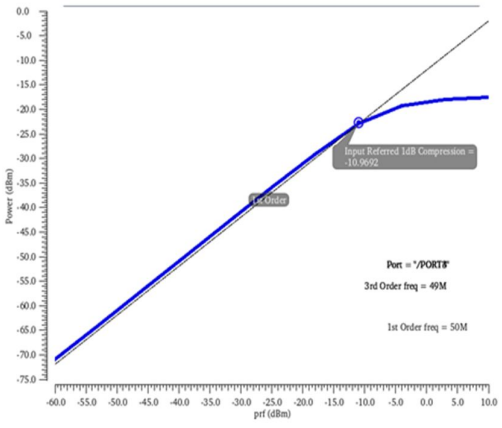

Fig. 16. 1 dB compression point of inphase port

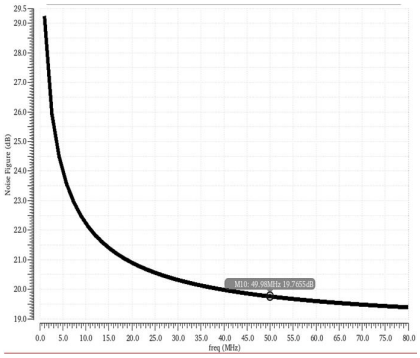

Fig. 17. Noise Figure of inphase port

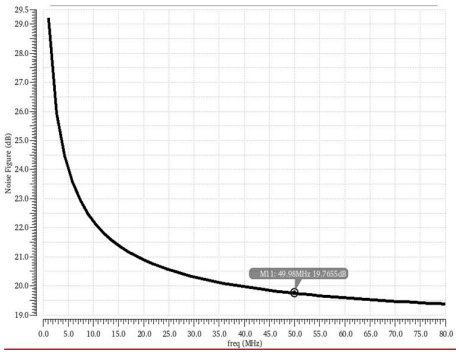

Fig. 18. Noise Figure of quadrature port

TABLE V. PERFORMANCE SUMMARY OF I/Q MIXER

Parameter	Values
Supply Voltage	1.8 V
Current	1.9 mA
Biasing voltage for RF	0.85 V
RF frequency	2.4 GHz
LO frequency	2.35 GHz
IF frequency	50 MHz
RF power	-50 dBm
LO power	1.2 V
Conversion gain of In-phase port	5.273 dB
Conversion gain of In-phase port	5.27 dB
P_1dB of inphase and quadrature port	-10.96 dBm
IIP3 of inphase and quadrature port	3.53 dBm
NF of inphase and quadrature port	19.7 dB

Figure 18 and 19 shows the IIP3 curve of inphase and quadrature port respectively is plotted as in figure 20 and 21 respectively. The noise figure of the inphase and quadrature port of the I/Q mixer is as shown in figure 22 and 23. The performance summary of the I/Q mixer is consolidated as in table V.

V. CONCLUSION

An active double balanced mixer followed by an I/Q mixer is been designed with specification shown in table II and III respectively and simulated using TSMC 180 nm CMOS technology using Cadence Virtuoso SpectreRF. The proposed I/Q mixer from the developed DB mixer exhibited performance metrics with minimal mismatches. The mixers exhibits better performance within 50 MHz IF signal.

ACKNOWLEDGMENT

The authors would like to thank Dr. Arun Ashok, Co-Founder and Director of Silizium Circuits, IIT-Hyderabad FabCI for sharing his pearls of wisdom and valuable guidance throughout the project and for the usage of the Cadence tool.

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