Design and Analysis of a LC-VCO using a single turn inductor

A seminar report (Course code:EE534) submitted in partial fulfillment of the requirements for the degree of

Master of Technology

by

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(Entry No. 2023EEM1020)

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Declaration

I declare that this written submission represents the analysis and design of LC-VCO using a single turn inductor. I have adequately cited and referenced the original sources. I also declare that no falsified interpretation has been done and I have adhered to all the ethics and principles of academic integrity. Further, if any violation of the aforementioned statement is found I will be held responsible and I fully understand the consequences.

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Abstract

The report presents the design an analysis of an LC VCO with uses the principle of an oscillating LC tank. Here, the focus is on the design of one such oscillator by using a single-turn inductor. The VCO has been designed in a 65nm CMOS technology with a supply voltage of 1.2v. And the achieved operating frequency is 4.6GHz. The main advantage is the use of a single turn inductor which reduces the occupied space to a great extent.

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Chapter 1

Introduction

The requirement for a tunable oscillator, i.e,the output frequency that can be tuned in accordance with the supply voltage, is ever increasing due to the need of such circuits in high frequency clock generation. One such oscillator which provide tunability is the LC-VCO(Voltage Control Oscillators) based on the principle of an oscillating LC tank and a cross coupled nmos core to mitigate the loss of the LC tank.

LC-VCO applications are found widely in many RF chips due to its easy implementation and low power consumption. Also, partly due to its property of minimizing phase noise and jitter. Also, one important aspect of such a circuit is the necessity to reduce the occupied area in a chip. Many high tuning range VCO are also reported [1] [2] but such VCO occupies a considerable amount of the chip area leading to a tradeoff between its usability and size. Also, to extend the tuning range of the VCO, proposals are made to use differential mode and multiple cores [3]. Techniques such as Colpitts's method [4] are also used sometimes to achieve the differential mode of operation.

Here, the reported circuit of LC-VCO [5] uses single turn inductor which lead to a very compact area. Also, a lossless switching is achieved and this in turn improves its tuning range.

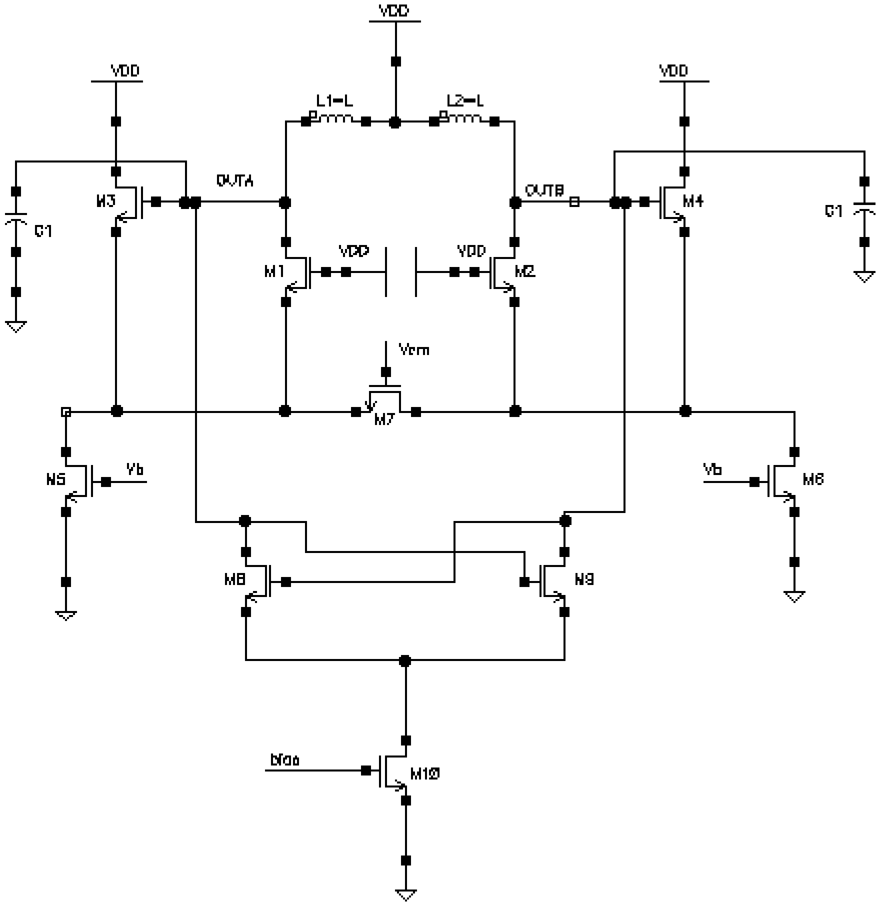

Figure 1.1: Circuit diagram of the LC-VCO under study

Chapter 2

Literature Survey

A VCO with mode switching is reported in [6] and this architecture provides an excellent impedance at both low and high frequency. This method rectifies the problem of Quality factor variation of an LC-VCO. The tuning range is also increased using multiple switching. The switching can be done between high band, mid band and low band with increasing impedance due to the increasing inductance.

A VCO with wide tuning range using a transformer-based oscillator is reported in [2]. It uses the principle of cross coupling of transformer-based tank. The oscillator has two separate core with a single oscillating tank. Interconnecting switches are used to control the inductance of the circuit tank.

Another architecture is reported in [1] with reduced phase noise by employing dual common mode. This design provides high impedances and also low flicker noise and the architecture provides automatic tuning.

Chapter 3

Circuit Operation

3.1 Circuit Description

The LC-VCO designed in this report [5] works with a pair of inductors coupled weakly. Both the inductor works as a pair of resonator working in separately and is designed to work in a sustained oscillation. The architecture is shown in figure3.1 where M5,M3 and M1 for one resonator and M6, M4 and M2 form the second resonator. M7 is turned off and the circuit is made to work in a differential mode and in this mode of operation, the tail current source, i.e., M10 is biased in the saturation region. The circuit operates with a power supply of 1.2V.

The core of the VCO is a cross coupled NMOS transitors which provide sufficient negative resistances to sustain the oscillation. The VCO is also fitted with inductors L1, L2 and C1, C2 which act as the oscillation tank of the circuit.

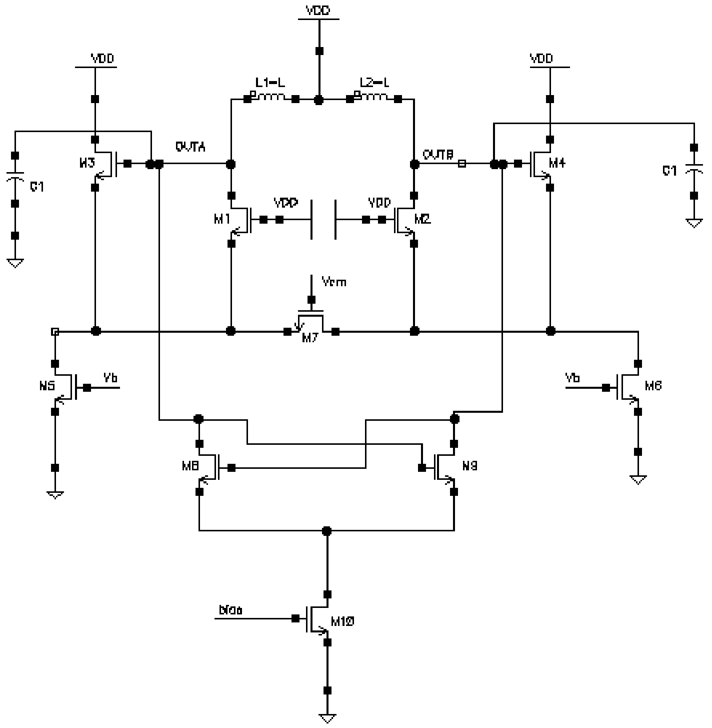

Figure 3.1: Schematic diagram of LC-VCO

3.2 Operation of Circuit

The operation of the circuit (in figure:3.1) is similar to that of any normal LC-VCO. The tail current source is biased appropriately to work in the saturation region. Transistors M8-M9 works as the cross coupled pair and oscillates in differential mode. Also, transistor M1-M2 is active and work as transconductors. The net value of the inductance is given by,

$$L = L1 + L2 - 2M$$

where M is the mutual inductance between the two inductors and is given by M = k$\sqrt{L1L2}$
Here, L1 = L2 therefore, M = kL
Therefore

$$L = 2L - 2kL$$

Consequently, the frequency of oscilation is given by,

$$f_{(osc)} = \frac{1}{2\pi\sqrt{L(1-k)C1}}$$

Also, the negative resistance offered by the VCO core is given by

$$R = \frac{-2}{gm_{M8-M9}} || \frac{-4}{gm_{M1-M4}}$$

Chapter 4

Design procedure of the LC-VCO

Assumptions made in the design [4]

VDD = 1.2 V

Power = 12 mW

Target Frequency = 4.6 GHz

Quality factor of Inductor = 10

Thus,

$$Current, I_{SS} = 10\ mA$$

For the required voltage swing of 0.6 V,

$$\frac{4}{\pi} I_{SS} R_p = 0.6\ V$$

$$R_p = 47\ \Omega$$

which we approximated and consider the value as 50 Ω

And using quality factor value of 10,

$$L = \frac{R_p}{Q\omega_0}$$

$$L = \frac{50}{10 \times 4.6 \times 10^9 \times 2\pi}$$

$$L = 172\ nH$$

Now for finding the capacitance value,

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

then,

$$C = \frac{1}{L(2\pi f)^2}$$

$$C = 6.9\ pF$$

Transistor sizing for the VCO core and tail current source.

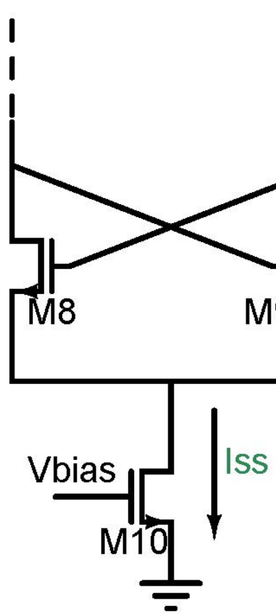

Figure 4.1: VCO core of the LC-VCO

Through simulation and $\frac{g_m}{I_d}$ approximations [7], sizing of the tail current source is $\left(\frac{W}{L}\right)_{10} = \frac{52\mu}{130n}$ Also for the core transistor, which provide negative resistance the sizing is chosen to facilitate complete switching and is found to be $\left(\frac{W}{L}\right)_{8,9} = \frac{50\mu}{130n}$

Chapter 5

Simulation Results

5.1 Transient Simulation

The simulation plot shown in figure6.1 is the result of the transient analysis and it shows the oscillation of the LC-VCO.

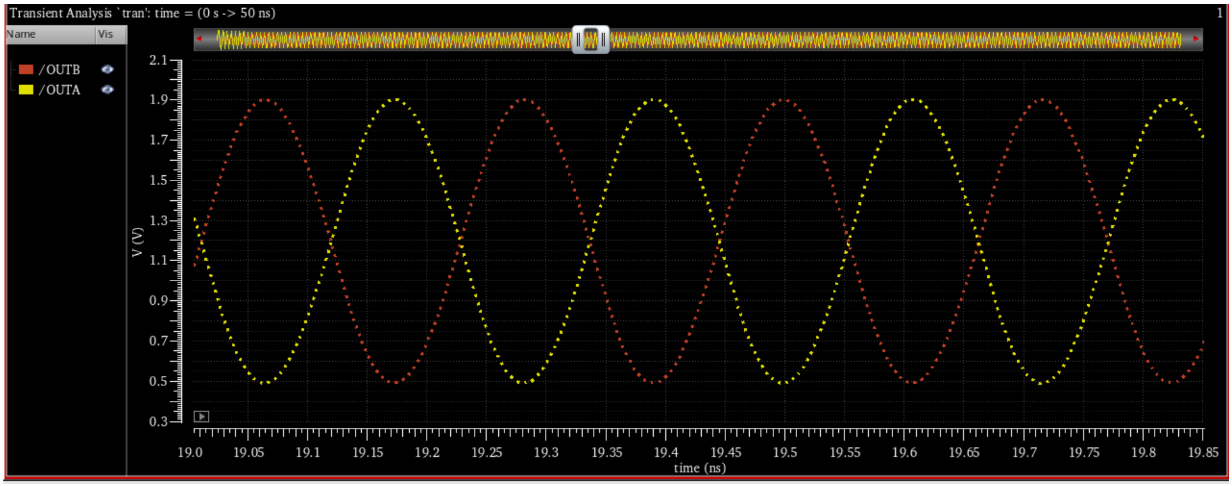

Figure 5.1: Transient Simulation of the LC-VCO

5.2 Frequency

The frequency of oscillation of the LC-VCO is shown in figure:5.2. Is is found to be 4.6 GHz and reaches the theoretically targeted value.

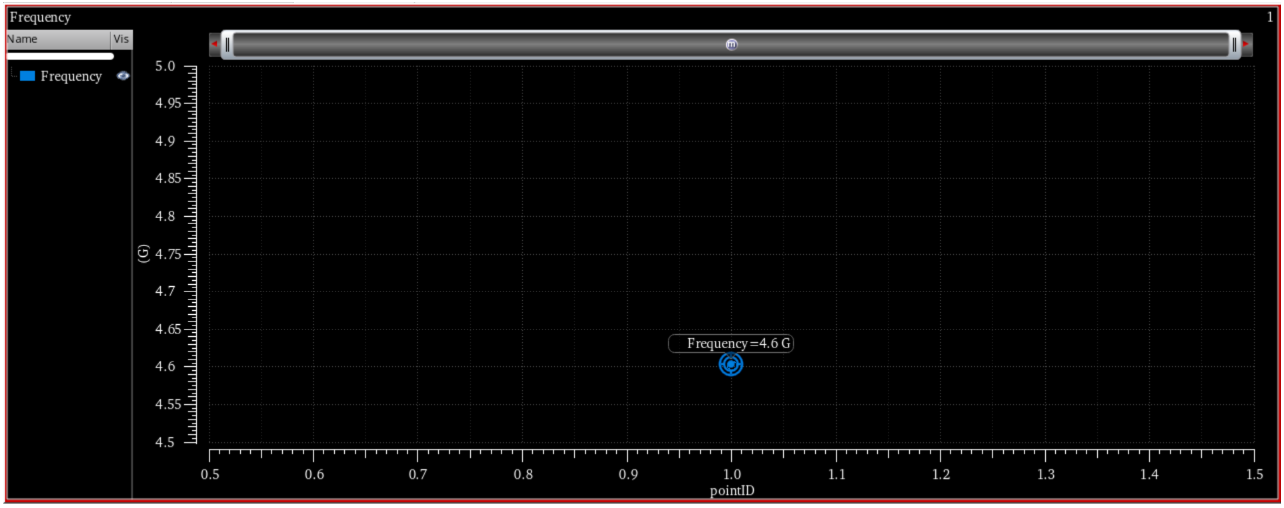

Figure 5.2: Frequency of Oscillation of the LC-VCO

5.3 Power Analysis

The power consumption of the design under study if presented in the form of a plot as shown in figure:5.3. The total power drawn from the main supply is around 46 mW.

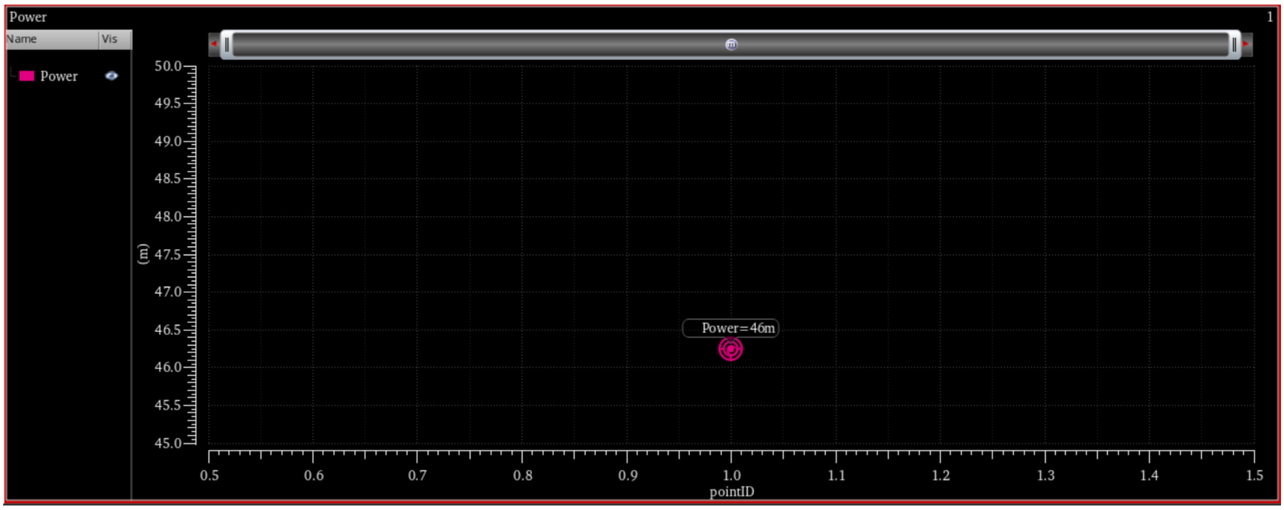

Figure 5.3: Power analysis of the LC-VCO

5.4 Stability Analysis

Stability analysis is done using the pstb analysis in ADEL and the plot for gain and phase margin of the designed LC-VCO is presented in the succeeding figure:5.4 and figure:5.5

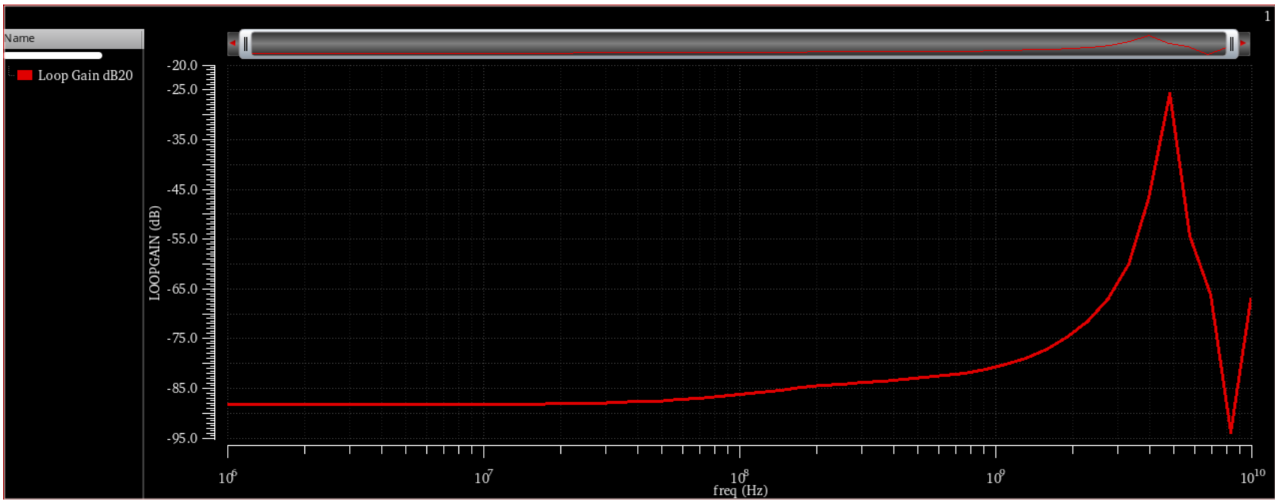

Figure 5.4: Gain of LC-VCO

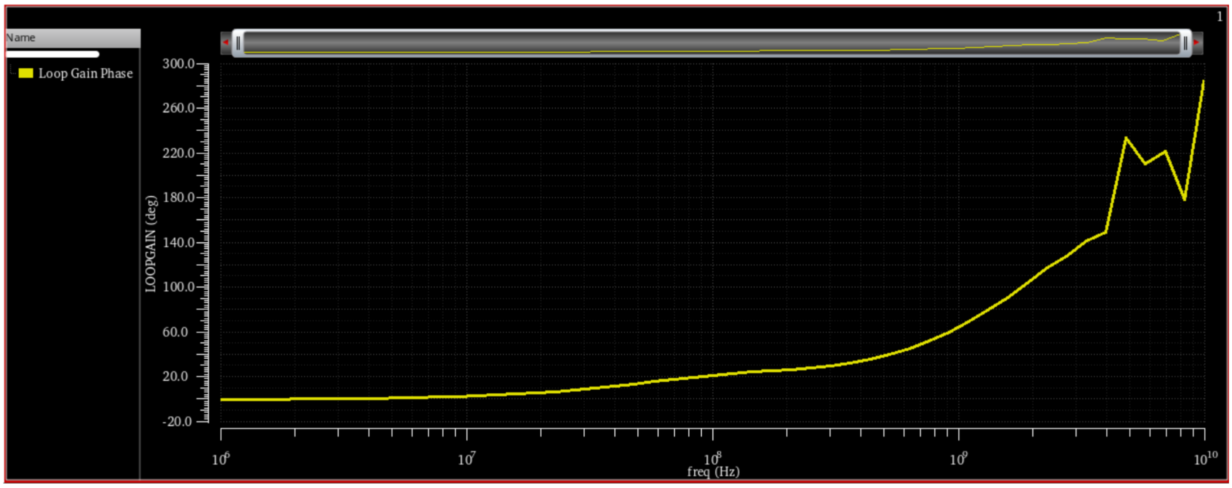

Figure 5.5: Phase of LC-VCO

5.5 Periodic Steady State Analysis

The periodic state analysis(pss) represents the periodic steady state response of the LC-VCO. The plot in figure:5.6 shows the power at different frequencies.

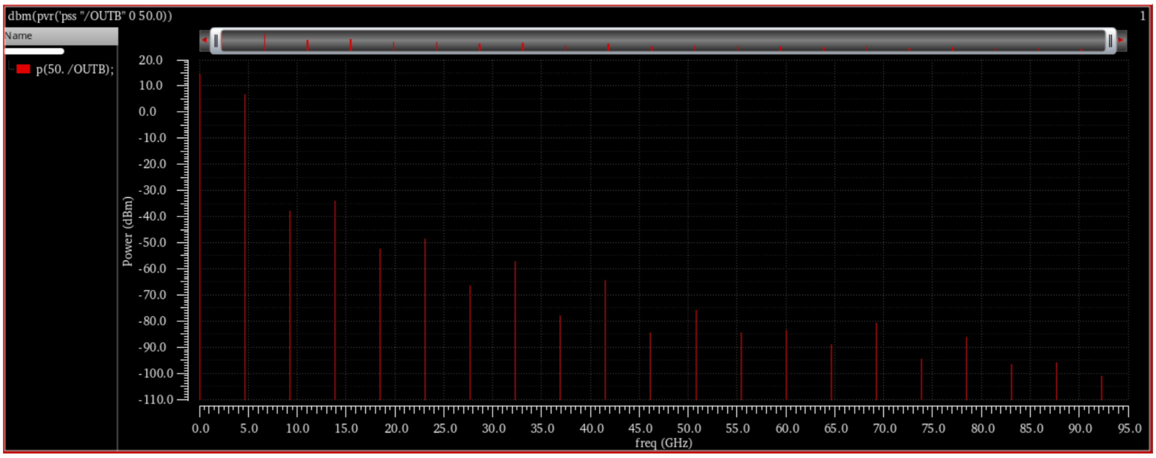

Figure 5.6: PSS Analysis

5.6 Noise Analysis

Figure:5.6 shows how phase noise change w.r.t. changing frequency. The pahse noise decreases with increasng frequency. Also, the marker in the plot shows the core frequency of the LC-VCO. Also phase noise at different frequency namely, @10 MHz and @20MHz can be seen from th graph with values -147 dBc/Hz and -153 dBc/Hz respectively.

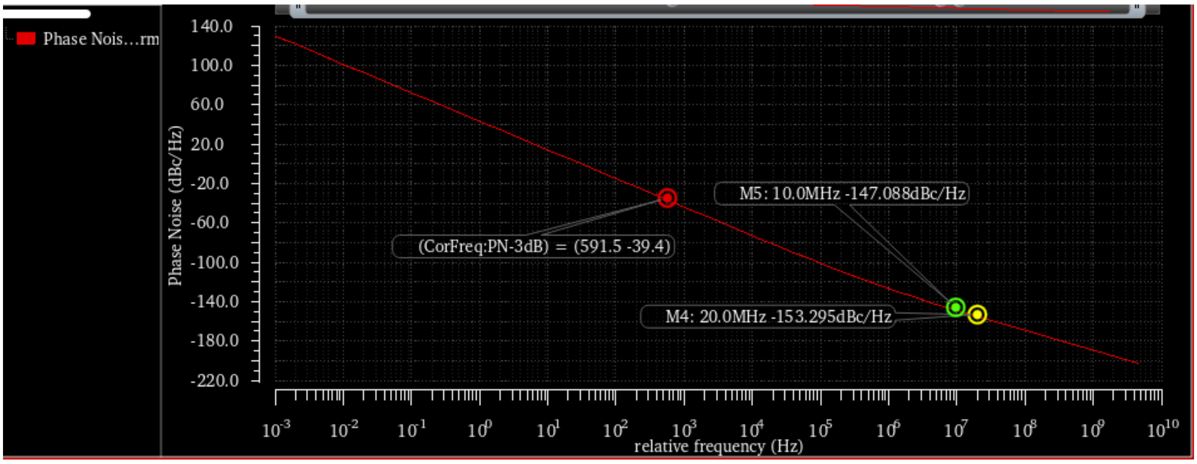

Figure 5.7: Gain of LC-VCO

Chapter 6

Comparison and Conclusion

6.1 Comparison

This section shows the comparison between different architecture of LC-VCO.

Parameters	RFIC [1]	TCASI [2]	TCASI [6]	This Report
Technology	65 nm	40 nm	65 nm	65 nm
Frequency (GHz)	6.39	3.37	8	4.6
DC power(mW)	10.3	12.5	6	46
PN@10 MHz (dBx/Hz)	-137	-149	-142	-147

Table 6.1: A comparison table for different architecture of LC-VCO

6.2 Conclusion

This seminar report presented the design and analysis of an LC-VCO. The architecture under study uses a single turn inductor with phase noise of 147 at 10 MHz. It also uses lesser space due to the use of a single turn inductor. Further improvement in the tuning range can also be achieved by using dual mode i.e., by adding a common mode of operation.

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