International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 3, No .3, July 2012 – www.ijais.org

# Low Power Low Phase Noise CMOS LC VCO – A Review

M.A.Nandanwar
Research Scholar
B.D.College of Engineering.Sewagram
Wardha(M.S.)INDIA

M.A.Gaikwad
P.G.Department of Electronics Engineering
B.D.C.O.E.Sewagram
Wardha(M.S.)INDIA

D.Dandekar
P.G.Department of Electronics Engineering
B.D.C.O.E.Sewagram
Wardha(M.S.)INDIA

## ABSTRACT
In this paper four different topologies of LC tank VCOs for low power consumption and low phase noise are studied. After comparing four different topologies,it is seen that LC tank VCO with pseudo resistance provides minimum phase noise i.e. -125.5 DBc/Hz @1MHz, and differential cross coupled LC tank VCO provides minimum power consumption i.e.0.675 mW at 180 nm technology.

## Keywords
Phase noise, power consumption, FOM, LC VCO.

## 1. INTRODUCTION
Oscillators are one of the most common functional blocks in communication systems. Integrated LC Voltage Controlled Oscillators (VCOs) are used as an input for mixers to up- and down-convert signals and have particular importance in fully integrated transceivers. Proper amplitude and low phase noise are two key criteria to achieve suitable performance for a VCO in any transceiver [1].
The voltage controlled oscillators (VCO) designed in CMOS technologies have become nowadays a real solution in the band of radio frequencies because of having achieved low power consumption and low phase noise values. The strong combination of very low phase noise specifications with very low power consumption (battery operation) pushes designers to use LC-VCOs.

## 2. LC VCO BASIC

A general LC-VCO can be shown as in Fig.1. The inductance *L* and the capacitance *C* consist of a parallel resonance tank. *RL* and *RC* are the parasitic resistances of *L* and *C*, respectively. In order to compensate the losses coming from *RL* and *RC*, active components like CMOS transistors are used to realize a negative resistance −*R*. According to [1], the loss in the tank can be expressed as

$$Ploss = 4\pi^2 RC^2 f0^2 Vpeak^2 = \frac{R}{4\pi^2 L^2 f0^2} Vpeak^2 \quad \text{-----------(1)}$$

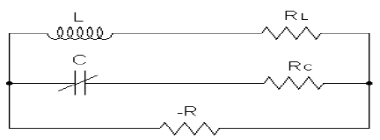


**Fig 1: basic LC VCO**

Where *R* represents the combined losses of the inductance and the capacitance, and *Vpeak* is the peak voltage amplitude across the capacitance. It can be observed from (1) that the power loss decreases linearly with the series resistance in the resonance tank, and it also decreases quadratically with an increase of the tank inductance.
In order for the resonance tank to resonate without any loss coming from parasitic, the parasitic resistance and capacitance coming from both the inductor and resistor need to be compensated. As for the compensation for parasitic resistance, a negative resistance, -R is formed in the tank in order to cancel out both of the parasitic resistances. However, in a real form, negative resistance does not exist. a negative resistance is formed by cross-coupling transistors that are connected to the resonant tank.

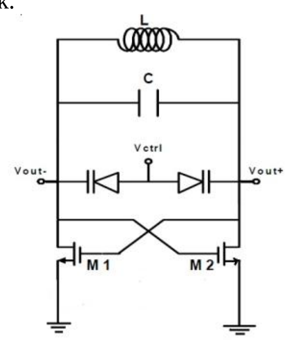


**Fig 2: Cross-Coupled Oscillator**

By cross-connecting the output to the input of the oscillator, negative resistance that has the same conductance as the transistor's transconductance ($g_m$) is created. The phase noise of a LC-VCO is inversely proportional to the $Q^2$ [9], where Q is the equivalent quality factor of the LC-tank. Since the quality factor of varactors are more than inductors, thus the quality factor of inductor plays dominant role in the Q of tank. 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 LC-VCO. The quality factor of a LC-tank can be expressed as bellow:

$$Q = 1/Gtot \sqrt{C/L} \quad \text{------- (2)}$$

Where Gtot is the transconductance of the LC-tank that can be confined with quality factor of the inductor. We can express Gtot as follow:

$$Gtot = Gp - G_N \quad \text{--------- (3)}$$

Where GN is the added negative conductance to the circuit that can decrease Gtot and therefore increase Q of the LC-tank.

## 3. FEEDBACK MODEL OF OSCILLATORS:

Oscillators are nonlinear in nature, though are usually viewed as a linear time invariant feedback system as shown in Figure 3. In the *s*-domain, the transfer function of this negative feedback system[2] is given by

$$\frac{V_{out}}{V_{in}}(s) = \frac{A(s)}{1+A(s)F(s)} \qquad \text{--------- (4)}$$

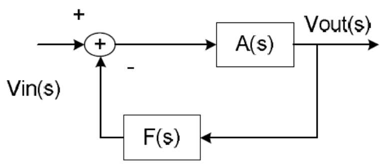


**Fig 3: Block diagram of negative feedback systems**

If the loop gain *A*(*s*)*F*(*s*) is equal to –1 at a specific frequency ω0, the closed loop gain approaches infinity. Under this condition, the feedback becomes positive and the system trends to be unstable. Separating the magnitude and the phase of *A*(*s*)*F*(*s*), the well-known "Barkhausen criteria" are obtained for the oscillation start-up.

$$|A(jw_0)F(jw_0)| \geq 1 \qquad \text{-------- (5)}$$

$$\angle A(jw_0)F(jw_0) = 180^0 \qquad \text{--------- (6)}$$

To guarantee the effective "regeneration" of the input signal, the magnitude of the loop gain has to be greater than unity. The "input signal" here may be generated by any noise or fluctuation in oscillators.

## 4. SPECIFICATIONS OF VCO

There are several specifications representing VCO performance; oscillation frequency, frequency tuning range, phase noise at a specific offset frequency, and power consumption. In addition, because of battery limitation on mobile devices, low power consumption is required as well. However, a trade-off exists between power consumption and

phase noise. The semi empirical phase noise model, known as the Leeson model [3], is given by

$$L(\Delta w) \propto \frac{N}{P_S.Q_L}.\left(\frac{w_0}{\Delta w}\right)^2 \qquad \text{--------- (7)}$$

where *N* is the noise factor, *Ps* is the signal power at the resonator, *QL* is the effective quality factor of the resonator with all the loadings in place, ω*o* is the oscillation frequency, and Δω is an offset frequency from the carrier. From equation 7, it is easily noted that the more signal power, the better the phase noise performance.

To evaluate a designed VCO compared with other VCOs in terms of performance, one of the general Figure-Of-Merit (FOM) formulas is expressed as[3]

$$FOM = L(\Delta w) - 20.\log\left[\left(\frac{w_0}{\Delta w}\right)\right] + 10.\log\left(\frac{P_{diss}}{1mW}\right) \qquad \text{------------ (8)}$$

Equation 8 includes phase noise, *L*(Δω) at an offset frequency of Δω, oscillation frequency, $\omega_0$, and power consumption of the core circuit, *Pdiss*.

### 4.1 Phase Noise

Definition:

Noise is injected into an oscillator by the devices that constitute the oscillator itself including the active transistors and passive elements[4]. This noise will disturb both the amplitude and frequency of oscillation. Amplitude noise is usually unimportant because non-linearities that limit the amplitude of oscillation also stabilize the amplitude noise.

Phase noise, on the other hand, is essentially a random deviation in frequency which can also be viewed as a random variation in the zero crossing points of the time-dependent oscillator waveform.

For an ideal oscillator i, its output can be expressed as:

$$Vout = A\cos[\omega_o t + \varphi] \qquad \text{---------- (9)}$$

where amplitude A and arbitrary phase φ are constant values. Therefore, the spectrum of this signal are two impulses at frequencies $\pm f_o = w_o/2\pi$, where f0 is the frequency of oscillation [5] . However, when using a real oscillator, the amplitude and the phase are affected by noise and are time-variant, so the output is now:

$$V_{out}(t) = A(t)cos[w_o t + \emptyset(t)] \qquad \text{----------(10)}$$

Where φ(t) is called the excess phase of the output. The spectrum of this signal has sidebands close to the frequency of oscillation f0. These instabilities in amplitude and phase can be characterized quantifying the single sideband noise spectral density around the carrier $w_0$ [5] . It has units of decibels below the carrier per hertz (dBc/Hz) and is defined as :

$$\mathcal{L}_{total}(\Delta w) = 10\log\frac{Psideband(w_0 + \Delta w, 1Hz)}{P_{carrier}} \qquad \text{-----------(11)}$$

where Psideband($w_0$ + Δw, 1Hz) is the single sideband power at an offset Δw from the carrier measured within a bandwidth of 1 Hz and Pcarrier is the power of the signal at $w_0$. This noise characterization includes the effect of both amplitude and phase fluctuations, which is a disadvantage because it is not possible to know them separately. On the other hand, this parameter has the advantage that is easily measurable using a Spectrum Analyzer because the values of Psideband($w_0$+Δw, 1Hz) and Pcarrier are easily obtained.

### 4.2 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

International Journal of Applied Information Systems (IJAIS) – ISSN : 2249-0868
Foundation of Computer Science FCS, New York, USA
Volume 3, No .3, July 2012 – www.ijais.org

frequency is a linear function of its control voltage (*Vcon*)[3], as shown in Figure 6

$$f_{out} = f_0 + K_{VCO} . V_{con} \quad \text{---------- (12)}$$

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

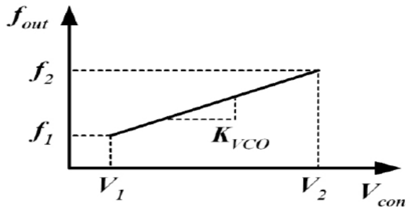


**Fig 4: Definition of *KVCO***

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-tank VCO is approximately equal to $f_{osc} = 1/(2\pi\sqrt{LC})$ that only the inductor and capacitor values can be varied to tune the oscillation frequency.

### 4.3 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

$$V \approx I_{total} . R_{eq} . \quad \text{--------- (13)}$$

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.

## 5. LC TANK VCO TOPOLOGIES

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

### 5.1 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. Rs is a poly silicon resistor which is almost 1/f noise-free.

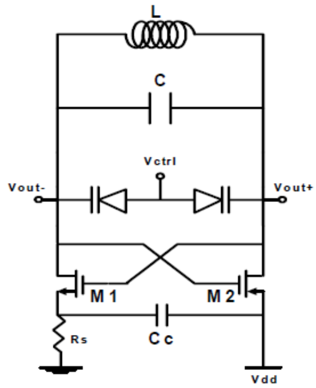


**Fig 5: Differential cross coupled VCO**

### 5.2 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.

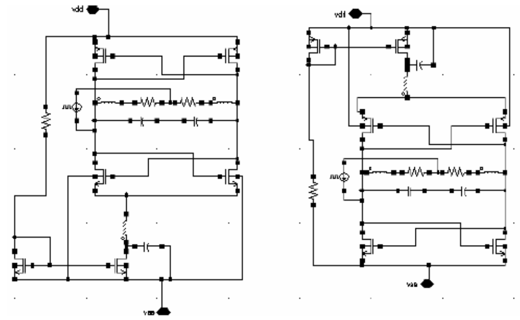

**Fig 6: Complimentary cross coupled LC tank VCO**

### 5.3 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 $Q^2$, 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 tranceconduce 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].

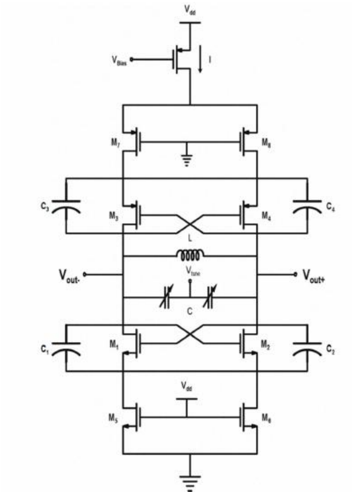

**Fig 7: Cross coupled LC tank VCO with double Pseudo resistance**

## 5.4 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, reconfigurable LC tank is adopted.

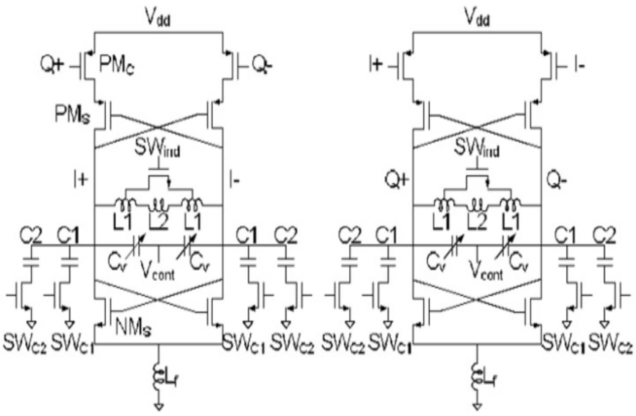


**Fig 8: Quadrature VCO using Reconfigurable LC tank**

## 6. COMPARISON AND DISCUSSION:

From this comparison table, it is seen that when we compared differential cross coupled LC tank VCO [7] and LC tank VCO with pseudo resistance [9], phase noise in second case is less than the differential LC tank VCO.For complimentary cross coupled VCO, phase noise for VCO designed using PMOS current mirror is less as compared to the VCO designed using NMOS current mirror. The quadrature VCO which designed for dual band operation, phase noise of lower frequency band is less than phase noise of higher frequency band.

**Table 1. comparison of parameters**

| Mode | Ref.7 | Ref.8 | Ref.9 | Ref.10 |
|---|---|---|---|---|
| Technology | 0.18 | 0.18 | 0.18 | 0.18 |
| Carrier Freq. | 2.4GHz | 2.4GHz | 2.55GHz | 1.80-2.06GHz(LFB) 4.12-4.89GHz(HFB) |
| Current consume | -- | -- | 1.27mA | 4mA |
| Supply voltage | 1.2V | 3.3V | 1.5V | 1.7V |
| Power consume | 0.675mW | -- | 1.9mW | 8.6mW |
| Tuning range | 2.28-2.47GHZ (8%) | 2.17-2.70GHz (21%) | 2,28-2.59GHz (12.2%) | -- |
| Tuning voltage | 0-1.8V | -- | 0-1.5V | -- |
| Phase noise | -121.11dBc/Hz @1MHz | <-119dBc/Hz@600K | -125.5dBc/Hz @1MHz | -115.06dBc/Hz @1MHz |
| FOM | -190.31 | -- | -190.84 | -181.8dB(LFB) -180.5dB(HFB) |

## 7. CONCLUSION

Phase noise and 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.

## 8. REFERENCES

[1] *Jie Long, Jo Yi Foo, Robert J. Weber*, "A *2.4 GHz Low-Power Low-Phase-Noise CMOS LC VCO*,"VLSI,IEEE computer Society Annual Symposium on (2004),pp.213-214

[2] *Varun K. Shenoy*, "*CMOS VCO & LNA Implemented by Air-Suspended On-Chip RF MEMS Inductors*," ," M.S. thesis,The University of Texas At Arlington,July 2007.

[3] *Yoon, Sangwoong,"* LC-tank CMOS voltage-controlled oscillators using high quality inductors embedded in advanced packaging technologies", PhD Thesis, GEORGIA INSTITUTE OF TECHNOLOGY, 2004.

[4] *John Starr Hamel* "*LC tank Voltage Controlled Oscillator Tutorial*," Waterloo, Ontario, Canada, 2005..

[5] *Rafaella Fiorelli*, "*Low power integrated lc voltage controlled oscillator in cmos tech-* nology at *900mhz*," M.S. thesis, Facultad de Ingenierıa..

[6] Sergio Gagliolo," Low Phase Noise Differential Cross-Coupled CMOS VCOs with Resistive and Inductive Tail Biasing",Ph.D. Thesis, Information and Communication Tecnhnology,2008.

[7] Hyun Seok Choi, Quang Diep Bui, and Chul Soon Park, "A low-power CMOS VCO for 2.4GHz WLAN," IEEE Compound Semiconductor Integrated Circuit (CSIC) Symposium, pp. 1–4, Oct. 2007.

[8] Yuemei Li Zheying Li Bo Li Chunlei Wang," 2.4GHz VCO Design and Tail Current Analysis",7th International conference on ASIC 2007.

[9] Mohammad Niaboli-Guilani" A Low Power Low Phase CMOS Voltage Controlled Oscillator" 17th IEEE International Conference on Electronics, Circuits, and Systems (ICECS), 2010.

[10] Cheol-Hoe Kim, Soo-Hwan Shin, and Hyung-Jou Yoo" A Low Phase Noise and Low Power Series Coupled Quadrature VCO Using Reconfigurable LC Tank" Radio and Wireless Symposium, vol.on page 395, 2008 IEEE.

[11] "Design of Analog CMOS Integrated Circuits"by Behzad Razavi.

[12] Andrew Y.Wang,"Energy Efficient Modulation and MAC for Asymmetric RF Microsensor Systems", ISLPED'01 August6-7, 2001.

[13] Y. H. Chee," A 46% Efficient 0.8dBm Transmitter for Wireless Sensor Networks", IEEE 2006 Symposium on VLSI Circuits Digest of Technical Papers.

[14] K.bult, ABurstein,"Low Power Systems for Wireless Microsensors", ISLPED 1996 Monterey CA USA.

[15] Bo Zhao," An Ultra-Low-Supply Dual-Band VCO for wireless Sensor Networks, "International Conference on Communication, Circuits and Systems, 2009,on pages 797-801.