UP-CONVERSION MIXER FOR PCS APPLICATION USING SI BJT

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Abstract: This paper analyzed three types of up-conversion mixer architectures for PCS applications using f_T = 25GHz Si bipolar process. An optimum architecture that combines the mixer cell with an active balun is proposed. The balun provides high linearity and LO suppression. Simulation results shows conversion gain = 0dB, LO to RF leakage = -24.8dBm, output third-order intercept point(OIP_3) = 9.6dBm, and output 1dB compression point(OP_{1dB}) = -0.2dBm, respectively, at f_{RF} = 1.9GHz, f_{IF} = 100MHz, 3V supply voltage, and 24.6mA current.

1. Introduction

In the early stage wireless communication RF systems, RFICs for cellular and PCS applications have been designed and fabricated using GaAs process. These days, RF transceivers increasingly use the silicon bipolar process to reduce the costs. In the future, Si CMOS devices which has poor high frequency performance, but enen lower cost, are expected to lead RFIC markets and may enable single chip RF system. In the meantime, the silicon-based bipolar, BiCMOS, or the SiGe BiCMOS are expected to dominate the commercial market.

In this paper, a bipolar based Gilbert Cell mixer combined with three types of active balun are analyzed and simulated for optimum linearity and LO supression.

Noise figure is an important characteristic but less important in the up-conversion mixer compare to the linearity, conversion gain(CG), and LO leakage. Noise figure had lower priority in this design.

2. Gilbert Cell Mixer Design Optimization

Fig. 1 represents a Gilbert Cell mixer architecture. In Fig. 1, R_3 and R_4 are used for IF impedance matching, and R_1, R_2 are adopted for linearity.

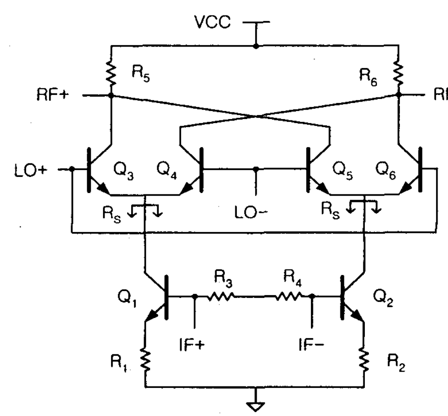

Fig. 1. Gilbert Cell mixer

Methods to obtain high conversion gain are to increase the output impedance R_5 and R_6, increase the transconductance of Q_1-Q_2 by increasing the currents, or cascade an RF amplifier after the mixer. An efficient way to increase the output impedance of the Gilbert Cell is adopt the L-C resonance circuits on the output.

CDMA systems require highly linear performance. Considering the high linearity requirement, the design is focused on the linearity improvement. In Gilbert Cell mixer, linearity tends to be dominated by the transcondumtace stage(Q_1-Q_2). It is important that Q_1 and Q_2 be safely in linear region at all operating conditions.

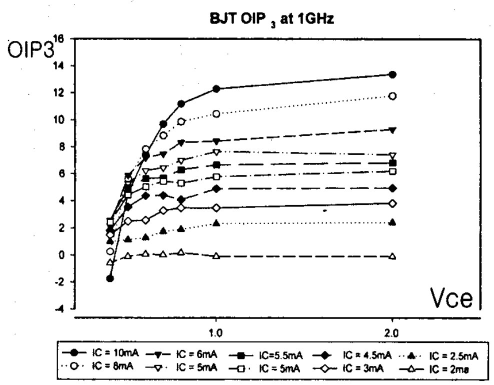

Fig. 2. Measured OIP_3 of a BJT as a function of bias

Fig. 2 shows the bias dependencies of the output third-order intercept points(OIP_3) of the f_T = 25GHz BJT used for the design. Based on Fig. 2, the DC bias conditions of Q_1 and Q_2 are determined considering the limited power and the supply voltage.

When the switching transistors of the Gilbert Cell mixer is driven fully differentially, theoretically, there is no LO leakage at the output. Common ways to drive the mixer LO ports are to use transformers or the active baluns. The major disadvantage of the transformer is that it is typically implemented as an external component other than the problems of insertion loss and the bulky size. Using a differential amplifier type active balun has problems as well. The noise generated by the balun tend to be injected into the switching transistors degrading the NF of the mixer. The balun tends to require large amount of DC currents for the efficient switching. Moreover, the balun requires high driving capability in order to turn on and off the switching transistors efficiently, which mandates a large DC current in the balun. Thus in many practical mixers, LO is driven single-endedly. The half of the Gilbert Cell is shown in Fig. 3(a) under single-ended LO drive. As shown in Fig. 3 (b), the single-ended drive can be equivalently represented as a sum of the half of LO in common-mode and the other half in differential mode. From Fig. 3(b), for $R_S \neq \infty$ the LO signal shows up at the output.

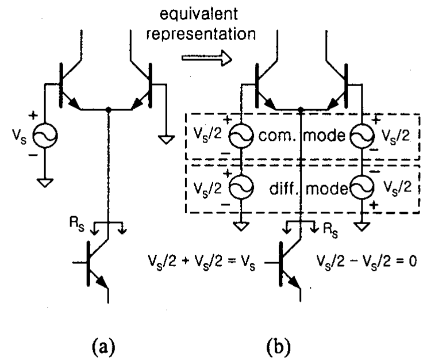

Fig. 3. An equivalent representation of a differential amplifier driver single-endedly

Contrary to the down-conversion mixer, the LO isolation at the output is critical with up-conversion mixer. From Fig. 1, reducing the size of the transconductance stage transistor helps to reduce the common-mode gain of the switching stage, or replacing the transconductance stage with a cascode topology. Typically, these variations in transconductance stages are not sufficient for the required LO suppression.

Cascading a balun at the output of the mixer has advantages as it can provide additional LO suppression and combines the wanted RF signal. Selecting the right balun topology and the proper allocation of the DC currents between the Gilbert Cell and the balun has significant influence on the overall performance of the mixer.

3. Balun topologies

Understanding the cascaded configuration of the Gilbert Cell with the active balun, the overall mixer OIP_3

tends to be dominated by the linearity of the balun, especially when the balun has gain [3]. Three different types of active baluns are investigated for maximum overall mixer linearity for a given amount of power consumption. For each topology, the DC bias conditions of the individual transistors are optimized based on the information provided on Fig. 2.

3.1 Differential amplifier type balun

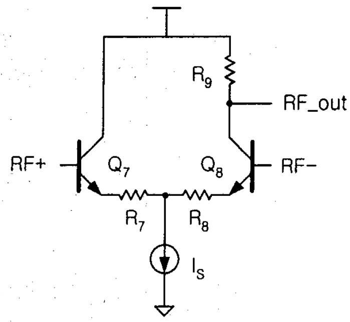

Fig. 3. Differential amplifier balun

Fig. 3 shows a differential amplifier type balun. The gain of balun is determined by transconductances of Q_7-Q_8, the degeneration resistors R_7-R_8, and the output resistor R_9. The amount of the LO suppression is determined by the common-mode gain of the balun. The higher the output impedance of the current source, the better the LO suppression. The third-order inter modulation product of the differential-pair is at least twice as large as that of common-emitter with the same bias current and transconductance[1]. As the result, the differential type balun tends to have poor linearity. For the given balun topology and the total amount of power, the mixer performance is optimized and the simulation results are shown in Table. 1.

3.2 Multi-tanh doublet type balun

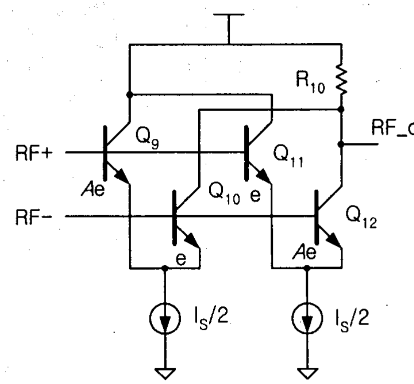

Fig. 4. Multi-tanh doublet balun

Fig. 4 shows a multi-tanh doublet type balun. In Fig. 4, the A defines the ratio among Q_9, Q_{10}, Q_{11}, and Q_{12}. The gain and LO suppression can be analyzed like the differential amplifier. In Fig.4 the individual hyperbolic tangent functions of the paralleled differential pairs Q_9-Q_{10} and Q_{11}-Q_{12} are offset by making the emitters of Q_9 and Q_{12} larger than those of Q_{10} and Q_{11}. The emitter area ratio A shifts the peak of the transconductanc(Gm) of each differential amplifier in opposite direction by an equivalent offset voltage. The addition of the two Gm segments results in an overall Gm which is much flatter than the simple differential pair, with a resulting improvement in linearity[2]. However when input signal goes outside the flat region, the linearity degrades abruptly. Since the balun comes after the Gilbert Cell, the signals applied at the input of the balun have not only been amplified but includes many large amplitude signals such as LO and second harmonics of LO. Therefore, a small flat region of Gm has minor effect on the linearity improvement. To extend the linear region, multi-paralleled differential pairs can be used at the cost of higher power consumption and lower overall Gm. Considering power consumption and gain, two-paralleled pairs with $A = 4$ are used. Simulation results are shown in Table. 1.

3.3 Push-pull type balun

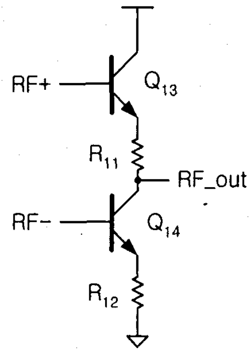

Fig. 5. Push-pull balun

Fig. 5 is a push-pull type balun which is composed of a common-emitter with degeneration and the common-collector. The degeneration resistor R_{12} controls the gain of the common emitter path for the same amount of gain for both inverting and non inverting signals, resulting in maximum cancellation of LO leakage at the output of the balun. R_{11} is included for RF output impedance matching. The gain of the balun is the sum of the two signal path gains. The common-collector path provides highly linear performance and the common-emitter is more linear than the differential-pair for the same bias current and transconductance[1]. So the push-pull type balun porvides better linearity than previous two baluns. Simulation results are shown in Table 1.

4. Conclusion

A highly linear up-conversion mixer topology for PCS application is presented. Various aspects of the optimization process to improve the Gilbert Cell mixer performance is discussed and applied to the design. The designs are optimized with higher priority on linearity and LO suppression. Three different architectures of active baluns are evaluated for linearity and LO suppression. The final design which has adopted the push-pull type balun demonstrated the best performance.

Table 1. Up-mixer simulation results with f_{RF} = 1.9GHz, f_{IF} = 100MHz, LO power = -3dBm, and V_{CC} = 3V

	Differential amplifier balun	Mult-tanh doublet balun	Push-pull balun
Conversion Gain(dB)	-1.1	2.9	0
OP_{1dB} (dBm)	-1.8	-3	-0.2
LO leakage at the RF(dBm)	-24.8	-29.6	-24.8
OIP_3 (dBm)	9.2	7	9.6
Total Current(mA)	26.6	26.7	24.6

References

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