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DESIGN AND ANALYSIS OF LC VCO USING DIFFERENT CMOS TECHNOLOGY

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ABSTRACT

This project reveals the different types of VCO topologies and their comparison on the basis of their voltage, power and frequency in different CMOS technology. These VCO's topology is designed using ring oscillator. The various topologies which we have design and compared Single Switch LC-VCO, Double Switch LC-VCO and Single Switch with current source LC-VCO. The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) is a transistor used for amplifying or switching electronic signals. CMOS is a Complementary Metal Oxide Semiconductor which is a combination of PMOS & NMOS. This technology is used because of it very low power dissipation. VCO is a Voltage Control Oscillator, in which the output frequency is controlled by its input controlled voltage. By using both of these in a combination, different VCO topology based on ring oscillator can be implemented A current mirror is a circuit designed to copy a current through one active device by controlling the current in another active device of a circuit, keeping the output current constant regardless of loading. For simulation of these VCO Tanner EDA is used, in which EDA is an Electronic Design Automation. The 13 version of Tanner EDA tool is used for simulation. CMOS VCO can be used in various applications. Some are Phase Locked Loop (PLL), frequency generator, testing circuits etc. In this VCO topology, we have used supply voltage of 1.5 V. This project reveals with the design and analysis of different LC-VCO. Here we have used the different types of topologies of the ring oscillator. Here we have used different strategies to enhance the performance of the ring oscillator such as frequency, power dissipation, area and PVT variation.

Keywords- *VCO, LC VCO, Colpits Oscillator, Hartley Oscillator, Clapp Oscillator, Ring Oscillators, Relaxation Oscillators, Tuned Oscillators*

I. INTRODUCTION

VCO are widely used in instrumentation and communication systems. Technical evolution and market requirements demand for High frequency generation.vco are also used in pacemaker. A voltage-controlled oscillator or VCO is an electronic oscillator designed to be controlled in oscillation frequency by an input voltage. The frequency of oscillation is varied by the applied DC voltage.

Voltage-controlled oscillator or VCO is an electronic circuit that uses amplification, feedback, and a resonant circuit to generate a repeating voltage waveform. The frequency, or rate or repetition per unit of time, is variable with an applied voltage, while alternating current audio or other signals may be fed into the VCO to generate frequency modulation (FM).For high-frequency VCOs, the voltage-controlled element is commonly a varicp connected in an ordinary LC oscillator of some form. For low-frequency VCOs.

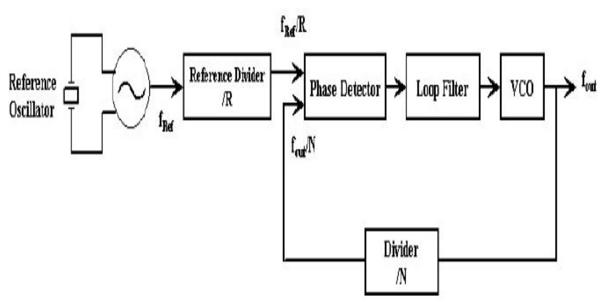

Fig.1.1 (a) Block Diagram of PLL in Used of VCO

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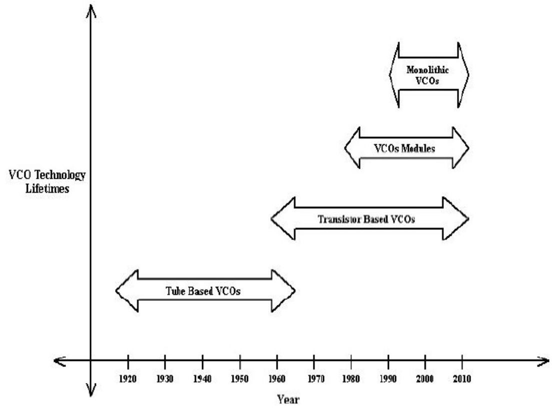

Fig 1.1 (b) Evolution of VCO Technology

In recent years, there has been a strong growth in the modern wireless data and voice communication standards in numerous frequency bands. Modern transceivers for the wireless communication consist of many building blocks, such as low-noise amplifiers (LNAs), mixers, frequency synthesizers (FS), filters and amplifiers. With the advancement of radio frequency (RF) technology and requirement for more integration, new RF wireless architectures are needed. There is a tremendous demand of mobile communication and wireless communication systems in today's modern life. This has placed certain limitations and requirements on the communication channel bandwidths and spacing. The modern wireless communication systems rely strongly on frequency conversion and switching of one frequency band to other frequency bands.

Frequency synthesizer is one of the most critical components in the wireless transceiver. It greatly affects the overall performance of the wireless transceiver system. Frequency synthesizers are commonly used as a local oscillator (LO) in the wireless transceivers for frequency translation and channel selection.

The key idea is to down convert the RF signal to the baseband signal and it is also known as direct conversion or zero-IF receiver. To avoid the loss of information, the down conversion must provide quadrature outputs for the frequency and phase modulated signals. Therefore, frequency synthesizer requires the accurate quadrature signal generation from local oscillator (LO) . RF transceivers require quadrature signal and quadrature voltage controlled oscillator (QV CO) provides the best solution for the generation of the quadrature signal.

A new generation of wireless transceivers is being integrated into CMOS technology. This includes the digital and mixed analog-digital baseband circuits, which influence the choice of radio transceiver architectures. The CMOS technology calls the elimination of discrete components in the favor of high level on chip integration. In general, there are various technologies available for the radio frequency integrated circuits (RFICs) implementation.

The oscillators are the major bottleneck for the system-on-chip (SOC) realization of the wireless transceivers. The oscillator plays an important role in the performance of wireless transceivers. Voltage controlled oscillator (V CO) spectral purity performance can limit the RF transceiver's performance. Voltage-controlled oscillator or VCO is an electronic circuit that uses amplification, feedback, and a resonant circuit to generate a repeating voltage waveform. The frequency, or rate or repetition per unit of time, is variable with an applied voltage, while alternating current audio or other signals may be fed into the VCO to generate frequency modulation (FM).For high-frequency VCOs, the voltage-controlled element is commonly a varicap connected in an ordinary LC oscillator of some form. For low-frequency VCO.

1.1 Ideal VCO Specifications

a) Low noise.

b) Low power.

c) Integrated.

d) Wide tuning range.

e) Small die area occupancy.

f) High frequency (GHz).

1.2 VCO application

a) The field of high-frequency circuit design is receiving significant industrial attention due to variety of radio frequency and microwave applications.

b) The rapid growth of commercial communication applications has led to a commensurate demand for better and cheaper devices.
c) New techniques or by the use of frequency dividers, frequency of VCO can be decreased further to obtain the desired frequency, so that it can be utilized for pacemaker application.
d) Voltage-controlled oscillators (VCO'S) are necessary in applications such as the demodulation of FM signals, and for clock recovery from digital data.
e) Function generators.
f) The production
g) of electronic music, to generate variable tones.
h) Phase-locked loops.
i) Frequency synthesizers used in communication equipment.

optical communication systems - In digital optical transmission systems, VCOs are used as the core circuit of the clock recovery circuit, whose output signal is used for data decision and regeneration

1.3 Different topology of VCO

1.3.1 Ring Oscillators

Ring oscillators consist of an odd number of single-ended inverters or an even/odd number of inverters with the appropriate connections and this is described in detail in the next chapter. It is primarily employed in some applications due to its wide tuning-range, high integration and small layout area. The oscillation frequency is directly related to the delay time of each inverter, resulting in high sensitivity to process and temperature variations. Its nonlinear voltage-to-frequency transfer characteristic gives high gain at low frequencies VCO.

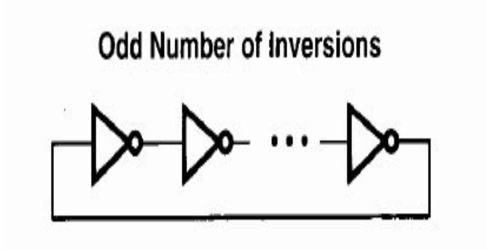

Fig.1.2 Block Diagram of Ring Oscillator

1.3.2 Relaxation Oscillators

Relaxation oscillators alternately charge and discharge a capacitor with a constant current between two threshold levels.

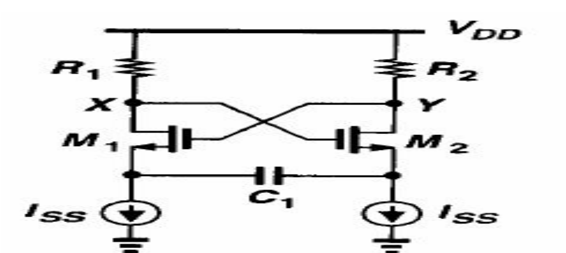

Fig.1.3 Relaxation Oscillator

1.3.3 Tuned or LC Oscillators

Tuned oscillators contain a passive resonator- LC tank, transmission line resonator, crystal, SAW - that serves as the frequency setting element. They are harder to integrate primarily because of the lack of high quality passive inductors in standard IC

Technologies and because of their large size. However, they have much higher frequency stability and spectral purity since it is set by the passive resonator. They generate their AC waveform with the assistance of an inductor–capacitor tank. Feedback to an amplifier is used to help maintain oscillation and to reduce damping. The frequency of the oscillator output is determined by the equation.

$$F_{osc} = \frac{1}{2\pi\sqrt{LC}}$$

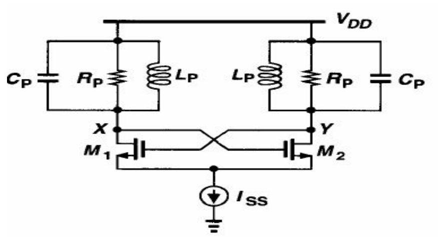

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Fig 1.4LC Oscillator

An input voltage can tune the frequency if a varactor (a semiconductor device with a voltage dependent capacitance) is used in place of the capacitor.

1.4 Basic topologies comparison

• Ring oscillators & relaxation oscillators

Advantage

a) Ease of integration

b) Wide tuning range

c) Linear tuning (voltage or current)

Disadvantage

a) Very sensitive to noise

b) Large phase noise

c) Difficult to obtain high frequencies

d) Open loop *Q* close to one

• LC oscillators

Advantage

a) Low phase noise

b) One-transistor oscillator possible

c) Very high frequency

d) Large spectral purity

1.5 CMOS VCO Topology

There are numerous CMOS VCO topologies which are available in today's communication systems. The single switch V CO (SS –V CO) and double switch (DS – V CO) are most commonly used in RFIC transceiver architectures. Both uses negative resistance concept to cancel the losses in resonator. The transistor dimensions are set to achieve the required value of the negative resistance. The inductor Q factor also influences the performance of the V CO. High Q value of the inductors and enough transconductance of the active device leads to the higher amplitude of the V CO output swing. There are different biasing techniques used in V Cos such as tail biasing, capacitive coupling and top biasing of the V CO circuit. By adding tail biasing i.e. current source effects the phase noise and oscillation amplitude of the V CO. The 1/f noise of the current mirror or current source is added in the V CO circuit and leads to the degradation in the phase noise of the V CO. Different techniques are used to reduce the 1/f noise by adding inductor degeneration or filters circuits. The basic SS – V CO consists of two Nmos cross-coupled transistors connected to the tank by its drains. The biasing is carried out by using a current source between MOS source and ground terminals (or between tank and Vdd), as shown in Fig 3.7 (a). The drawback of this topology is the direct dependence of the properties of the circuit with the voltage source's fluctuations and technology parameter variations.

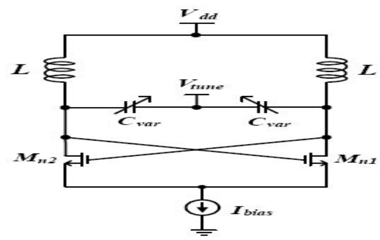

Fig. 1.5 (a) circuit of SS- VCO

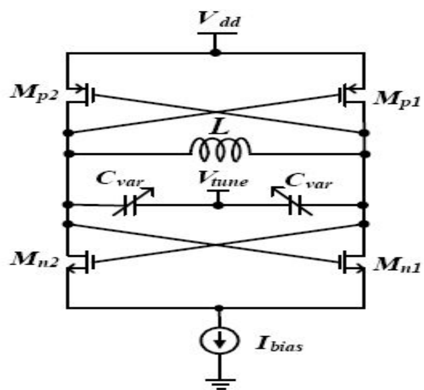

Fig.1.5 (b) circuit DS-VCO

The non-constant value of the bias current can lead in poor phase noise. However, on the other hand DS−V CO uses two blocks of cross-coupled pair transistor Pmos and Nmos and an MOS current source as shown in Fig 3.8 (b). Cross-coupled oscillators have been preferred over other topologies due to their ease of implementation, relaxed start-up condition and differential operation.

The noise generated by the active devices of the complementary cross-coupled oscillator is maximum when the oscillator's phase is sensitive to perturbations. In this topology, the noise generated by both Pmos and Nmos transistors add to theoverall active noise of the oscillator. The complementary cross-coupled (DS –VCO) oscillator shows a better phase noise performance when compared to SS – V CO for the same supply voltage and the bias current.

The complementary cross coupled oscillator presents a larger maximum output swing than SS−V CO only cross-coupled oscillators. In complementary cross coupled oscillator, the additional Pmos device enhances the overall phase noise performance. However, the major disadvantage of the DS – V CO is that Pmos device exhibits.

Larger parasitic capacitances such as gate-to-source capacitance Cgs and gate-to-drain capacitance Cgd usually five times more than the Nmos device. However, the overall 1/f noise is not degraded as in SS – V CO structure.

1.6 Parameters of VCO

Oscillator performance depends on various parameters. Some of the important parameters such as phase noise issues and figure of merit will be discussed in the following section.

1.6.1 Phase Noise

The phase noise in the oscillator has great importance because poor phase noise

can lead to the degradation in the performance of the whole transceiver. Oscillator consists of active and passive devices. Noise sources can be divided into two groups, namely device noise and interference. All devices exhibits some noise such as thermal noise, flicker noise and shot noise which lies in the category of device noise. Therefore, the substrate noise in the later group. Phase noise is the random variation of the frequency signal from its actual position or from its ideal position. The phase noise in actual oscillator cannot be removed totally and there is no phase noise in an ideal oscillator. In RF circuits, the phase noise means that the output signal contains the energy components at other frequencies rather than from its carrier signal frequency. In actual oscillator the spectrum exhibits some skirts around the carrier signal while ideal oscillator's spectrum exhibits impulse shape. To express the phase noise we consider the unit bandwidth at an offset frequency of $\Delta\omega$ with respect to $\omega 0$ or we

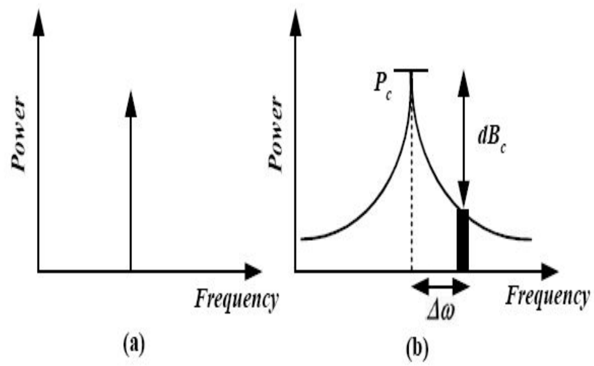

Fig 1.6 Frequency spectrum of an (a) Ideal (b) practical

can say that ratio of power at particular offset frequency (_$\Delta\omega$ from the carrier to the power at center frequency. The phase noise unit is "dBc/Hz". The phase noise can be expressed Eq.

$$L(\Delta\omega) = 10\log\left(\frac{P_{1Hz}(\omega_\circ + \Delta\omega)}{P_c}\right)$$

where Pc is the carrier power and $\omega 0$ represents the carrier frequency. The above expression shows that phase noise can be improved significantly as Pc is increased.

1.6.2 Figure of merit (FOM)

The figure of merit (FOM) is one of the key factors which is most widely used to examine the performance of the oscillator. The phase noise, power dissipation, offset frequency and carrier frequency are used in the formulation. The designers use this formulation to compare their oscillator performance with the state of the art work. Low phase noise at higher frequencies is one of the key challenges which is observed with FOM. The FOM can be given by Eq.

$$FOM = L(\Delta\omega) + 20\log\left(\frac{\omega_\circ}{\Delta\omega}\right) - 10\log\left(\frac{P_{diss}}{1mW}\right)$$

Throughout where Pdiss is the dc power dissipated in the oscillator and L($\Delta\omega$) is the phase noise

eq. is used in this thesis to calculate FOM.

1.6.3 Frequency Tuning Range

The output frequency of the oscillator is varied by varying the dc tune voltage, it is known as voltage controlled oscillator (V CO). The required tuning range is dictated by the variation of the V CO center frequency with process and temperature. The oscillation frequency of the V CO can be varied by the process variation and temperature. The sufficient tuning range is required to guarantee that V CO output frequency can be driven to the required value. The standard V LSI process includes pn-junction capacitance of the reverse biased diode and MOS varactor. The Q factor of the varactor is also one of the important factors which influences the tuning range of the oscillator. The MOS varactors exhibit the better Q factor. The LC oscillators exhibit 10 % to 12 % limited frequency tuning range . It is widely used in many applications which require the tunable frequency output. An ideal V CO exhibits the linear relation between control voltage and its output frequency signal. The V CO is the variation of the phase and frequency as the result of the noise on the control line. The noise is proportional to the (Kvco) and is given by Eq.

$$\omega_{out} = \omega_\circ + K_{vco}V_{cont}$$

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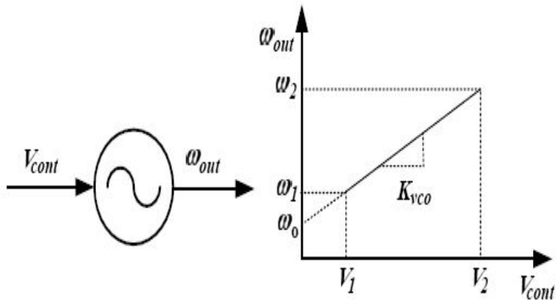

Figure 1.7 VCO sensitivity

where $\omega 0$ shows the intercept corresponding with Vcont= 0 and Kvco is the gain of the circuit. To minimize the effect of the noise in Vcont, the V CO gain must be minimized. The $\omega 2 - \omega 1$ is the tuning range of the V CO and is shown in Fig. The variable voltage ranges from V1 to V2 and the tuning range must span from $\omega 1$ to $\omega 2$. Thus, Kvco must satisfy the following requirement given by Eq.

$$K_{VCO} \geq \frac{\omega_2 - \omega_1}{V_2 - V_1}$$

A significant research has been carried out to increase the tuning range of the oscillators. The wideband/dualband CMOS V CO is presented with the wide tuning range. The tuning range is 98 % in two independent frequency bands with accurate quadrature signals outputs.

2 DESIGN OF LC-VCO

2.1 CMOS Voltage Controlled Oscillator

To determine the design equations for use with the LC-VCO. The total capacitance of variable capacitor.
$C_{tot} = Q/V$.

Where C_{tot} is total capacitance of LC-VCO. And Q is the electron charge its value is that

$$Q=1.6 * 10^{-19} \text{ Colum}$$

The oscillation frequencies of the signal switch LC-VCO.

$$F = 1/\ 2\pi\sqrt{LC}.$$

The average power dissipated by the VCO is

$P=CV^2F$.

There are three CMOS LC-VCO topology

1) **Singal Switch LC-VCO.**

2) **Double Switch LC-VCO.**

3) **Singal Switch with current source LC-VCO.**

2.2 Single Switch LC-VCO

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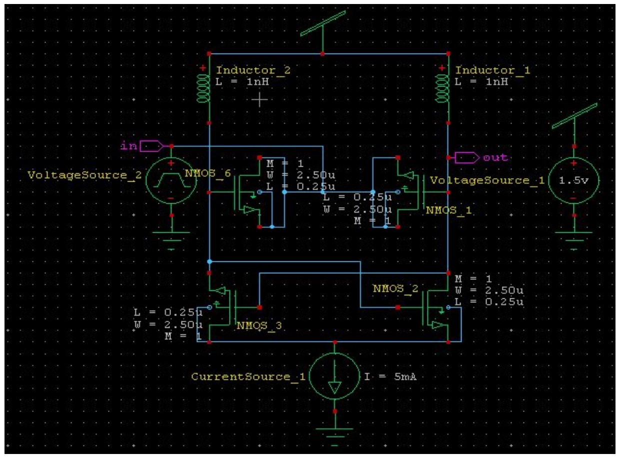

Fig 2.1 Schematic circuit of SS LC-VCO

2.3 Double Switch LC-VCO

Depicts the LC-VCO. It consist double switch LC-VCO.

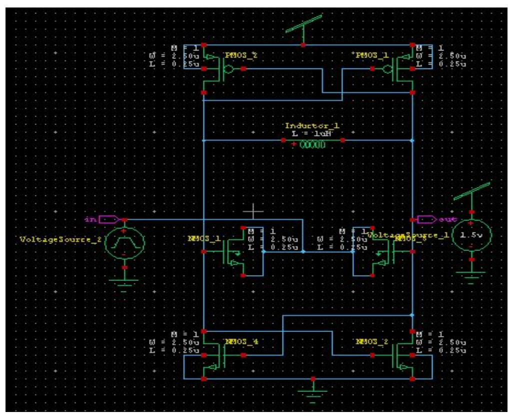

Fig 2.2 Schematic circuit of DS LC-VCO

2.4 Single Switch with current source LC-VCO

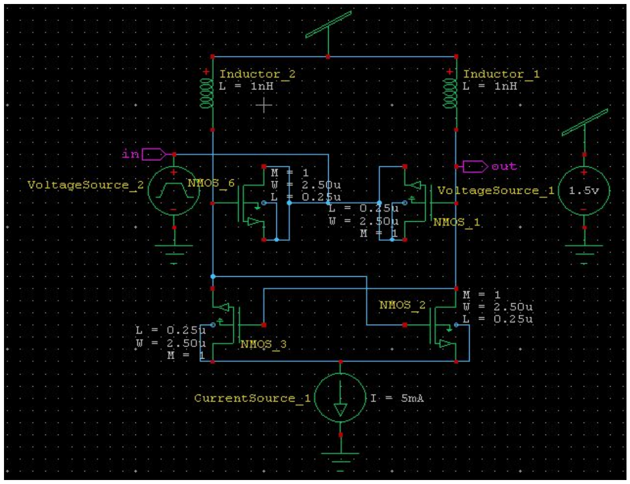

Fig 3.3 Schematic circuit of SS LC-VCO

3. RESULT AND ANALYSIS

Waveform is generated by using W-Edit. The transient response of various cells is given below

The single switch LC-VCO circuit stimulated using Tanner EDA T-spice simulator.

The single switch LC-VCO draws maximum 2.5GHZ frequency from supply voltage of 1.5V.

W-Edit

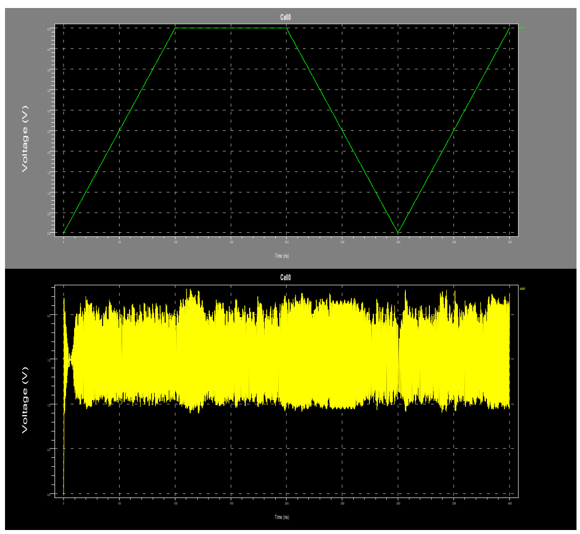

Fig 3.2 Simulation result with pulse input voltage

The summary of simulated result waveform is shown in table below:

Table1 signal switch LC-VCO

S.No.	Control Voltage (V)	Time (ps)	Frequency (GHz)
1.	0.5	0	0
2.	01	4 ns	0.25
3.	1.5	470.5	2.125
4.	02	470.7	2.124
5.	2.5	438.9	2.278
6.	03	439.39	2.275
7.	3.5	398.30	2.51
8.	04	400	2.5
9.	4.5	364.30	2.744
10.	05	404.8	2.47

Table 3.1 result of SS LC-VCO

A graph is plotted between voltage and frequency, which is shown in the figure in order to observe the relation between these two quantities.

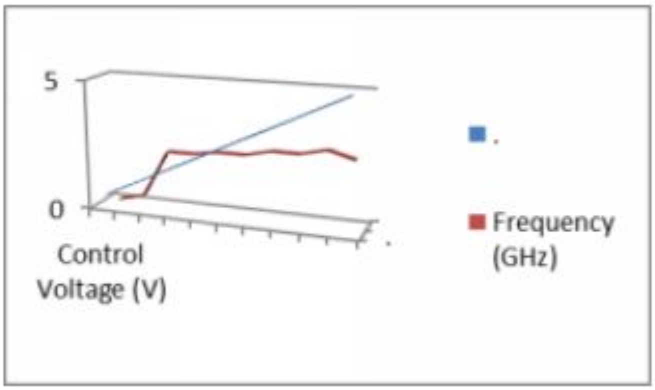

Fig. 3.3 Voltage vs. Frequency Plot of Single Switch LC-VCO

The double switch LC-VCO draws 1.8GHZ frequency from supply voltage of 1.5V.

W-EDIT

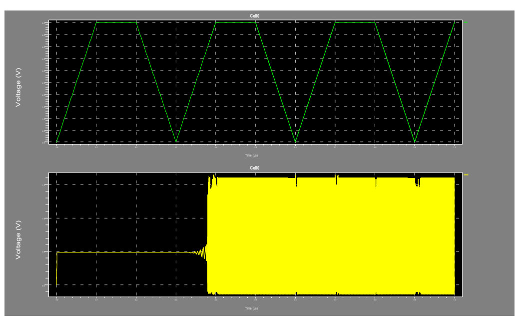

Fig 3.4 Simulation result with pulse input voltage

The summary of simulated result waveform is shown in table below:

Table1 Double switches LC-VCO.

S.No.	Control Voltage V)	Time (ps)	Frequency (GHz)
1.	0.5	0	0
2.	01	4ns	0.25
3.	1.5	726.29	1.376

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4.	02	643.84	1.553
5.	2.5	589.21	1.697
6.	03	612.24	1.663
7.	3.5	568.8	1.758
8.	04	587.5	1.701
9.	4.5	528.66	1.891
10.	05	538.31	1.857

Table 3.2 Result of DS LC-VCO

A graph is plotted between voltage and frequency, which is shown in the figure in order to observe the relation between these two quantities.

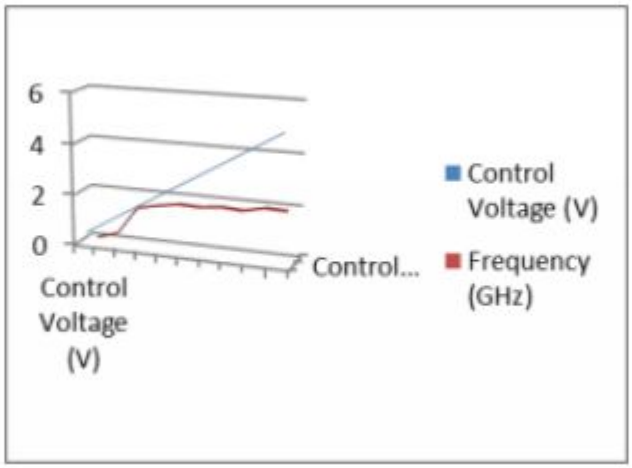

Fig 3.5 Voltage vs. Frequency Plot of Double Switch LC-VCO

The single switch LC-VCO circuit stimulated using Tanner EDA T-spice simulator.The single switch LC-VCO draws maximum 2.5GHZ frequency from supply voltage of 1.5V.

W-Edit

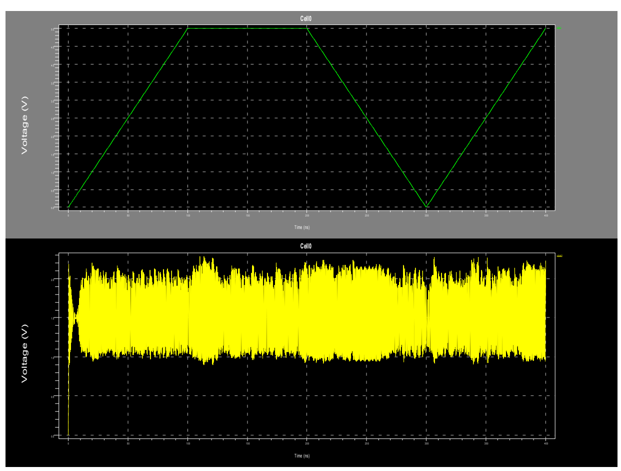

Fig 3.6 Simulation result with pulse input voltage

The summary of simulated result waveform is shown in table below:

Table1 signal switch LC-VCO

S.No.	Control Voltage (V)	Time (ps)	Frequency (GHz)
1.	0.5	0	0
2.	01	4 ns	0.25
3.	1.5	451	2.217
4.	02	477.9	2.092
5.	2.5	579.4	1.725
6.	03	375.6	2.662
7.	3.5	410.6	2.435
8.	04	398.7	2.508
9.	4.5	362.69	2.757
10.	05	529.50	1.888

Table 3.3 Result of SS LC-VCO

A graph is plotted between voltage and frequency, which is shown in the figure in order to observe the relation between these two quantities.

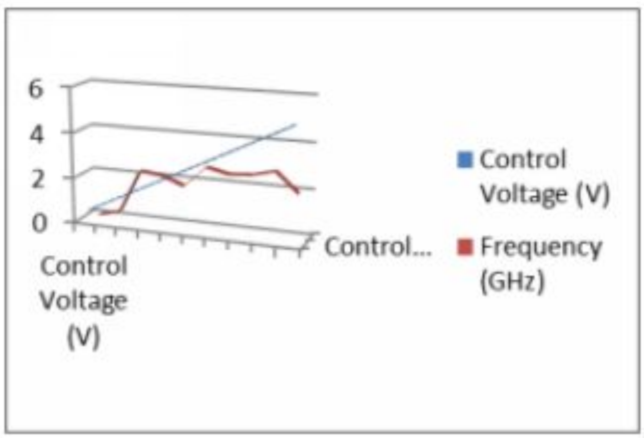

Fig. 3.7 Voltage vs. Frequency Plot of Single Switch LC-VCO

3.1 Comparison of various VCO Topologies in Terms of Power and Frequency

S.No.	Topology	Frequency (in GHz)		Power Dissipation (uW)
		Fmin.	Fmax.	
1.	Single Switch LC-VCO.	5.4	6.9	0.0036
2.	Double Switch LC-VCO	10.2	11.79	0.0100
3.	Single Switch with current source LC-VCO	8.89	9.80	0.0129

Table 3.4 Comparison of various VCO Topology in Terms of Power and Frequency

4. CONCLUSION

Tracks the history of voltage-controlled oscillators (VCOs) since approximately 1910. Provides examples of VCO integration in

RF ICs. Presents technology, performance and size evolution to the present date. Based on history and technology, future trends are projected

Voltage-controlled oscillators (VCOs) are commonly found in wireless systems and other communications systems that must tune across a band of frequencies. VCOs are available from a wide range of manufacturers in a variety of package styles and performance levels. Modern surface-mount and radio-frequency-integrated-circuit (RFIC) VCOs however, owe their heritage to engineering developments that began almost a hundred years ago. Improvements in VCO technology have continued throughout that time, yielding ever smaller sources with enhanced phase noise and tuning linearity.

Oscillators have been essential components from the time Edwin Armstrong discovered the heterodyne principle. In this application, an oscillator feeds sinusoidal signals to a nonlinear mixing element to effect frequency translation by multiplying the oscillator's signals with other input signals. Of course, Armstrong realized that what he needed to control the frequency translation was an electrical circuit which produced a stable sinusoidal time-varying voltage (or current) with a corresponding frequency. He discovered around that same time that an Audion (an early vacuum tube) could be configured to produce an oscillation, and he effectively devised the first electronic oscillator (rather than the crude spark-gap oscillators used in early wireless transmitters).

Future Scope

a) Implementation of this design will give better power consumption, phase noise, tuning range and FOM.
b) It is also useful for RF communication system where the low phase noises, low power consumption, wide tuning range are the basic requirements.
c) In our proposed design we use a single stage VCO with no mirror, with tail current and then we add current mirror for improvement in its parameter which will become beneficial for VCO user and manufacturers.
d) Taking the layout level up to fabrication.Improve the oscillation frequency range.

6. REFERENCES

[1] Srivathsava N. L & Tripti Kulkarni, "Novel Design of VCO with Output Peak to Peak Control, " Dept. of Electronics and Communication, PES Institute of Technology, 100-ft Ring Road, BSK 3rd Stage, Bangalore-560085, Karnataka, India.

[2] Namrata Prasad1, R. S. Gamad2 and C. B. Kushwah3, "Design of a 2.2-4.0 GHz Low Phase Noise and Low Power LC VCO, " 1Electronics & Instrumentation Engineering Department, SGSITS, 23, Park Road, Indore, M.P., India – 452003.

[3] Debashis Mandal and T. K. Bhattacharyya," Implementation of CMOS Low-power Integer N Frequency Synthesizer for SOC Design " JOURNAL OF COMPUTERS, VOL. 3, NO. 4, APRIL 2008.

[4] Alan W. L. Ng and Howard C. Luong, Senior Member, IEEE "A 1-V 17-GHz 5-mW CMOS Quadrature VCO Based on Transformer Coupling" IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 42, NO. 9, SEPTEMBER 2007.

[5] Shailesh S. Rai, Student Member, IEEE, and Brian P. Otis, Member, IEEE "A 600 _W BAW-Tuned Quadrature VCO Using Source Degenerated Coupling" IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 43, NO. 1, JANUARY 2008.

[6] Murat Demirkan, Student Member, IEEE, Stephen P. Bruss, Student Member, IEEE, and Richard R. Spencer, Fellow, IEEE "Design of Wide Tuning-Range CMOS VCOs Using Switched Coupled-Inductors" IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 43, NO. 5, MAY 2008.

[7] 1S. Zafar, Student Member, IEEE, 2M. Awan, Member, IEEE and 3T. Z. A. Zulkifli, Member, IEEE "5-GHz Low-Phase Noise Quadrature VCO in 0.13-µm RF CMOS Process Technology " Department of Electrical and Electronics Engineering, Universiti Teknologi PETRONAS, 31750, Tronoh, Perak, Malaysia.

[8] M.H. Seyedi1, H. Mokari1 and A.Bazdar2" A High Performance 5.4 GHz 3V Voltage Controlled Oscillator in 0.35-mm BiCMOS Technology" World Applied Sciences Journal 7 (7): 829-832, 2009 ISSN 1818-4952.

[9] Mohamed Al-Azab IEEE member "Modeling and Characterization of a 5.2 GHz VCO for Wireless Communications" 26th NATIONAL RADIO SCIENCE CONFERENCE (NRSC2009).

[10] Lu Peiming, Huang Shizhen ,Song Lianyi , Chen Run "Design of A 2GHz Low Phase Noise LC VC " Proceedings of the International MultiConference of Engineers and Computer Scientists 2009 Vol II IMECS 2009, March 18 - 20, 2009, Hong Kong.

[11] Zhang Li, Wang Zhihua and Chen Hongyi," A 5-GHz CMOS VCO for IEEE 802.11a WLAN application " Institute of Microelectronics, Tsinghua University, Beijing 100084, P. R. China.

[12] MYLES H. WAKAYAMA ANDASAD A. ABIDI, MEMBER, IEEE "A 30-MHz Low-Jitter High-Linearity CMOS Voltage-Controlled Oscillator" IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. SC-22, NO.6, DECEMBER1987.

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[13] Y. Boulghassoul, Student Member, IEEE, L. W. Massengill, Fellow, IEEE, A. L. Sternberg, Student Member, IEEE, and B. L. Bhuva, Member, IEEE "Effects of Technology Scaling on the SET Sensitivity of RF CMOS Voltage-Controlled Oscillators " IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 52, NO. 6, DECEMBER 2005.

[14] Yao-Huang Kao and Meng-Ting Hsu "Theoretical Analysis of Low Phase Noise Design of CMOS VCO " IEEE MICROWAVE AND WIRELESS COMPONENTS LETTERS, VOL. 15, NO. 1, JANUARY 2005.