Current-mode CMOS Active Inductor with Applications to Low-Voltage Oscillators

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Abstract— **This paper investigates a current mode active inductor. In the proposed active inductor, three current mirrors have been connected to each other to realize the negative feedback. This active conductor has a two layer transistor structure. A 4.257 GHz, 1.2-V power supply non-inductive LC negative resistor oscillator, base on two of the proposed active inductors, is demonstrated.**

Keywords-active inductor; current mirror; low-voltage

I. INTRODUCTION

Wireless and mobile communications are two of the fastest growing microelectronics applications and have an enormous impact on everyday life. Driven by the insatiable demand for lower cost, lower power and higher data rates in wireless and mobile communications systems, a growing demand for CMOS wireless System-on-a-Chip(SoC) solutions is recorded. This trend has motivated the evolution and research on low voltage, low power, low cost RFIC designs [1, 2].

The oscillator is an important building block in RF transceivers. Inductive characteristics are critically needed in LC tank oscillators to realize frequency selection. Traditionally, passive inductors are off-chip discrete components. The need for off-chip communications with these passive components severely reduces the reliability, and increases the cost. CMOS active inductors have been widely used in the design of ring and LC tank oscillators because of their small chip area and wide tenability [3-6].

All these circuits [3-6] suffer from a tradeoff between low voltage and low cost. Here, we propose a LC oscillator based on the current mode active inductor. Current mode approach has several advantages, such as extended bandwidth, simple circuit structure, higher dynamic range, suitability of operation in reduced power supply environment, low power consumption, low voltage operation [7-12].

In the next section, the current mode active inductor is introduced and analyzed. In section III, an LC oscillator based on the active inductor is described. Section IV is the conclusion.

II. THE PROPOSED ACTIVE INDUCTOR

The active inductor proposed is depicted in Figure 1. It is based on three current mirrors ($M_{1,2}$, $M_{3,4}$, $M_{5,6}$). I_O is the bias current. Consider the equivalent network shown in Figure 2 where a current mirror can be equivalent to a trans-impedance (T_i) and a trans-conductance (g_m). G_{o1} and G_{O2} denote the total conductances at nodes 1 and 2 respectively. Note that G_{o1} is due to the finite output impedance of the g_{m1} and the finite input impedance of T_{i2}. $C_{1,2}$ are the parasitic capacitors.

The following equations apply:

$$\left.\begin{aligned} (sC_1 + Go_1)V_1 &= -V_2 g_{m1} \quad (node 1) \\ (sC_2 + Go_2)V_2 - V_1 g_{m2} T_{i3} g_{m3} &= I_{in} \quad (node\ 2) \end{aligned}\right\} \quad (1)$$

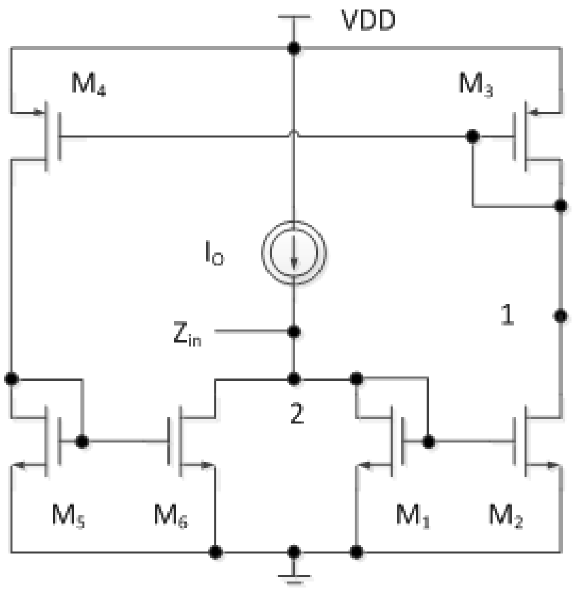

Fig. 1. Proposed current mode active inductor

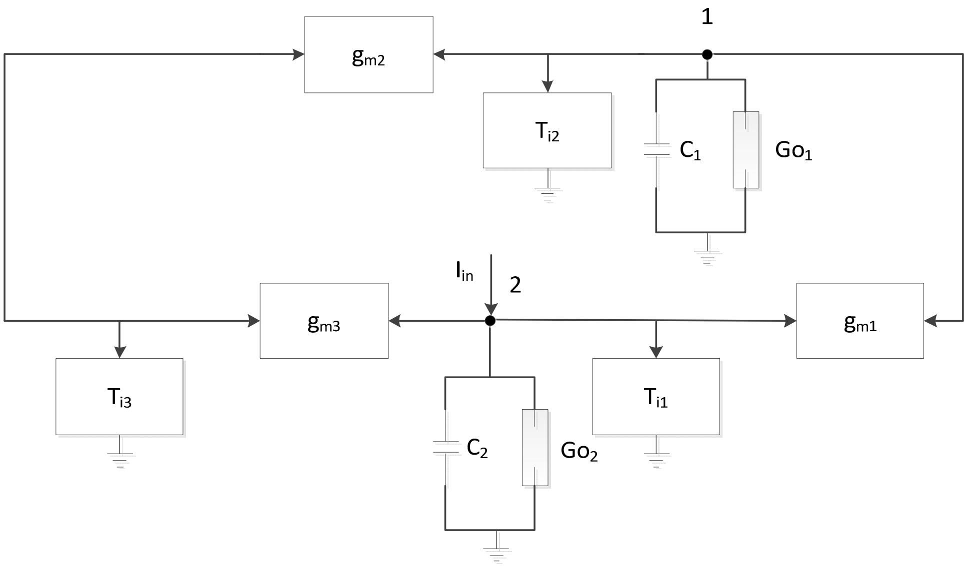

Fig. 2. equivalent network of the current mode active inductor

The admittance looking into port 2 of the equivalent network is obtained from

$$Y=\frac{I_{in}}{V_2}=sC_2+Go_2+\frac{1}{s\frac{C_1}{g_{m1}g_{m2}T_{i3}g_{m3}}+\frac{Go_1}{g_{m1}g_{m2}T_{i3}g_{m3}}} \qquad (2)$$

Equation (2) can be represented by the RLC networks shown in Figure 3 with parameters given by:

$$R_p=\frac{1}{Go_2},\ C_p=C_2,\ R_s=\frac{Go_1}{g_{m1}g_{m2}T_{i3}g_{m3}},\ L=\frac{C_1}{g_{m1}g_{m2}T_{i3}g_{m3}} \qquad (3)$$

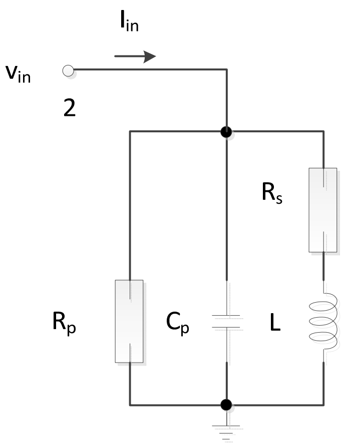

Fig. 3. The admittance looking into port 2

The proposed circuit contains only three current mirrors that all are of a two layer transistor structure. The minimum voltage required for proper circuit operation is $V_{gs}+V_{dsat}$ where V_{dsat} is the minimum V_{ds} voltage required to keep a MOS transistor in saturation. The compactness of the circuit results in low voltage supply and low power consumption.

The active inductor has been simulated in Cadence (5.10.41_USR6.12) using parameters for chartered 0.18 µm RF CMOS Process with VDD=1.2 V. All transistors have the same channel length of 0.18 µm. The width of the transistors and the value of I_o were chosen as W_1=10 , W_2=30 , W_3=40 , W_4=120 , W_5=30 , W_6=42.85 , I_o=3 mA. The simulated Im(Z) and Re(Z) is shown in Figure 4. Q_{Lmax}=7.8 is achieved at 4.257 GHz.

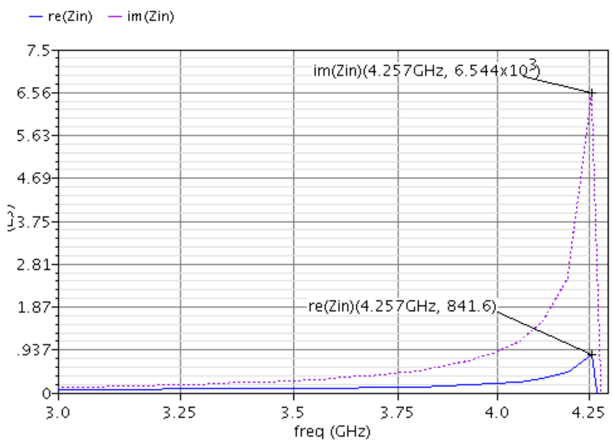

Fig. 4. Simulated Im(Z) and Re(Z)

III. AN LC-TANK OSCILLATORS USING THE PROPOSED ACTIVE INDUCTORS

The proposed low-voltage current mode active inductor is applied to LC oscillator shown in Figure 5. This LC oscillator consists of two active inductors. The capacitor of the LC tank is the parasitic capacitors of transistors. The negative resistor, which is used to cancel the input resistance of the active inductors, is realized by the cross coupling between M_7 and M_{27}.

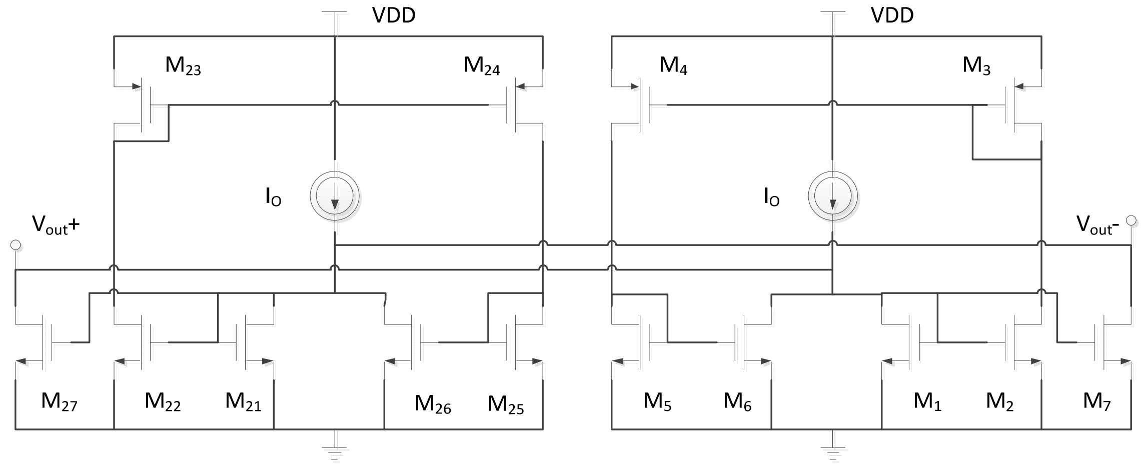

Fig. 5. Current mode LC oscillator based on the active inductor

Figure 6 shows the output voltage of the LC oscillator shown in Figure 5. Its frequency is set to about 4.257 GHz. Spectre from Cadence design systems is used for the phase noise simulation. It is approximately -105 dBc/Hz (1 MHz frequency offset). Figure 7 shows the simulated phase noise. Table I lists the comparison of the performance of previous active inductors oscillators to the one proposed in this paper.

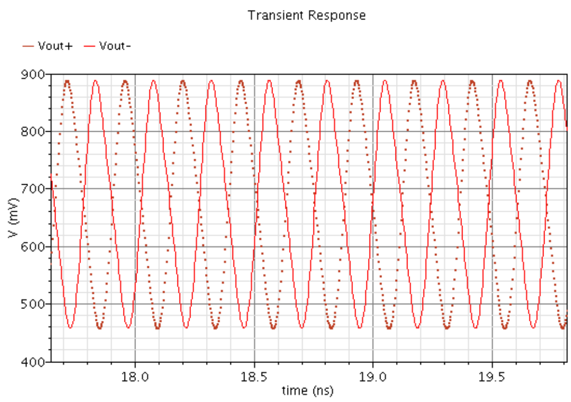

Fig. 6. The output voltage of the proposed oscillator

TABLE I. COMPARISON OF ACTIVE INDUCTOR OSCILLATORS PERFORMANCE

Ref.	Tech. (μm)	Vdd	Phase noise	PDC (mW)	F (GHz)
[3]	0.18	1.8V	-101~-118	6-28	3
[4]	0.18	1.8V	110	30	1.6
[5]	0.18	1.8V	-122.9	----	1.6
[6]	0.18	1.8V	-109.4	30.5	1.5
This work	0.18	1.2V	-105 t	20	4.257

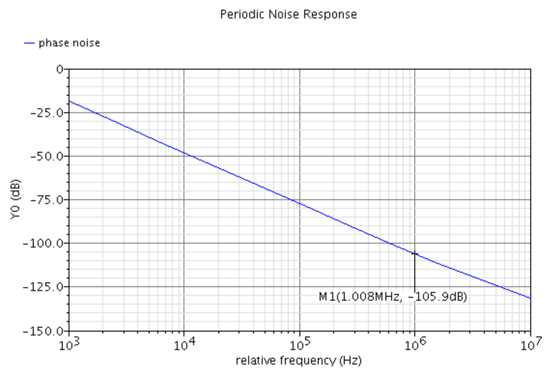

Fig. 7. The simulated phase noise at the oscillation frequency of 4.257GHz

IV. CONCLUSION

This paper proposes a current mode active inductor build with three current mirrors. A 4.257 GHz, 1.2-V power supply, LC negative resistor oscillator, based on the proposed active inductor, is also demonstrated. Considering that the phase noise of the oscillator is approximately -105dBc/Hz at 1 MHz frequency offset, it is hinted that it can be used in a current domain circuit or a voltage domain circuit with low-voltage supply and small size.

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