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Analysis of Voltage Controlled Oscillator Using RLC Resonator in 32 Nm Technology

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ABSTRACT
The designing and analysis of a VCO in CMOS model with 32nm technology is presented. Two different Voltage controlled oscillator models have been proposed. The proposed Voltage controlled oscillator oscillates at 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

To transfer a large amount of data at very high speed, very fast clock of the processor could be used. MOSFET technology must be used for the designing of these circuits [2] [3]. The use of CMOS technology further advances the high speed communication. A phase locked loop with a VCO is used for the generation of clock in communication systems [1]. In recent years, a 94 GHz VCO in 65 nm digital CMOS using low leakage transistors processed with 6 metal layers has been implemented which may be tuned from 91.8GHz to 97.4 GHz which may be sufficient to accommodate the capacitance and positive variations which is a result from the process variations [4]. In [1], the high speed voltage controlled oscillator with fourth order LC resonator in 65 nm CMOS technology has been designed. This Voltage controlled oscillator has been incorporated in PLL to generate the clock signal of 100 GHz and above. The tuning range for this Voltage controlled oscillator is from 103.057 to 104.581 GHz [1]. In this paper, a Voltage controlled oscillator 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.

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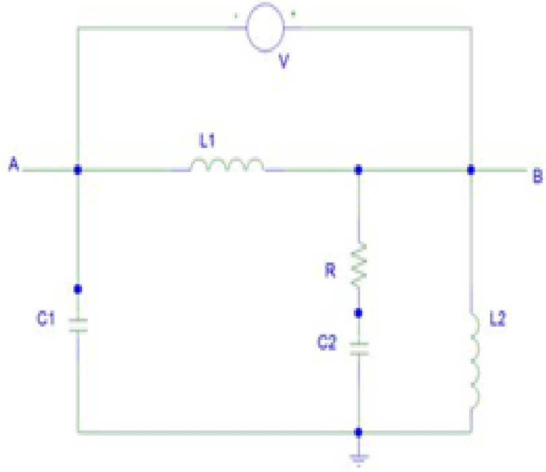

Fig. 1 Fourth order RC-L resonator.

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.

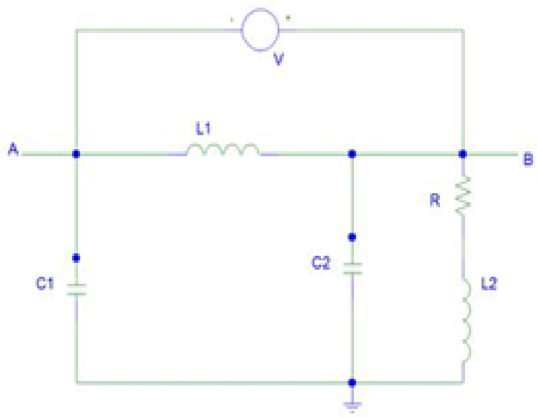

Fig. 2 Fourth order RL-C resonator.

2. ANALYSIS OF RLC RESONATOR

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

2.1 ANALYSIS OF RC-L RESONATOR WITH A FOURTH ORDER CIRCUIT

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

$$Z_{in} = \frac{(s^3RC_1L_2C_2+s^2C_1L_2+sRC_2+sL_2+1)sL_1}{s^4RL_1L_2C_1C_2+s^3(RL_2C_1C_2+C_1L_1L_2)+s^2(L_2C_1+RL_1C_2+L_1L_2)+s(L_1+L_2+RC_2)+1} \quad (1)$$

By equating the denominator of Z_{in} to 0, the pole frequencies can be calculated. Thus pole frequency ω becomes:

$$\omega^2 = \frac{C_1L_2+RL_1C_2+L_1L_2}{2RC_1C_2L_1L_2} \pm \sqrt{\frac{C_1^2L_2^2+R^2L_1^2C_2^2+L_1^2L_2^2+2L_1L_2(RL_1C_2+C_1L_2-RC_1C_2)}{2RC_1C_2L_1L_2}} \qquad (2)$$

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

$$\omega^2_{first} = \frac{C_1L_2+RL_1C_2+L_1L_2}{2RC_1C_2L_1L_2} - \sqrt{\frac{C_1^2L_2^2+R^2L_1^2C_2^2+L_1^2L_2^2+2L_1L_2(RL_1C_2+C_1L_2-RC_1C_2)}{2RC_1C_2L_1L_2}} \qquad (3)$$

$$\omega^2_{second} = \frac{C_1L_2+RL_1C_2+L_1L_2}{2RC_1C_2L_1L_2} + \sqrt{\frac{C_1^2L_2^2+R^2L_1^2C_2^2+L_1^2L_2^2+2L_1L_2(RL_1C_2+C_1L_2-RC_1C_2)}{2RC_1C_2L_1L_2}} \qquad (4)$$

For obtaining more information about the resonant pole frequencies of RLC resonator, consider this special case of $L_1 = 2L_2 = L$ and $C_1 = C_2 = C$. Thus, ω^2_{first} and ω^2_{second} becomes:

$$\omega^2_{first} = \frac{L+C+2RC}{2RLC^2} - \frac{\sqrt{(L+C)^2+4RLC}}{2RLC^2} \qquad (5)$$

$$\omega^2_{second} = \frac{L+C+2RC}{2RLC^2} + \frac{\sqrt{(L+C)^2+4RLC}}{2RLC^2} \qquad (6)$$

From (5) and (6), ω_{first} and ω_{second} are given by

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

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

With $L_1 = 2L_2 = L = 290$ pH and $C_1 = C_2 = C = 30$ fF, $R = 1k\Omega$, the first image shows that Z_{in} has its max value at the first pole resonant frequency ω_{first} of 15.86 GHz while V_A and V_B are in phase with each other. The second image of Figure 2 shows that Z_{in} resonates at the second resonant pole frequency ω_{second} of 183.56 GHz while V_A and V_B are 180 out of phase.

f_{first} = 15.86 GHz

f_{second} = 183.56 GHz

2.2 ANALYSIS OF RL-C RESONATOR WITH FOURTH ORDER CIRCUIT

Figure 2 shows a RL-C resonator with fourth order circuit. Assume all the passive components to be ideal, input impedance is calculated as:

$$Z_{in} = \frac{s^3L_1L_2C_2+s^2(RC_1L_1+C_1L_1L_2+RL_1C_2)+sL_1}{s^4L_1L_2C_1C_2+s^3RL_1C_1C_2+s^2(2L_1C_1+L_2C_2)+s(RC_1+RC_2)+1} \qquad (9)$$

The pole frequencies (ω) can be calculated by equating the denominator of Z_{in} to 0. That is

$$\omega^2 = \left(\frac{1}{L_2C_2} + \frac{1}{2L_1C_1}\right) \pm \sqrt{\left(\frac{1}{L_2^2C_2^2} + \frac{1}{4L_1^2C_1^2}\right)} \qquad (10)$$

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$$\omega^2_{first} = \left(\frac{1}{L_2C_2} + \frac{1}{2L_1C_1}\right) - \sqrt{\left(\frac{1}{L_2{}^2C_2{}^2} + \frac{1}{4L_1{}^2C_1{}^2}\right)} \qquad (11)$$

$$\omega^2_{second} = \left(\frac{1}{L_2C_2} + \frac{1}{2L_1C_1}\right) + \sqrt{\left(\frac{1}{L_2{}^2C_2{}^2} + \frac{1}{4L_1{}^2C_1{}^2}\right)} \qquad (12)$$

To obtain more details about the resonant pole frequencies, lets consider the special case of $L_1 = 2L_2 = L$ and $C_1 = C_2 = C$. Thus, ω^2_{first} and ω^2_{second} are calculated as

$$\omega^2_{first} = \frac{5}{LC} - \sqrt{\frac{17}{4L^2C^2}} \qquad (13)$$

$$\omega^2_{second} = \frac{5}{LC} + \sqrt{\frac{17}{4L^2C^2}} \qquad (14)$$

From (5) and (6), ω_{first} and ω_{second} are given by

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

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

With $L_1 = 2L_2 = L = 290$ pH and $C_1 = C_2 = C = 30$ fF, the first image shows that Z_{in} has a max value which is located at the first resonant pole frequency ω_{first} of 92 GHz while V_A and V_B are in phase. And the second image of Figure 2 shows that Z_{in} resonates at the second resonant pole frequency ω_{second} of 143 GHz while V_A and V_B are out of phase.

f_{first} = 92 GHz

f_{second} = 143 GHz

3. SIMULATION FREQUENCY

Resonant frequencies are the preferred frequencies of vibration of every design [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.

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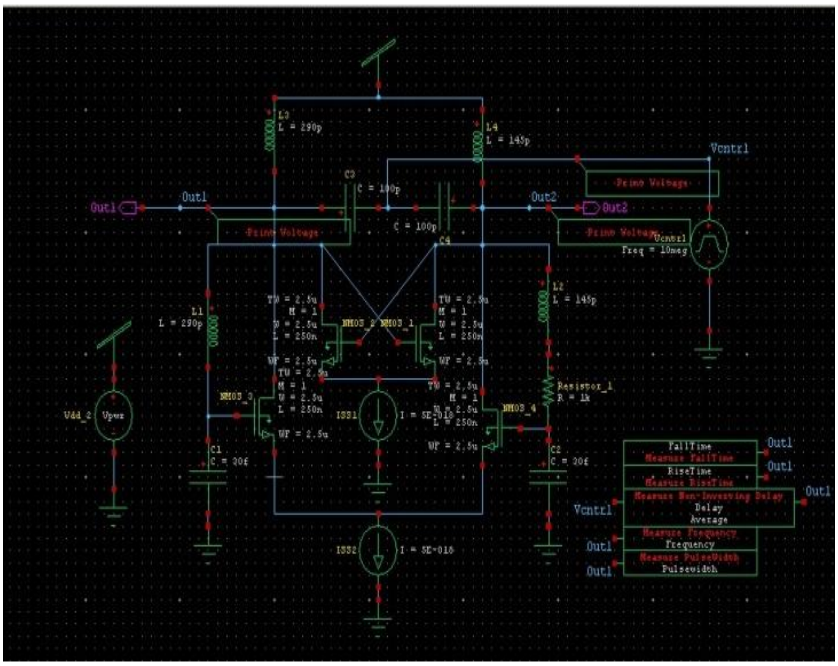

Fig. 3 VCO fourth order RL-C resonator

Analysis of DC operating point: 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, fall time, rise 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

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.

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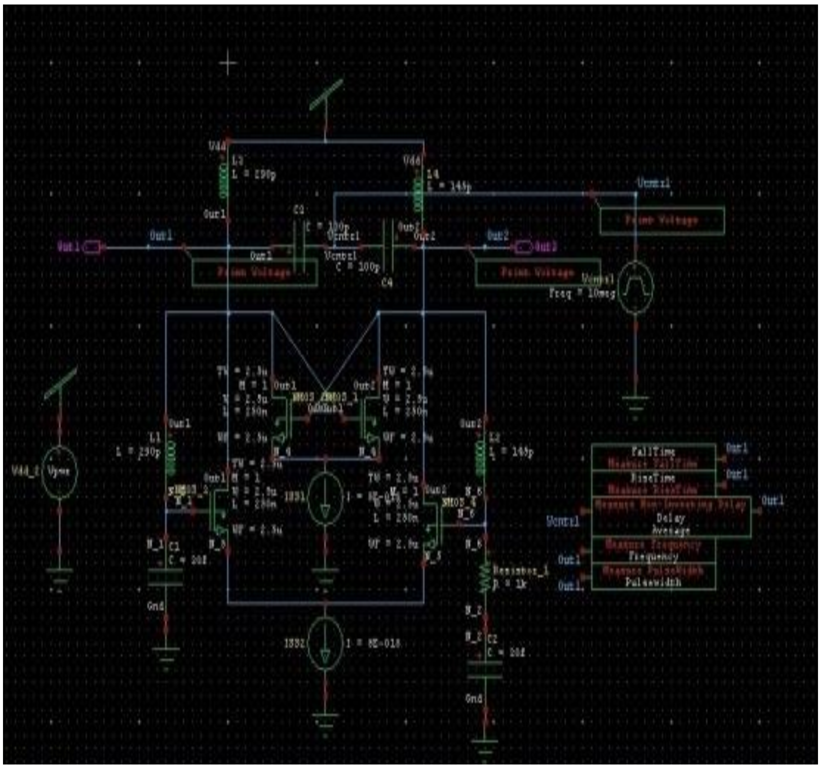

Fig.5 VCO fourth order RC-L resonator

Analysis of DC operating point: 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.

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

```
   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
-----------------------------------------
Total                        1.34 seconds

Simulation completed
```

Fig.6 Simulation result of RC-L resonator

4. COMPARISON

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Vol-22-Issue-16-August-2019

It is seen from the comparison table that when we compared the fourth order LC resonator, RL-C resonator and RC-L resonator, the resonant frequency has been improved to 143 GHz and 183 GHz respectively.

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

5. CONCLUSION

The fourth order resonators with different topologies of voltage controlled oscillator have been compared. By implementing fourth order RL-C resonator, the resonance frequency has been increased to 143 GHz and by implementing fourth order RC-L resonator, the resonance frequency has been increased to 183 GHz.

6. REFERENCES

[1] Tsai, Kun-Hung, Shen-Iuan Liu. "A 104-GHz phase-locked loop using a VCO at second pole frequency." Very Large Scale Integration (VLSI) Systems, IEEE Trans. on 20.1 (2012): 80- 88.

[2] Ali, M. H., N. J. Chidume. "Design of 800 MHz to 1.5 GHz Voltage Controlled Oscillator for Data Communication." International Journal of Scientific and Research Publications 4.11(2014).

[3] Stewart, Malcolm D.” A 20-GHz Bipolar Varactor-tuned VCO Using Switched Capacitors to Add Tuning Range”. Diss. Carleton University Ottawa, Canada, 2003.

[4] Zhang, Ning. "94 GHz voltage controlled oscillator with 5.8% tuning range in bulk CMOS." Microwave and Wireless Components Letters, IEEE 18.8 (2008): 548-550.

[5] http://www.solidworks.in/sw/products/simulation/frequency-analysis.htm