

# Design and analysis of VCO in 32 nm technology using RLC resonator

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**Abstract-**The design and implementation of a voltage controlled oscillator in 32 nm CMOS technology is presented. Two different VCO models have been proposed. The proposed VCO's oscillates at the secondary resonant pole frequency of 183 GHz and 143 GHz as compared to fourth order LC resonator which oscillates at 100 GHz resonant pole frequency [1]. For a 1.2V supply, the measured simulation frequencies are 0.09285 GHz and 0.09281GHz.

**Keywords-**Resonant pole frequency, VCO, CMOS.

## 1. INTRODUCTION

As the large amount of data transfer is required at high speed, very fast clock of the processor can be used. MOSFET technology must be used for the designing of these circuits so as to be operated at high frequencies and high power [2] [3]. The use of CMOS technology further advances the high speed communication. For the generation of clock in communication systems, a phase locked loop with a voltage controlled oscillator is used [1]. In recent years, a 94 GHz VCO using low leakage transistors in 65 nm digital CMOS processed with 6 metal layers has been implemented which can be tuned from 91.8 to 97.4 GHz which should be sufficient to tolerate the capacitance and positive variations resulting from the process variations [4]. In [1], the high speed voltage controlled oscillator (VCO) with fourth order LC resonator in 65 nm CMOS technology has been designed. This VCO has been incorporated in phase locked loop (PLL) to generate the clock signals above 100 GHz. The measured tuning range for this VCO is from 103.057 to 104.581 GHz [1]. In this paper, a VCO with a fourth order RLC resonator has been designed to improve the resonant frequency beyond 100GHz. It has been operated at 1.2V supply and implemented with resonant frequency of 183 GHz and simulation frequency of 0.09285GHz. Figure 1 shows the RC-L resonator.

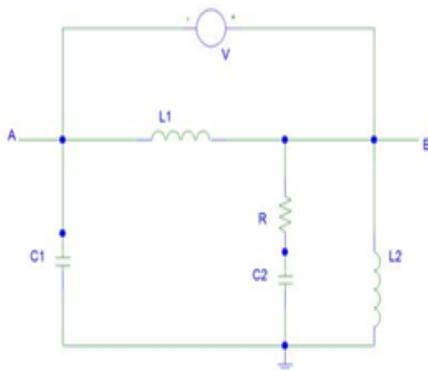


Fig. 1 Fourth order RC-L resonator.

Another VCO design has also been implemented with resonant frequency of 143 GHz and simulation frequency of 0.09281 GHz. Figure 2 shows the RL-C resonator.

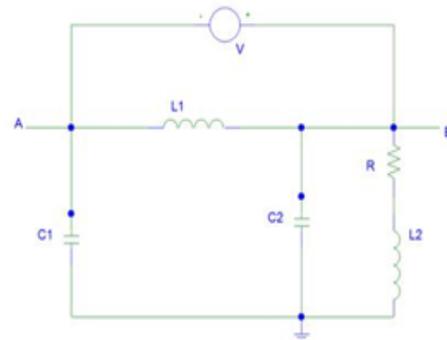


Fig. 2 Fourth order RL-C resonator.

## 2. ANALYSIS OF RLC RESONATOR

Two models of RLC resonator has been designed for the calculation of resonant frequency.

### 2.1 ANALYSIS OF FOURTH ORDER RC-L RESONATOR

#### 2.2

Fig. 1 shows a fourth order RC-L resonator. The input impedance  $Z_{in}$  between nodes A and B is calculated as:

$$Z_{in} = \frac{(s^3 RC_1 L_2 C_2 + s^2 C_1 L_2 + s RC_2 + s L_2 + 1) s L_1}{s^4 R L_1 L_2 C_1 C_2 + s^3 (R L_2 C_1 C_2 + C_1 L_1 L_2) + s^2 (L_2 C_1 + R L_1 C_2 + L_1 L_2) + s (L_1 + L_2 + R C_2) + 1} \quad (1)$$

By equating the denominator of  $Z_{in}$  to zero, the pole frequencies can be calculated. Thus pole frequency  $\omega$  becomes:

$$\omega^2 = \frac{C_1 L_2 + R L_1 C_2 + L_1 L_2}{2 R C_1 C_2 L_1 L_2} \pm \sqrt{\frac{C_1^2 L_2^2 + R^2 L_1^2 C_2^2 + L_1^2 L_2^2 + 2 L_1 L_2 (R L_1 C_2 + C_1 L_2 - R C_1 C_2)}{2 R C_1 C_2 L_1 L_2}} \quad (2)$$

Two pole frequencies can be calculated from above equation. These are  $\omega_{first}$  and  $\omega_{second}$ . That is

$$\omega_{first}^2 = \frac{C_1 L_2 + R L_1 C_2 + L_1 L_2}{2 R C_1 C_2 L_1 L_2} - \sqrt{\frac{C_1^2 L_2^2 + R^2 L_1^2 C_2^2 + L_1^2 L_2^2 + 2 L_1 L_2 (R L_1 C_2 + C_1 L_2 - R C_1 C_2)}{2 R C_1 C_2 L_1 L_2}} \quad (3)$$

$$\omega_{second}^2 = \frac{C_1 L_2 + R L_1 C_2 + L_1 L_2}{2 R C_1 C_2 L_1 L_2} + \sqrt{\frac{C_1^2 L_2^2 + R^2 L_1^2 C_2^2 + L_1^2 L_2^2 + 2 L_1 L_2 (R L_1 C_2 + C_1 L_2 - R C_1 C_2)}{2 R C_1 C_2 L_1 L_2}} \quad (4)$$

To obtain more details about the pole frequencies, let us consider the special case of  $L_1 = 2L_2 = L$  and  $C_1 = C_2 = C$ . Thus,  $\omega_{\text{first}}^2$  and  $\omega_{\text{second}}^2$  becomes:

$$\omega_{\text{first}}^2 = \frac{L+C+2RC}{2RLC^2} - \frac{\sqrt{(L+C)^2+4RLC}}{2RLC^2} \quad (5)$$

$$\omega_{\text{second}}^2 = \frac{L+C+2RC}{2RLC^2} + \frac{\sqrt{(L+C)^2+4RLC}}{2RLC^2} \quad (6)$$

From (5) and (6),  $\omega_{\text{first}}$  and  $\omega_{\text{second}}$  are given by

$$\omega_{\text{first}} = \pm \sqrt{\frac{L+C+2RC}{2RLC^2} - \frac{\sqrt{(L+C)^2+4RLC}}{2RLC^2}} \quad (7)$$

$$\omega_{\text{second}} = \pm \sqrt{\frac{L+C+2RC}{2RLC^2} + \frac{\sqrt{(L+C)^2+4RLC}}{2RLC^2}} \quad (8)$$

With  $L_1 = 2L_2 = L = 290$  pH and  $C_1 = C_2 = C = 30$  fF,  $R = 1$  k $\Omega$ , the upper figure shows that  $Z_{\text{in}}$  has a maximum value located at the first pole frequency  $\omega_{\text{first}}$  of 15.86 GHz while  $V_A$  and  $V_B$  are in phase. On the other hand, the lower figure of Fig. 2 shows that  $Z_{\text{in}}$  resonates at the second pole frequency  $\omega_{\text{second}}$  of 183.56 GHz while  $V_A$  and  $V_B$  are out of phase.

$$f_{\text{first}} = 15.86 \text{ GHz}$$

$$f_{\text{second}} = 183.56 \text{ GHz}$$

## 2.2 ANALYSIS OF FOURTH ORDER RL-C RESONATOR

Figure 2 shows a fourth-order RL-C resonator. Assuming that all of the passive components are ideal,  $c$  is calculated as

$$Z_{\text{in}} = \frac{s^3 L_1 L_2 C_2 + s^2 (RC_1 L_1 + C_1 L_1 L_2 + RL_1 C_2) + s L_1}{s^4 L_1 L_2 C_1 C_2 + s^3 RL_1 C_1 C_2 + s^2 (2L_1 C_1 + L_2 C_2) + s(RC_1 + RC_2) + 1} \quad (9)$$

The pole frequencies ( $\omega$ ) are found by equating the denominator of  $Z_{\text{in}}$  to zero. That is

$$\omega^2 = \left( \frac{1}{L_2 C_2} + \frac{1}{2L_1 C_1} \right) \pm \sqrt{\left( \frac{1}{L_2^2 C_2^2} + \frac{1}{4L_1^2 C_1^2} \right)} \quad (10)$$

$$\omega_{\text{first}}^2 = \left( \frac{1}{L_2 C_2} + \frac{1}{2L_1 C_1} \right) - \sqrt{\left( \frac{1}{L_2^2 C_2^2} + \frac{1}{4L_1^2 C_1^2} \right)} \quad (11)$$

$$\omega_{\text{second}}^2 = \left( \frac{1}{L_2 C_2} + \frac{1}{2L_1 C_1} \right) + \sqrt{\left( \frac{1}{L_2^2 C_2^2} + \frac{1}{4L_1^2 C_1^2} \right)} \quad (12)$$

To gain more insight about the pole frequencies, let us consider the special case of  $L_1 = 2L_2 = L$  and  $C_1 = C_2 = C$ . Thus,  $\omega_{\text{first}}^2$  and  $\omega_{\text{second}}^2$  are simplified as

$$\omega_{\text{first}}^2 = \frac{5}{LC} - \sqrt{\frac{17}{4L^2 C^2}} \quad (13)$$

$$\omega_{\text{second}}^2 = \frac{5}{LC} + \sqrt{\frac{17}{4L^2 C^2}} \quad (14)$$

From (5) and (6),  $\omega_{\text{first}}$  and  $\omega_{\text{second}}$  are given by

$$\omega_{\text{first}} = \pm \sqrt{\frac{5}{LC} - \frac{\sqrt{17}}{2LC}} \quad (15)$$

$$\omega_{\text{second}} = \pm \sqrt{\frac{5}{LC} + \frac{\sqrt{17}}{2LC}} \quad (16)$$

With  $L_1 = 2L_2 = L = 290$  pH and  $C_1 = C_2 = C = 30$  fF, the upper figure shows that  $Z_{\text{in}}$  has a maximum value located at the first pole frequency  $\omega_{\text{first}}$  of 92 GHz while  $V_A$  and  $V_B$  are in phase. On the other hand, the lower figure of Figure 2 shows that  $Z_{\text{in}}$  resonates at the second pole frequency  $\omega_{\text{second}}$  of 143 GHz while  $V_A$  and  $V_B$  are out of phase.

$$f_{\text{first}} = 92 \text{ GHz}$$

$$f_{\text{second}} = 143 \text{ GHz}$$

## 3. SIMULATION FREQUENCY

Every design has its preferred frequencies of vibration, called resonant frequencies, and each such frequency is characterized by a specific shape or mode of vibration [5]. Frequency analysis using standard values of all components using s-edit has been characterized.

**3.1 RL-C resonator:** In this RL-C resonator, a resistor R has been connected in series with inductor L2. The RL-C resonator oscillates at frequency 143 GHz. A 1.2V supply has been used for implementation of circuit. Figure 3 shows the VCO circuit with 32nm NMOS technology.

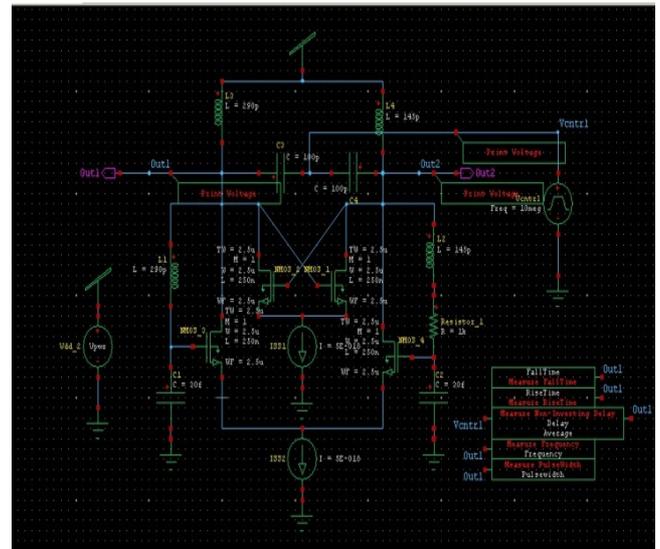


Fig. 3 VCO fourth order RL-C resonator

**DC operating point analysis:** The DC operating point analysis of the circuit diagram shown in figure 3 using T-spice has been done. The DC output voltage is 1.2V at node Out 1 and Out 2.

**Transient Analysis:** The delay, rise time, fall time, pulse width and frequency have been calculated using T-spice simulation. Figure 4 shows all the results of above parameters.

```

Opening output file "C:\DOCUME~1\ADMINI~1\LOCALS~1\Temp\RLnew.out"

Measurement result summary
Delay = 2.6193e-010
RiseTime = 1.8908e-010
FallTime = 1.9388e-010
Pulsewidth = 7.2938e-010
Frequency = 9.2816e+008

Parsing          0.02 seconds
Setup           0.03 seconds
Transient Analysis 0.59 seconds
Overhead        1.36 seconds
-----
Total           2.00 seconds

Simulation completed
    
```

**Fig.4 Simulation result of RL-C resonator**

**Transient Analysis:** The delay, rise time, fall time, pulse width and frequency have been calculated using T-spice simulation. Figure 6 shows all the results of above parameters.

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Opening output file "C:\DOCUME~1\ADMINI~1\LOCALS~1\Temp\RCnew.out"

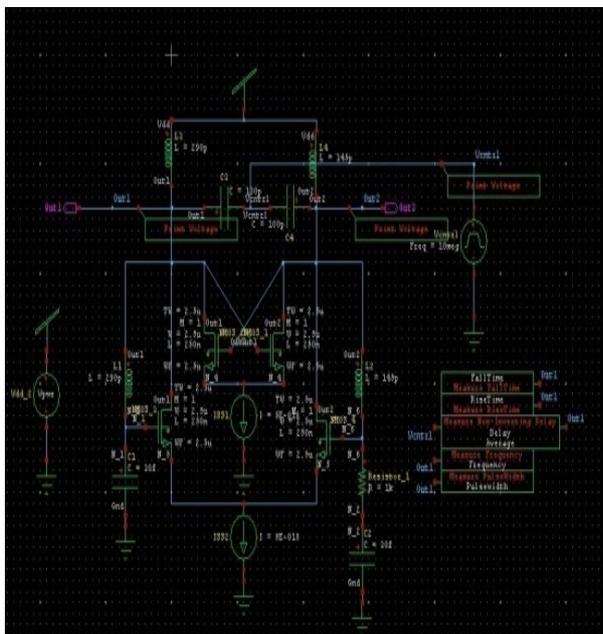
Measurement result summary
Delay = 2.6169e-010
RiseTime = 1.8908e-010
FallTime = 1.9267e-010
Pulsewidth = 7.2890e-010
Frequency = 9.2853e+008

Parsing          0.01 seconds
Setup           0.06 seconds
Transient Analysis 0.61 seconds
Overhead        0.66 seconds
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Total           1.34 seconds

Simulation completed
    
```

**Fig.6 Simulation result of RC-L resonator**

**3.2 RC-L resonator:** In this RC-L resonator, a resistor R has been connected in series with capacitor C2. The RC-L resonator oscillates at frequency 183.56 GHz. A 1.2V supply has been used for implementation of circuit. Figure 5 shows the VCO circuit and the output waveforms with 32nm NMOS technology.



**Fig.5 VCO fourth order RC-L resonator**

**DC operating point analysis:** The DC operating point analysis of the circuit diagram shown in figure 5 has been done using T-spice. The DC output voltage is 1.2V at node Out 1 and Out 2.

**4. COMPARISON AND DISCUSSION**  
 From this comparison table, it is seen that when we compared, 64 GHz, 94 GHz, an array and base paper, the phase noise of first is minimum as compare to others. Also the power consumed by an array is minimum i.e 7.59 mW.

**TABLE 1: Comparison of Parameters**

Parameters	Fourth order LC resonator[1]	Fourth order RL-C resonator	Fourth order RC-L resonator
Technology	65nm CMOS	32nm CMOS	32nm CMOS
Resonant frequency	100GHz	143GHz	183GHz
Supply	1.2V	1.2V	1.2V
Simulation Frequency	.09280GHz	.09281GHz	.09285GHz

**CONCLUSION**

For four different topologies of VCO, phase noise and power consumptions have been compared. From this it is studied that as the supply voltage increases, FOM also increases. Also with the increase in phase noise, the power consumption decreases.

**REFERENCES**

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