

A Study on the Design and Analysis of a Bulk-driven Gilbert Cell Downconversion Mixer

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Abstract

In this work, we have designed Gilbert cell downconversion mixer using 0.25um Anam CMOS process, we also have analyzed Conversion gain and IIP3 using Taylor series in our own unique way. Especially, bulk terminal is used as LO(Local Oscillator) input for reduction of power consumption and supply voltage. Supply voltage used in this design is lower than 1.8V and core current is less than 500uA. The simulation experiments showed that the conversion gain, IIP3, and power consumption were -1dB, 4.46dBm, and 0.8mW, respectively,

Keywords — Downconversion mixer, Gilbert Cell, conversion gain, IIP3, Bulk, Power Consumsuption.

1. Introduction

In a view of the production cost and the power consumption, it is preferable for wireless applications to realize the RF front ends circuits on a same chip as the digital signal processing circuits. The downconversion mixer is one of the indispensable RF blocks in communications receivers, A CMOS downconversion mixer is considered for the single chip approach, because most baseband chips are implemented using CMOS process. To meet the requirements of low power consumption mixer, the various structures of mixer have been studied[1]. In this paper, we present a 1.8V Gilbert cell

downconversion mixer for ISM band, using bulk terminals to alleviate the stacking architecture. The conversion gain and IIP3 of the proposed mixer were analyzed using Taylor series.

2. Basic concept and Theoretical analysis of Bulk driven mixer

As shown in Fig. 1, bulk terminal is driven by a large square signal. If the PMOS device is switched between on and off according to variations of V_{sb} (the bulk terminal voltage) PMOS device can be linear system under small

signal RF swing in the saturation[2]. It is an appropriate assumption because the LO signal is sufficiently larger than the RF signal. LO signal and RF signal are applied to the bulk and the gate, respectively, as shown in Fig. 1.

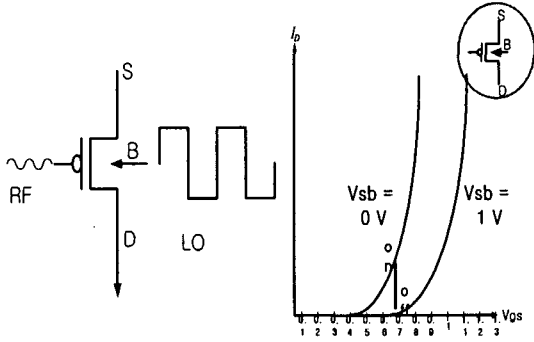


Figure 1. Basic concept of one PMOS switch

With uses of MOSFET I-V characteristics including short channel effects [3], Kirchoff's voltage law, and Volterra series technique [4], we calculate the differential current I_{RF} as a function of the signal source voltage V_{in} ;

$$I_{RF} = \alpha_1 V_{in} + \alpha_2 V_{in}^2 + \alpha_3 V_{in}^3 \dots \quad (1)$$

Assuming the complete switching of LO driven transistors, we can obtain the desired IF by multiplying ω_{RF} and ω_{LO} together. So the power conversion gain, A_p , can be expressed by [2];

$$A_p = A_v^2 \frac{R_{source}}{R_{load}} \quad (2)$$

$$A_p = A_v^2 \frac{R_{source}}{R_{load}} \quad (3)$$

In our calculation, We have used the current equation including short channel effects and body effect to accurately calculate the conversion gain and IIP3 [3].

$$I_d = I_z \times \left(\frac{\left(\text{Log} \left[1 + e^{\left[\frac{V_{gs} - V_{tp}}{2n\phi_T} \right]} \right] \right)^2}{\left(\text{Log} \left[1 + e^{\left[\frac{V_{gs} - V_{tp} + nV_{ds}}{2n\phi_T} \right]} \right] \right)^2} \right) \quad (4)$$

where n and I_z are given by;

$$I_z = 2\mu C_{ox}' \frac{W}{L} n\phi_T^2 \quad (5)$$

$$n = -1 - \frac{\gamma}{\sqrt{-V_{sb} - \phi}} \quad (6)$$

All symbols have their usual meanings and accurate expressions for which are given elsewhere[5]. Note that all voltages expressed in Eq. (4) and equation (6) are taken with respect to the body. Therefore, Eq. (4) and Eq. (6) are very important to analyze the conversion gain and IIP3 in this calculation. Since bulk is used as a switch, we can express the value of transconductance (G_m) using Eq. (3)

$$G_m = I_z \times \left(\frac{\left(\frac{e^{\left[\frac{V_{gs} - V_{tp}}{2n\phi_T} \right]} \text{Log} \left[1 + e^{\left[\frac{V_{gs} - V_{tp}}{2n\phi_T} \right]} \right]}{\left[1 + e^{\left[\frac{V_{gs} - V_{tp}}{2n\phi_T} \right]} \right] n\phi_T} \right)}{\left(\frac{e^{\left[\frac{nV_{ds} + V_{gs} - V_{tp}}{2n\phi_T} \right]}}{\left[1 + e^{\left[\frac{nV_{ds} + V_{gs} - V_{tp}}{2n\phi_T} \right]} \right] n\phi_T} \right)} \times \frac{\text{Log} \left(1 + e^{\left[\frac{nV_{ds} + V_{gs} - V_{tp}}{2n\phi_T} \right]} \right)}{\left[1 + e^{\left[\frac{nV_{ds} + V_{gs} - V_{tp}}{2n\phi_T} \right]} \right] n\phi_T} \right) \quad (7)$$

Substituting Eq.(7) to Eq.(2), conversion gain can be easily obtained. Fig.2 shows that the difference of the Gm by the difference of Vsb in accordance with an increase of Vgs.

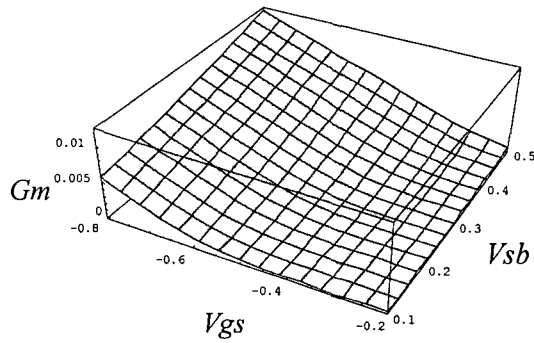


Figure 2. Gm versus Vgs and Vsb

IIP3 which is the intercept point between the basic frequency output power and the output power of third-order frequency components is well known to be simplified by using the coefficient of the Eq. (1), It is also expressed as equation (6).

$$IIP3 = 20 \times \text{Log} \left(\sqrt{\frac{4}{3} \times \frac{|\alpha_1|}{|\alpha_3|}} \right) \quad (9)$$

IIP3 can be determined by the coefficient which is used in Eq.(1) by applying to Eq. (6).

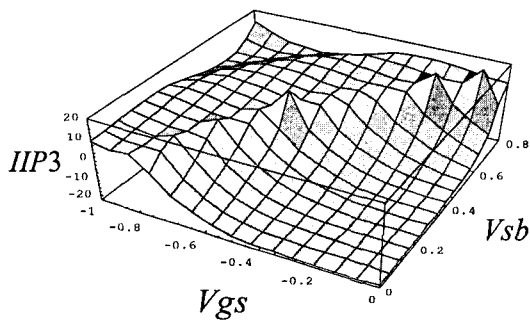


Figure 3. IIP3 versus Vgs and Vsb

Fig.(3) shows the variations of the IIP3 according to the alternative of Vgs and Vsb. The proposed mixer is shown in Fig.4. This mixer is Gilbert cell type, where the bulk is driven by large LO(Local Oscillator) signal. The gate terminals are driven by the differential RF signal having frequency of 2.45GHz, and the bulk terminals are driven by the differential LO signal having frequency of 2.4GHz.

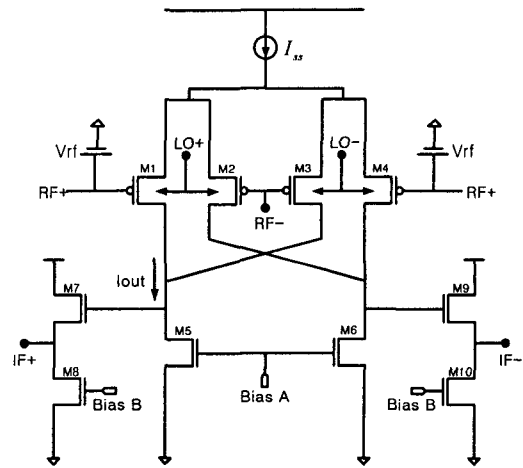


Figure 4. Proposed Gilbert cell mixer

M1, M2, M3 and M4 are PMOS devices. There are two important reasons why pMOS transistors are used as switches in this architecture. One is that the f_T (unity current gain frequency) of pMOS transistors is relatively high (>20GHz), they can be used in RF circuits to drive current, and the other is that the pMOS transistor can be used to fold the RF signal from one supply branch to another. Therefore, the use of pMOS transistor as a switch can reduce the overall supply voltage of the circuit[6]. M5 M6 are nMOS transistors. These transistors were used as load resistors

to realize the desired conversion gain. The value of the load resistance is controlled by their width and the bias A. M7, M8 and M9, M10 are output buffers designed for driving 50Ω load. Since the conventional Gilbert cell mixer where RF and LO path consist of cascode structure has voltage headroom problems, the design of mixer structures without tail current source have been studied. However, the characteristics of relationships between Vrf and Iout may show different characteristics each other when the mixer includes the tail current source or not. Vrf and Iout mean the RF input voltage and output current showed in Fig.4. Saturation voltage (Vs) can be expressed as follows.

$$V_s = \sqrt{\frac{2I_{SS}}{\mu C_{ox} W / L}} \quad (9)$$

According to the equation(7), the increase of DC current or the decrease of the ratio the W/L causes the increase of Vs. However, since, both cases have trade-off between the linearity and the conversion gain, designer should make a choice of profitable structures in accordance with the purpose of the design specification. In this work, the structure having tail current source has been selected to improve linearity.

3. Simulation Results

Table 1 summarizes the simulation results. The RF, LO, and IF frequencies used are 2.45GHz, 2.4GHz and 100MHz. respectively, the conversion gain is illustrated in Fig. 5. According

to the Figure, the power conversion gain is -1 dB up to the RF power of -13 dBm. Fig. 6 shows the result of conversion gain, where Vrf voltage variations are starting from 0.3 V to 0.5 V. Fig. 7 shows the result of IIP3 where the Vrf is swept from 0.2 V to 0.8 V. As expected in the previous analysis, IIP3 value is very sensitive to Vrf.

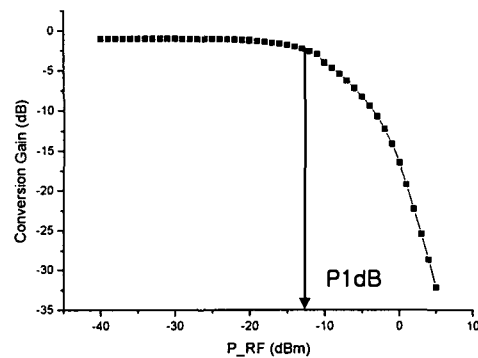


Figure 5. A_p versus RF input power

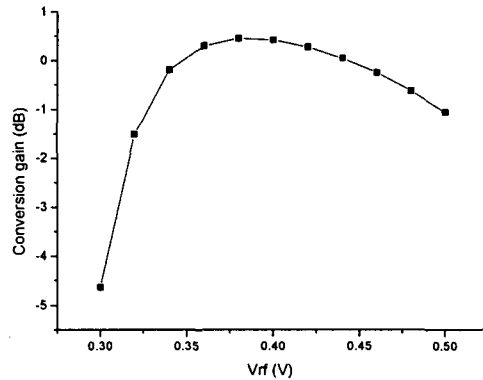


Figure 6. Simulated Conversion gain

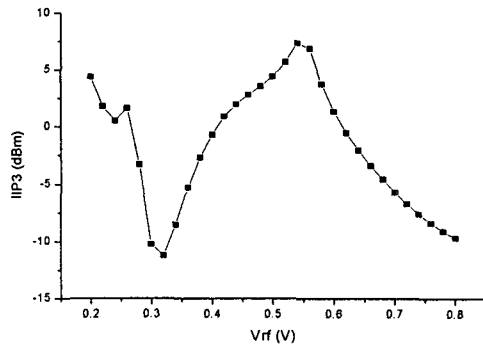


Figure 6. Simulated IIP3

Table 1.

Summary of mixer performance

	Performance
Supply voltage	1.8 V
Power dissipation	0.8 mW
Input LO power	0 dBm
RF frequency	2.45GHz
LO frequency	2.4GHz
Conversion gain (Ap)	-1.2 dB
IIP3	4.46dBm

4. Conclusion

In this work, we have designed Gilbert cell downconversion mixer using bulk terminal for LO path, and have analyzed conversion gain and IIP3 in our own unique way. The results of analyzed conversion gain and IIP3 are in agreement with the results of simulation. This proposed Gilbert cell mixer's power dissipation is less than 0.8mW.

5. References

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