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Low Power CMOS LC VCO for RF Applications– A Review

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Abstract: *In this paper, we have studied about the different topologies used to design CMOS LC VCO for lower power consumption and lower phase noise. Here we have studied four different topologies and compare it on the basis of power consumption and phase nose. After comparison between these topologies, it is observed that CMOS LC VCO with pseudo resistance provides minimum phase noise and differential cross coupled CMOS LC VCO provides lower power consumption. The cross coupled differential LC VCO topology is widely used for optimization the trade- off between the phase noise and power consumption.*

Keywords: *Voltage Controlled oscillator (VCO), phase noise, tuning, power consumption, CMOS*

1. Introduction

Oscillators are one of the important common functional blocks in communication systems. Integrated LC tank Voltage Controlled Oscillators (VCOs) are used to provide input for mixers to up-convert and down-convert signals and have main importance in fully integrated transceivers. Proper amplitude, power consumption and low phase noise are three key criteria to achieve good performance for a VCO in the transceiver [1]. The voltage controlled oscillators (VCO) designed in different CMOS technologies have become a real solution in the range of radio frequencies because of the low power consumption and low phase noise values. The best combination of very low phase noise specifications with very low power consumption (battery operation) encourages designers to use LC-VCOs.

2. Feedback Model of Oscillator

Oscillator are nonlinear in nature, though are usually viewed as a linear time invariant feedback system as shown in Figure 1. In the *s*-domain, the transfer function of this negative feedback system is given by

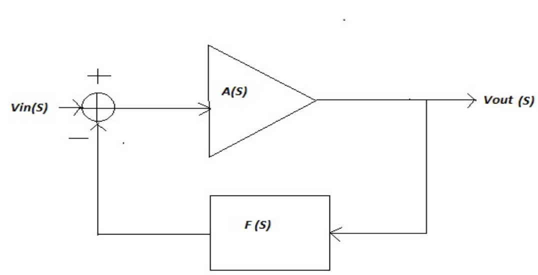

Fig.1. Negative feedback system with frequency selective network.

$$\frac{V_{out}}{V_{in}}(s) = \frac{A(s)}{1 + A(s)F(s)}$$

If the loop gain $A(s)F(s)$ is equal to –1 at a specific frequency ω0 , the closed loop gain approaches to infinity. Under this condition, the feedback becomes positive and the system trends to be not stable. Separating the magnitude and the phase of $A(s)F(s)$, the well known "Barkhausen criteria" are obtained for the oscillation start-up.

$$|A(j\omega_0)F(j\omega_0)| \geq 1$$
$$\angle |A(j\omega_0)F(j\omega_0)| = 180$$

The Barkhausen Criteria for oscillation is Compulsory but not sufficient [1].

3. LC Tank VCO Topologies

The Voltage Control Oscillator (VCO) is a important building block for transmitter, which determines the overall phase noise (jitter) performance. Lower phase noise, lower power consumption and best FOM are the three main design objectives for a VCO

3.1 Differential cross coupled LC tank VCO

In this[7] differential cross coupled LC tank VCO used decoupled capacitor along with polysilicon resistor which use to reduce power as well as phase noise. the P-MOSFET used in the cross-connected pair helps to reduce phase noise due to less flicker noise. Poly silicon resistor Rs which is almost 1/f noise-free. Paste your essay in here..

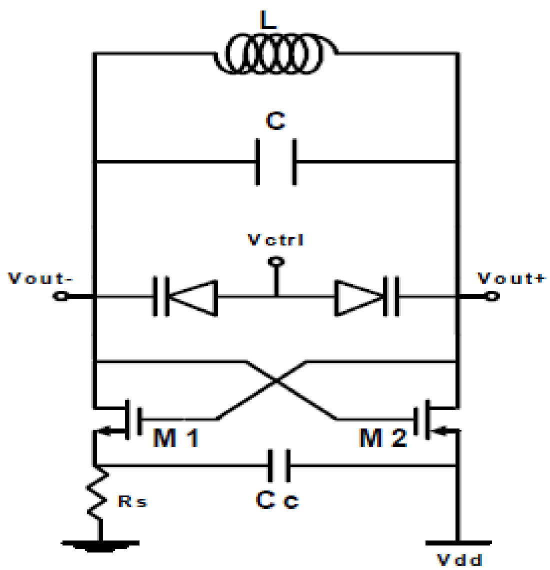

Fig.2. Cross coupled differential topology

3.2 Complimentary cross coupled LC tank VCO

Complimentary differential transistor pairs can produce twice the negative resistance as a single differential transistor pairs do which is good for the oscillation amplitude and power limitation [8]. In this complimentary cross coupled LC tank VCO, two LC tank VCOs are designed. One by using NMOS current mirror and other by using PMOS current mirror. After comparing phase noise of both the circuits by Keeping tail current constant, the circuit which is designed by using PMOS current mirror shows lower phase noise as compared to the circuit designed by using NMOS current mirror.

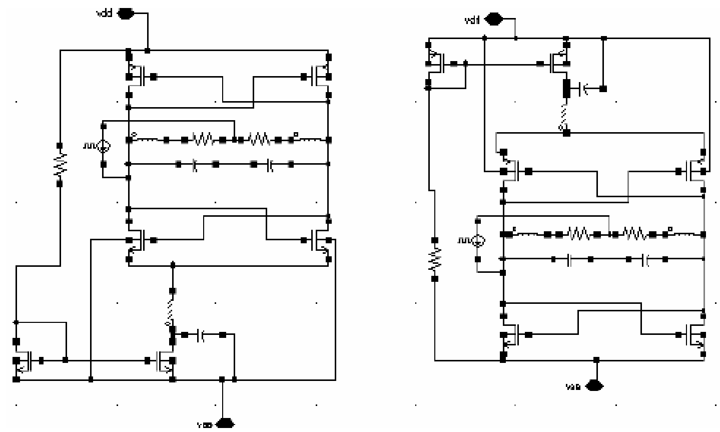

Fig.3. Complimentary cross coupled LC tank VCO.

3.3 Cross coupled LC tank VCO with double Pseudo resistance

In this, VCO with double pseudo resistance is designed to achieve low power consumption without decrease the phase noise. The phase noise of a LC-VCO is inversely proportional to the Q2, where Q is the equivalent quality factor of the LC-tank[9]. The CMOS inductors in RF circuits suffer from low quality factor. So, if one can increase the Q of the LC-tank, the phase noise will be improved. For this goal, we have used added negative transconductance technique in the proposed LC-VCO. Four capacitors Cl to C4 are added to the circuit in parallel with drain-source of NMOS and PMOS cross-coupled transistors. Adding these capacitors to the circuit provides negative transconductance and hence reduces the total tranceconduncе that leads to increase the quality factor. Basis goal in this technique is to decrease the power consumption of VCO. For this two resistances are added to the VCO in the path of power supply in order to decrease the power consumption. Two PMOS and NMOS pairs works in triode region and so plays the role of a resistance in the circuit[9].

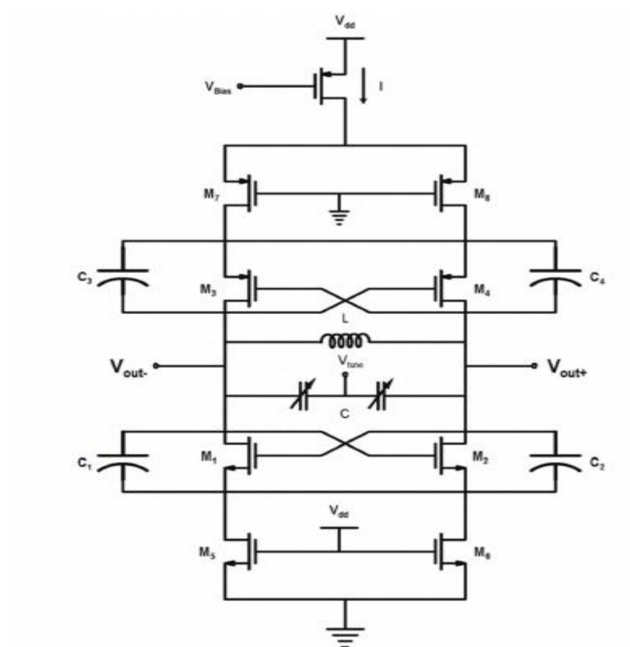

Fig.4. Cross coupled LC tank VCO with double Pseudo resistance.

3.4 Quadrature VCO using Reconfigurable LC tank

Quadrature VCO used in multi standard and multi band transceiver system[10]. It provides low phase noise with low current consumption. To accomplish dual band operation the reconfigurable LC tank is adopted.

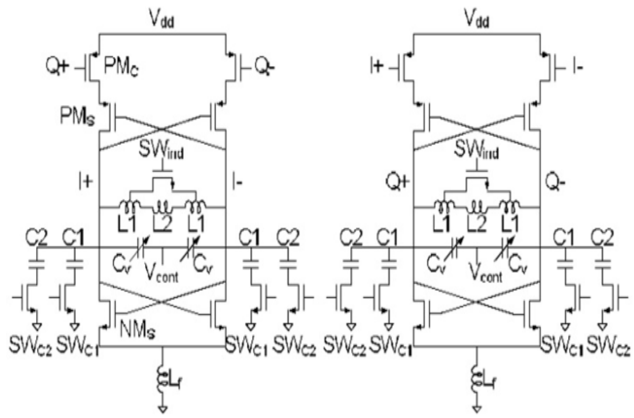

Fig.5. Quadrature VCO using Reconfigurable LC tank

4. Voltage Controlled Frequency Tuning

Most wireless applications require a tunable oscillator, which means its output frequency is a function of a control input, usually a voltage. An ideal VCO is a circuit whose output frequency is a linear function of its control voltage (Vcon)[3], as shown in Figure 6

$$f_{out} = f_0 + K_{vco}.V_{con}$$

where, fo is the oscillation frequency at Vcon = 0 and KVCO represent the gain or sensitivity of the circuit. The achievable range of frequency, f2 – f1, is called the frequency tuning range.

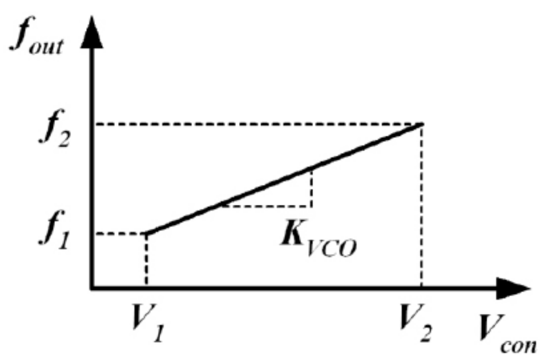

Fig.6. Definition of *KVCO*

Frequency tuning is required not only to cover the whole application bandwidth but also to compensate for variations of the center frequency of the VCO that are caused by the process and by temperature. The oscillation frequency of an LC VCO is approximately equal to $fosc = \frac{}{2}$
that only the inductor and capacitor values can be varied to tune the oscillation frequency.

5. Power Consumption

Mobile devices are required to have long standby times, indicating a need for low power consumption. Phase noise is inversely proportional to the power dissipated in the resistive part of the resonant LC tank. This seems to suggest that an arbitrarily small phase noise can be achieved by simply increasing the bias current, but there are practical limitations as to how small phase noise can be made. As bias current is increased, so is the VCO's output voltage amplitude. However, any CMOS transistor has a maximum voltage that cannot be exceeded without permanent damage[6]. The voltage amplitude of the tank for the CMOS cross-coupled differential topology shown can be expressed by assuming that the differential stage switched from one side to the other[6]. As the tank voltage changes, the direction of the current flow through the tank reverses. The differential pair can be modeled as a current source switching between *Itotal* and *Itotal* in parallel with an RLC tank. *Req* is the equivalent parallel resistance of the tank. The tank amplitude can be approximated as

$$V=I_{tot}\,.R_{eq.}$$

This is referred to as the current-limited operation because tank amplitude mainly depends on the total current flowing and the tank's equivalent resistance. However, equation (11) becomes invalid when the tank amplitude becomes the supply voltage through an increase of *Itotal*. This operation is called the voltage-limited operation. With current limited operation, as the current increases (consuming more power), the phase noise lowers because the tank amplitude is increasing simultaneously.

7.Comparison and Discussion

A comparison of this work with previous wide-tuning range design is shown in Table given below. From this comparison table, it is seen that cross coupled differential LC VCO topology has low power consumption and high frequency .

TABLE I.
COMPARISON OF PARAMETER

S. No	Parameter	Ref.[24]	Ref.[25]	Ref.[28]	Ref.[21]	Ref.[41]	Ref.[27]	Ref.[29]	Ref.[30]	Ref.[31]	Ref.[33]
1.	Technology (nm)	350	350	350	250	250	180	180	180	180	65
2.	Supply Voltage (V)	2.5	2.5	2.5	1.5	3	1.5	0.9	-	1.8	1.2
3.	Power Consumption (mW)	12.5	7	6	6	2	1.9	0.5	3.15	53.2	3.4
4.	Frequency (GHz)	1.86	4.25-6.25	2.9	1.8	315-3.85	2.28-2.59	1.86-2.01	1.9-2.2	1.8	0.75-1.5
5.	Tuning Voltage(V)	-	-	1	-	0.3-2.2	0-1.5	-	0-2.5	-	-
6.	Tuning Rang*(GHz)	-	-	-	-	0.7	0.31	0.15	0.3	-	0.75

6. Conclusions

power consumptions of four different topologies of LC tank VCO has been compared above. From this it is studied that as supply voltage decreases, power consumption also decreases and we will get lower phase noise. This lower phase noise will offers to reduce the start up energy conserved by the RF transmitter.

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