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CMOS LC-oscillator with simulated inductor for QPSK

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Abstract

This paper proposes a novel implementation of a Quadrature LC oscillator using an active inductor on-chip. The significance of active inductor in Quadrature oscillators is discussed in many papers. In this lecture we propose a circuit for active inductor in QPSK Oscillator.

Keywords: *QPSK Oscillator; Active Inductor; quadrature; CMOS; LC Oscillators; nPSK;*

1. Introduction

Commercial mobile wireless communication systems such as cellular, personal communications services (PCS), personal area networks (PAN), wireless local area networks (WLAN) and Internet of things (IOT) play a significant role in modern technology and it is an undeniable fact. Should we realize the importance of modern communication system products we will ponder over them much more scrupulously. Discussing about highly integrated circuits has recently been the topic of debate in many papers and demanding for smaller size and lower cost of circuits in different products have continuously increased. Because of this reason, modern communication system products require multifunctional, highly integrated circuits. Many different methods for implementing inductors on-chip have been proposed over the last decades. Implementing inductor on-chip in integrated circuits is an important issue and exhaustively presented in [7], [8], [9], [10] and [11]. In this paper, a novel circuit for QPSK oscillator is presented. Quadrature Oscillators are commonly used in wireless communication systems (WSN) because of their good phase noise characteristics, low cost, low-power, and ease of implementation. Quadrature oscillator can be design with LC tanks and using LC tanks for Quadrature oscillator provides great phase noise performance. In the high frequency applications, the inductors that are used have small inductance values and can easily be implemented on-chip. For medium frequencies, inductors with large inductance values are required. Passive inductor requires considerable silicon area and because of silicon area limitation, inductors can be implemented as active inductors. The purpose of this paper is to seek the possibility of using active inductors in QPSK oscillator circuits as substitutes for passive ones.

2. ACTIVE INDUCTOR

In this paper the basic circuit block for LC oscillator, shown in Fig. 1. The circuit in Fig. 1a is consisting of pair of transistors with inductor load [4]. The inductor provides resonate situation to determine the oscillation frequency. In second circuit the authors present a method of optimizing the LC differential oscillator with complementary outputs [3] as presented in Figure. 1b.

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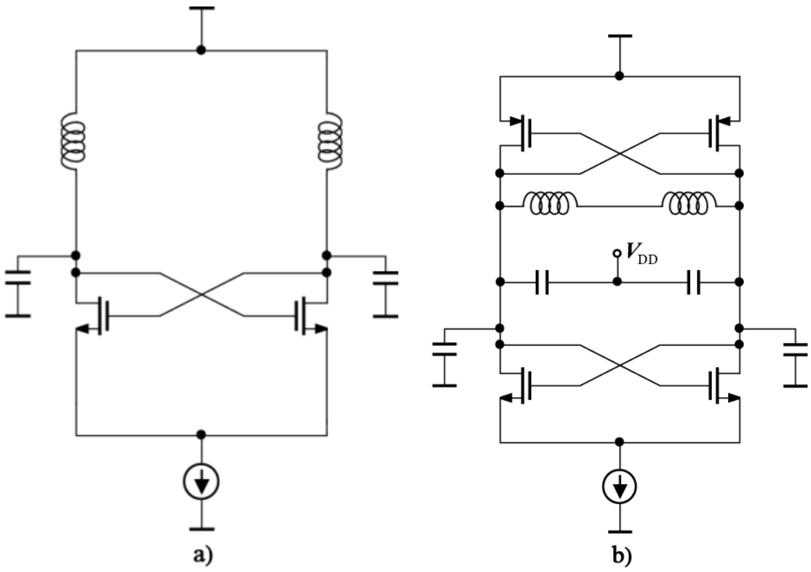

Fig. 1. a: Rofougaran Oscillator, **b)** Complementary LC oscillator

The proposed circuit in [1] consists of two latch type structures that are used as negative resistances. In LC oscillators for medium frequencies the designer must usually make use of inductors with large inductances that are impossible to implement in a CMOS process because of this reason we are going to propose a method for implementing active inductor on-chip. In [1] and [5] the authors presented a method for optimizing LC differential oscillator with complementary outputs. The proposed circuit for this part shown in Fig. 2.

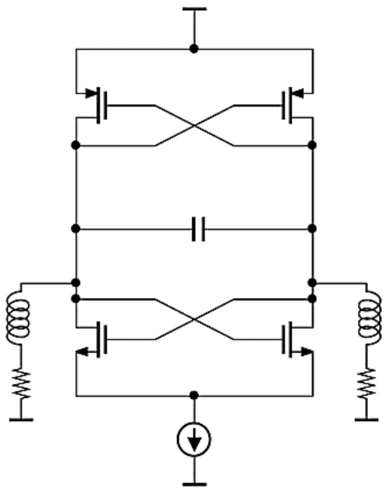

Fig. 2: Superseded circuit for Complementary LC oscillator

The main implementation of the active inductor for integrated circuits is presented in Fig. 3 and it has been discussed in [1], [5] and [6].

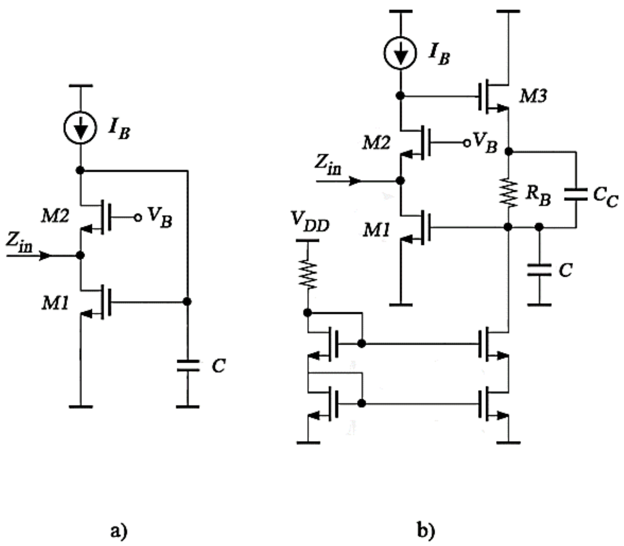

Fig. 3 a: Simulated active inductor, **b)** Proposed circuit

The input impedance of the simulated inductor in Fig. 3a can be express as:

$$Z_{in} = \frac{1}{(g_{m2}+g_{mb2})(1+\frac{g_{m1}}{sC})} \tag{1}$$

$$Z_{in} = \frac{sC\,(sC - g_{m1})}{(g_{m2}+g_{mb2})(s^2C^2 - g_{m1}^2)} \tag{2}$$

$$Z_{in} = \frac{-(\omega^2C^2 + j\omega C g_{m1})}{(g_{m2}+g_{mb2})(-\omega^2C^2 - g_{m1}^2)} \tag{3}$$

It can be easily observed that the impedance of circuit in Fig. 3a consist of an inductor and series resistance. In mentioned equations g_{mb2} is the backgate transconductance of transistor M_2 . Due to the two conditions $\omega < \frac{g_{m1}}{C}$ and $g_{mb2} < g_{m2}$ are verified we can divide the relation (3) as:

$$R_{in} = \frac{\omega^2C^2}{(g_{m2}+g_{mb2})(\omega^2C^2 + g_{m1}^2)} \tag{4}$$

$$L_{in} = \frac{C\,g_{m1}}{(g_{m2}+g_{mb2})(\omega^2C^2 + g_{m1}^2)} \tag{5}$$

In proposed circuit in Fig. 3b, C_C provides compensation to the loop transfer and R_B has the role to provide the necessary voltage from drain to source in transistor M_2 . So this transistor can operate in saturation region by the quiescent current that goes through cascode current mirror. If we consider that transistors in current source are identical we can write the output resistance of current mirror as:

$$r_o \cong r_{ds}^2 g_m \tag{6}$$

Considering to (6), cascode current source provides large output resistance so we can neglect the output resistance of current source in (1-3). Transistor M_3 has the responsibility of eliminating the current mirror effect on the current of M_1 and M_2. Considering that the output resistance from the I_B is r_{out} , input impedance for the circuit in Fig. 3b can be estimated as follows:

$$Z_{in} \cong \frac{1}{g_{m1}g_{m2}r_{out}} + j\omega\frac{R_B}{r_{out}}\cdot\frac{C}{g_{m1}g_{m2}} \quad (7)$$

If we consider that transistors M_1 , M_2 and M_3 are identical we can write the following equation set for proposed circuit in Fig. 3b:

$$R_{in} \cong \frac{1}{(g_{m1}^2 r_{out})} \quad (8)$$

$$L_{in} \cong \frac{R_B\, C}{r_{out}\, g_m^2} \quad (9)$$

From equations (8) and (9) we can conclude that the circuit presented in Fig. 3b can be model as an inductor and series resistance. In next section new QPSK oscillator is presented based on circuit in Fig. 3b.

3. QUADRATURE OSCILLATOR

In this section we reuse the concept of "coupling" an external signal to an oscillator which proposed in [2] to make a new oscillator. We want to prove that an oscillator consisting of a cross-coupled pair of subsystems that are themselves cross-coupled each other can generate four signals those are quadrature in phase. The proposed circuit for "injected" oscillator can be shown in Fig. 4a.

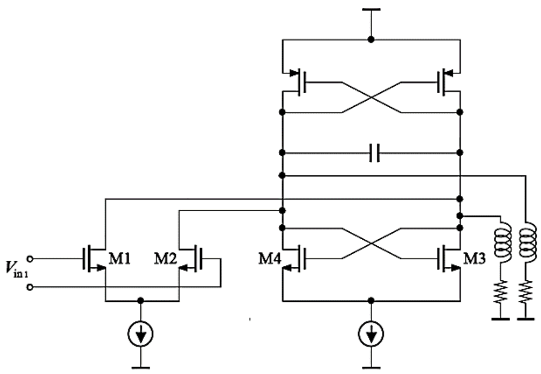

Fig. 4-a: Proposed injected oscillator

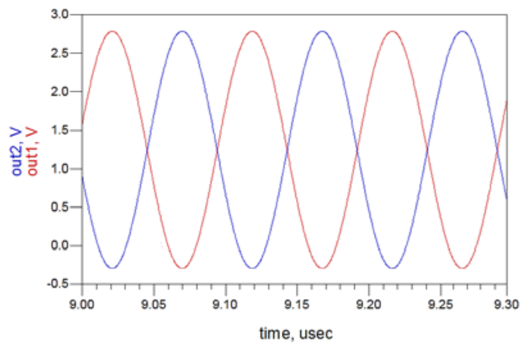

Fig. 4-b: Simulated outputs of the proposed oscillator

In proposed circuit M_1 and M_2 convert V_{in} to a differential current and inject the result into the next section of circuit. If V_{in} has the same frequency as the frequency of the oscillator, then the coupling can shift the phase of output voltage. We can employ the active inductor presented in Fig. 3 in proposed injected oscillator in Fig. 4a. The simulation results of oscillator presented in Fig. 4a shown in Fig. 4b. For this simulation we have used CMOS 0.18um technology. Final result of implementing

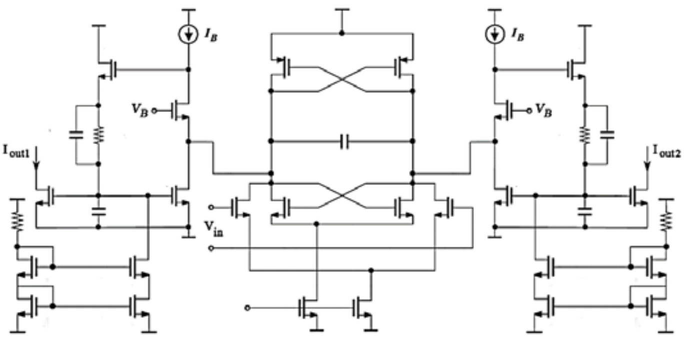

Fig. 5-a: Proposed injected oscillator with active inductor

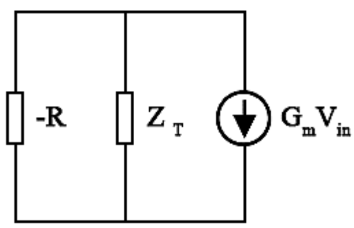

Fig. 5-b: Small signal model

active inductor in proposed oscillator presented in Fig. 5a. The proposed circuit has the advantage of frequency and amplitude tuning through the use of input currents.

The circuit in Fig. 5a is the main circuit for BPSK. The small signal model of this circuit is presented in Fig. 5b. In higher order PSK we should couple two or more identical oscillators. Following generation needs two identical oscillators for QPSK oscillator. Block diagram for this oscillator presented in Fig. 6a.

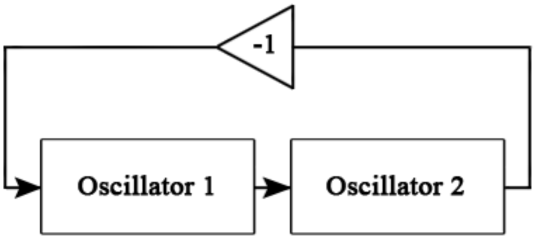

Fig. 6-a: Model of two coupled-oscillators (QPSK oscillator)

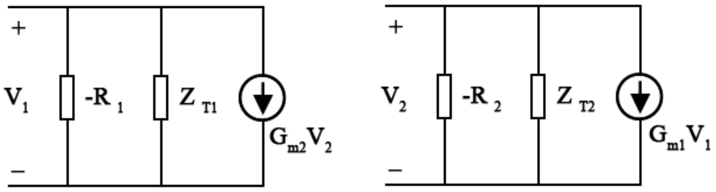

Fig. 6-b: Small signal model

Generally for nPSK oscillator, our circuit needs $n/2$ of proposed oscillator in Fig. 5a coupled to each other. The main idea for injected voltage is proposed in Fig. 6a. In coupled oscillators a fraction of each oscillator's output is injected into the other oscillator [2]. Thus relations between V_1 and V_2 of the circuits in Fig. 6b can be derived as:

$$G_{m1}V_1\frac{-R_1Z_{T1}}{Z_{T1}-R_1} = V_2 \tag{10}$$

$$G_{m2}V_2\frac{-R_2Z_{T2}}{Z_{T2}-R_2} = V_1 \tag{11}$$

Oscillators are identical, so we can conclude that $R_1 = R_2$ and $Z_{T1} = Z_{T2}$. Assuming $V_1, V_2 \neq 0$ and dividing (1) by (2) we can arrive at:

$$G_{m2}V_2^2 - G_{m1}V_1^2 = 0 \tag{12}$$

If $G_{m1} = G_{m2}$ we can write $V_1 = \pm V_2$ and if $G_{m1} = -G_{m2}$ the output voltage of oscillators can be written as $V_1 = \pm jV_2$. So the two oscillator's outputs operate with a phase difference of $-90°$, $0°$, $+90°$ and $180°$.

For higher order PSK we can connect more stage of base oscillator. Idea for Cross-coupled pairs for higher order PSK presented in Fig. 6. Each stage in the oscillator is coupled with an explicit phase shift of 180°.

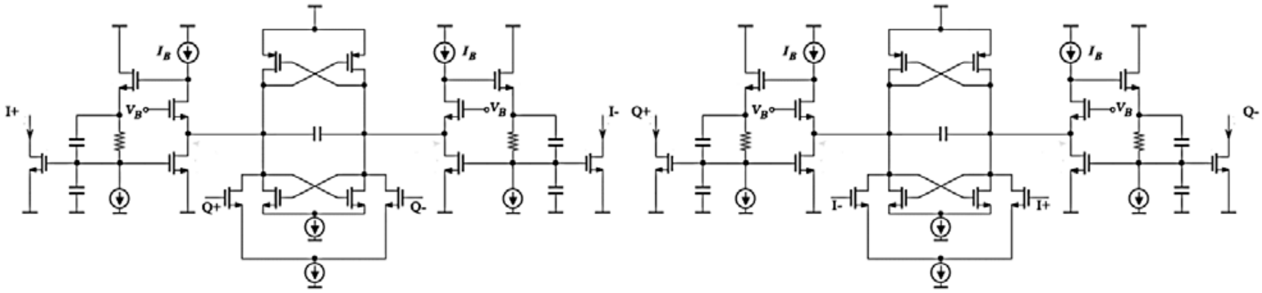

Fig. 8: QPSK with proposed active inductor

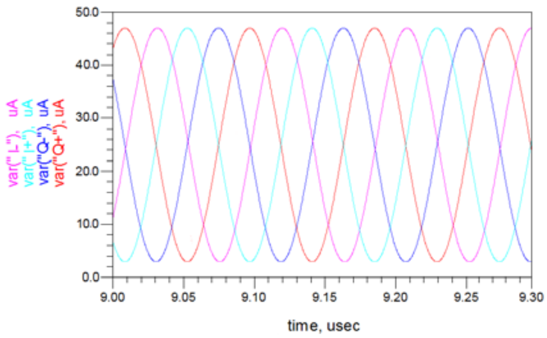

Fig. 9: Simulated outputs of the proposed QPSK shown in Fig. 8

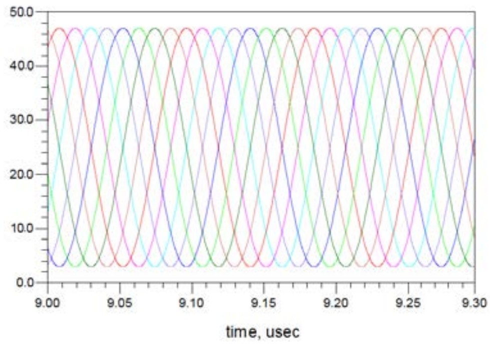

Fig. 10: Simulation result of 8PSK

Now we can present a circuit for higher order PSK by connecting proposed stages in Fig. 4a. In this paper we simulate the circuit presented in Fig. 5a in QPSK mode based on the idea presented in Fig. 6a.The related circuit is presented in Fig. 8 and simulation result for this circuit is presented in Fig. 9. The proposed circuit in this study has been implemented based on 0.18um CMOS technology. In this circuit inductors are implemented as active inductor and can easily be implemented on-chip. Simulation results for higher order PSK has been shown in Fig. 10.The oscillator for 8PSK can be implemented on the basis of proposed oscillator in Fig. 5.

Conclusion

A method for implementing inductors on-chip has been proposed in this paper. Active inductor can easily be implemented in integrated circuits. In addition, this method can be expanded to construct higher order PSK oscillators.

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