University of Tehran
College of Engineering
School of Electrical and Computer Engineering

# Communication Circuits

# Computer Assignment 1

Soroush Mesforush Mashhad

SN:810198472

Ordibehesht 02

# Contents

**Abstract**

In this project we shall briefly get familiar with a voltage controlled oscillator and its functionality. All of the simulations have been completed with **ADS** and the results have been included accordingly.

In the first part we shall calculate the oscillation frequency of the tank and the entire oscillator accordingly.

In the next part we shall go on to change the transistor width values to secure the wanted changes in the oscillator resistance.

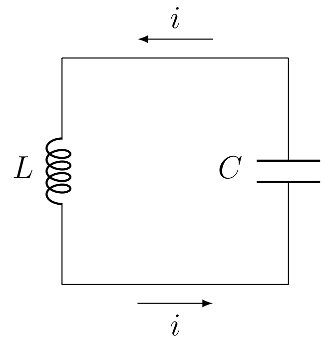
Next we shall replace the $C_1$ capacitor with a varactor circuit as instructed, we shall make sure it functions same as the capacitor which it replaces, we have checked this via simulation.

In the final section, we shall use the **Harmonic Balance** mode to see how this oscillator is actually a **Voltage Controlled Oscillator (VCO)**.

# 1 Question 1

Here we shall calculate the value for our capacitor and the resistance seen from the Tank which is named $R_p$.

We draw an **LC Tank** as follows.




We have learned that the oscillation frequency is derived as follows.

$$\omega_0 = \frac{1}{\sqrt{LC}} \longrightarrow C = \frac{1}{L\omega_0^2}, \quad \omega_0 = 2\pi f_0, \quad L = 10^{-8}F, \quad f_0 = 1GHz$$

$$C = \frac{1}{4\pi^2 f_0^2 L} \longrightarrow C = \frac{1}{4\pi^2 10^{10}} = 2.5330296pF$$

Now we want to calculate the parallel resistance seen from the tank. We learned in the **Electronics II** course that to do this for cross coupled circuits we shall use half of the circuit as shown below.

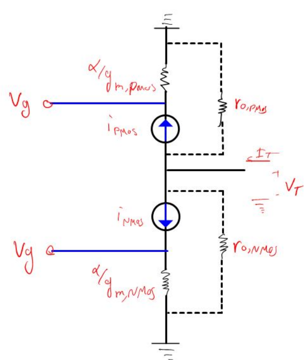



Figure 1: Half Differential Circuit

### 1.1 First approach

$$\alpha \approx 1, \quad i_{\text{PMOS}} = g_{m_{\text{PMOS}}} Vg, \quad i_{\text{NMOS}} = g_{m_{\text{NMOS}}} Vg$$
$$R_P = 2\frac{V_T}{I_T} = \frac{-Vg}{(i_{\text{PMOS}} + i_{\text{NMOS}})} = \frac{-Vg}{(g_{m_{\text{PMOS}}} Vg + g_{m_{\text{NMOS}}} Vg)}$$
$$R_P = \frac{-2}{(g_{m_{\text{PMOS}}} + g_{m_{\text{NMOS}}})}$$
$$g_{m_{\text{PMOS}}} = \sqrt{2I_{D_{\text{PMOS}}}\mu_p C_{ox}\left(\frac{W}{L}\right)}, \quad g_{m_{\text{NMOS}}} = \sqrt{2I_{D_{\text{NMOS}}}\mu_n C_{ox}\left(\frac{W}{L}\right)}$$

### 1.2 Second approach

Another understanding would be to calculate $R_P$ as follows.

$$R_P = \frac{\omega^2 L^2}{R} = \pi^2 \times 100\Omega$$

## 2 Question 2

### 2.1 First approach

In this question we aim to have an equivalent resistance of $-\frac{R_P}{2}$ seen from the sides of the tank but excluding the tank itself, so we aim to have

$$R_{eq} = \frac{1}{(g_{m_{\text{PMOS}}} + g_{m_{\text{NMOS}}})}$$

We also have the knowledge that the size of the PMOS transistors are 3 times the NMOS transistors in other words:

$$W_{\text{PMOS}} = 3W_{\text{NMOS}}$$

To execute this we easily deduce that we need to multiply the ratio of $g_{m_{\text{PMOS}}} + g_{m_{\text{NMOS}}}$ by two, so we multiply the W of each transistor by four.

## 2.2 Second approach

Due to the fact that $W_{\text{PMOS}} = 3W_{\text{NMOS}}$ and because the transistors have the same current it is evident that $g_{m_{\text{PMOS}}} = g_{m_{\text{NMOS}}}$, so we have:

$$R_{eq} = \frac{1}{g_{m_{\text{PMOS}}} = g_{m_{\text{NMOS}}}} \longrightarrow R_P = \frac{1}{g_{m_{\text{PMOS}}}} = \frac{1}{g_{m_{\text{NMOS}}}}$$

$$g_{m_{\text{PMOS}}} = g_{m_{\text{NMOS}}} = \frac{1}{100\pi^2} = 0.0010132118, \quad g_{m_{\text{PMOS}}} = \sqrt{2I_{D_{\text{PMOS}}}\mu_n C_{ox}\left(\frac{W}{L}\right)}$$

$$0.0010132118 = \sqrt{0.0005 \times 0.000067\left(\frac{W}{L}\right)_{\text{PMOS}}},$$

$$\left(\frac{W}{L}\right)_{\text{PMOS}} = \frac{0.0010132118^2}{0.00005 \times 0.000067} = 30.6447231483 \xrightarrow{L=0.18\mu m} = W_{\text{PMOS}} = 5.5161\mu m$$

$$W_{\text{NMOS}} = \frac{1}{3}W_{\text{PMOS}} = 1.8387\mu m$$

To be exactly precise, I have simulated both these scenarios Via ADS

# 3 Question 3

Here we shall first include a picture of our circuit.

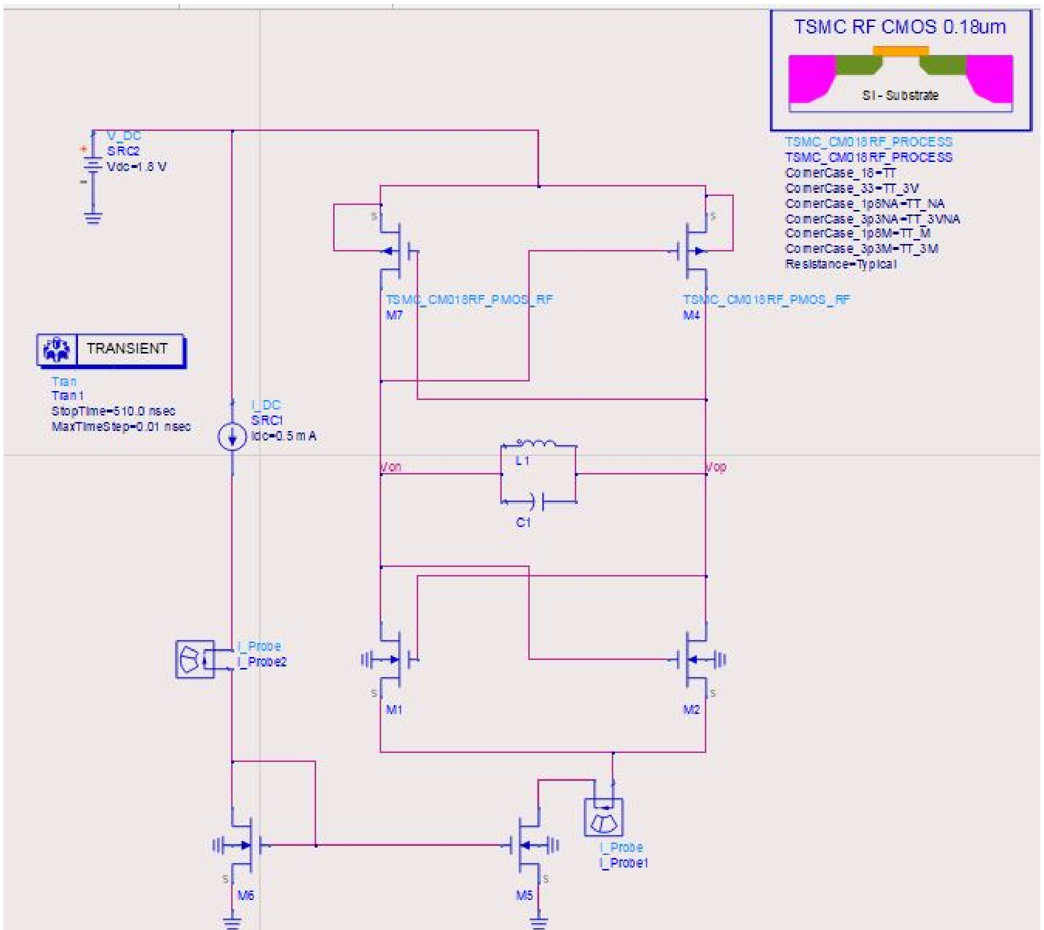



Figure 2: The Circuit in ADS

This is the preliminary circuit, before committing any changes in it, now we shall go on to calculate $R_P$ before and after changing the widths, a picture of the circuit is also included accordingly.

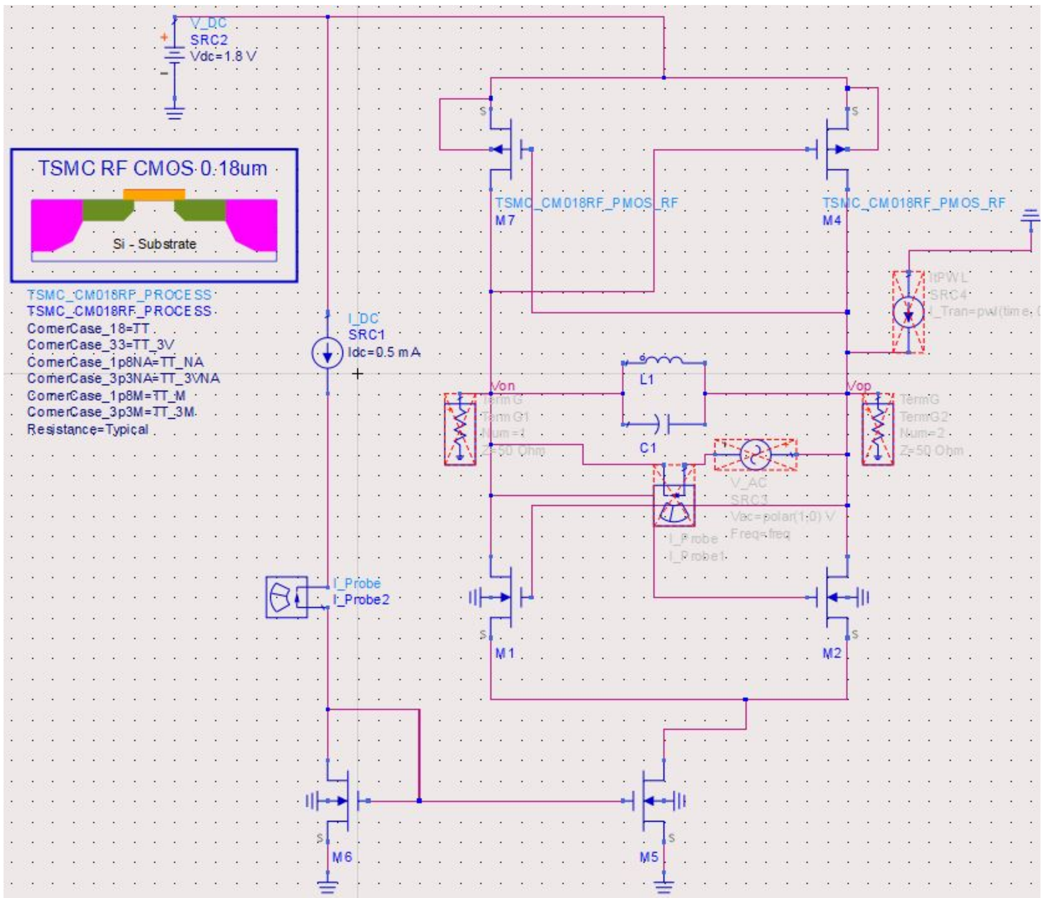



Figure 3: The Circuit in ADS

Now we shall check $R_P$ before and after changing the widths.

## 3.1 First Approach

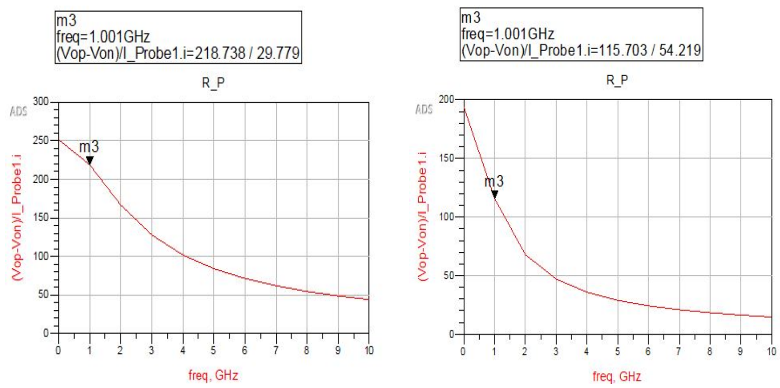



Figure 4: $R_P$ before and after width change.

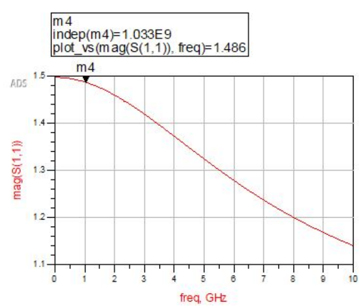



Figure 5: S Parameters

## 3.2 Second Approach

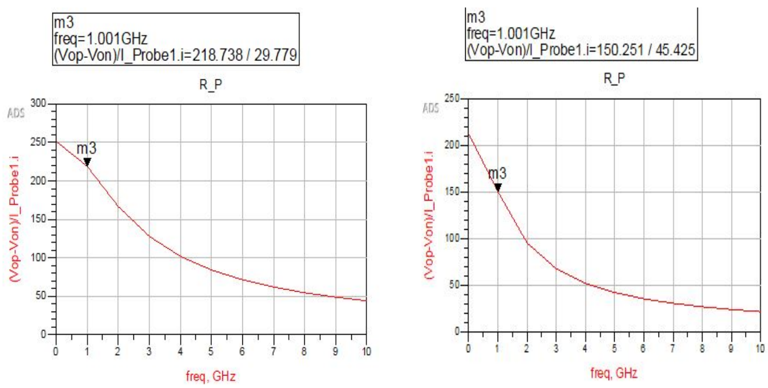



Figure 6: $R_P$ before and after width change.

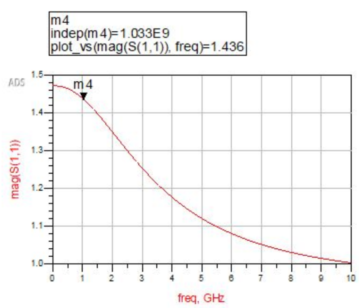



Figure 7: S Parameters

As we can see the resistance has been halved accordingly in both approaches. It is important to note that when using SPARAMETERS we have:

$$Z_{in} = \frac{1 + |\Gamma|}{|\Gamma| - 1} Z_0, \quad Z_0 = 50\Omega$$

# 4 Question 4

In this part using transient analysis we plot the $V_{op}$ and $V_{on}$ plots accordingly then we go on to pot $V_{op}-_{on}$ in an appropriate interval. After this we shall plot the tank current then we shall calculate the oscillation frequency.

It is important to note that to start the oscillator we have used an ItPWL current source as instructed.

## 4.1 First Approach

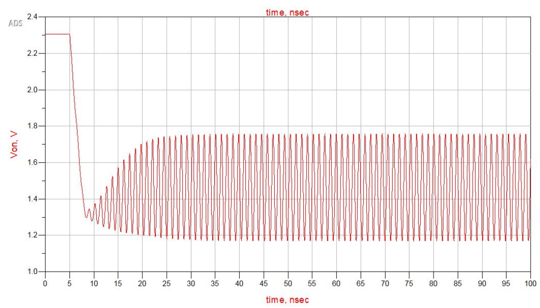



Figure 8: $V_{on}$

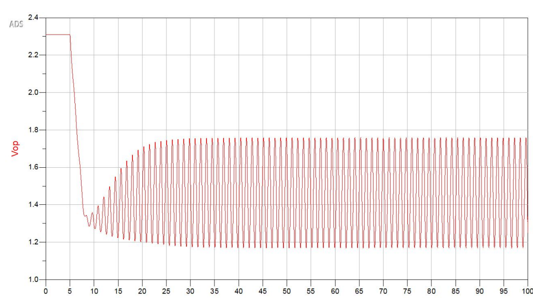



Figure 9: $V_{op}$

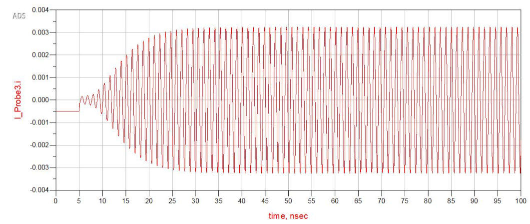



Figure 10: Tank Current

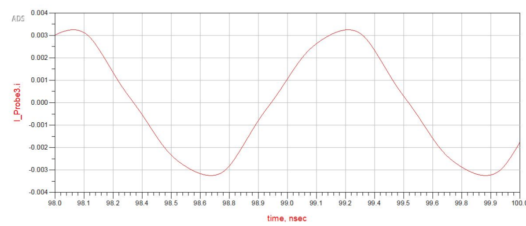



Figure 11: Tank Current

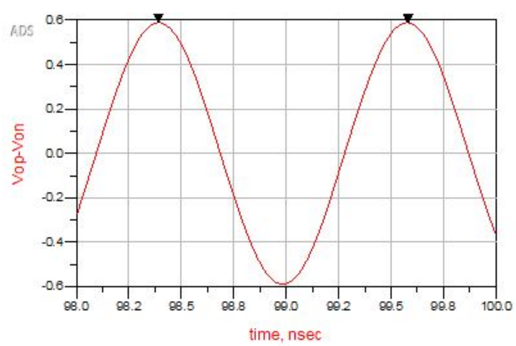



Figure 12: $V_{op} - V_{on}$

I used cursors and the **Eqn** method to calculate the oscillation frequency, the results are quite close to what it should be.

| time | f | T |
|---|---|---|
| <invalid>sec | 8.403E8 | 1.190E-9 |

Figure 13: Oscillation frequency

## 4.2 Second Approach

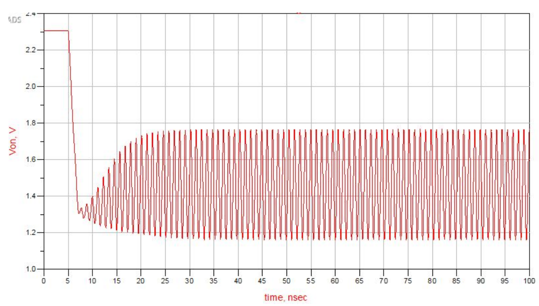



Figure 14: $V_{on}$

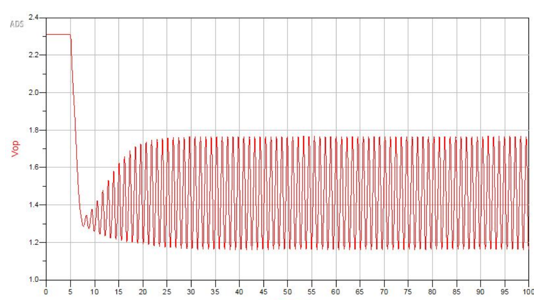



Figure 15: $V_{op}$

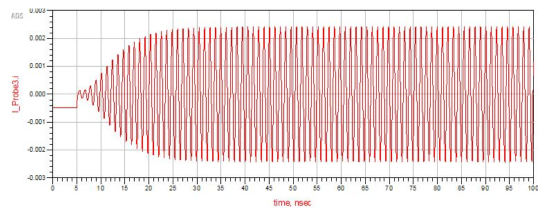



Figure 16: Tank Current

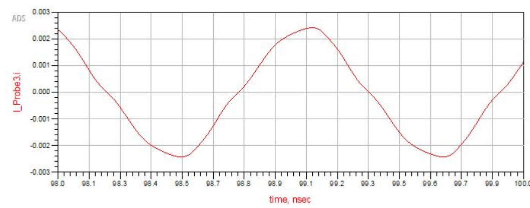



Figure 17: Tank Current

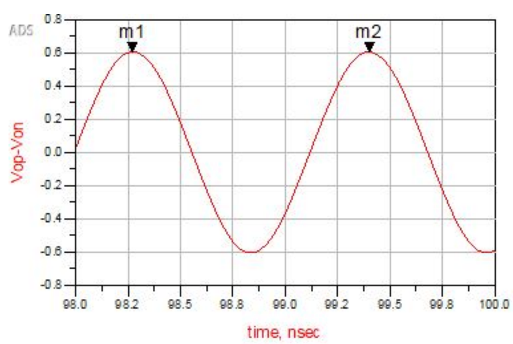



Figure 18: $V_{op} - V_{on}$

I used cursors and the **Eqn** method to calculate the oscillation frequency, the results are quite close to what it should be.

| time | f | T |
|---|---|---|
| <invalid>sec | 8.850E8 | 1.130E-9 |

Figure 19: Oscillation frequency

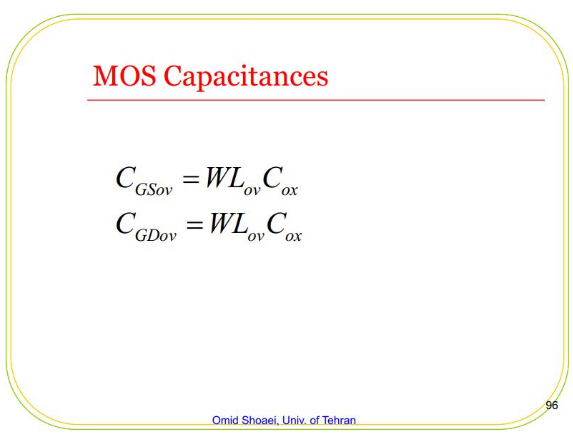
# 5 Question 5

We know from the **Electronics III** course that in a **MOS** transistor you see a capacitance when you look through the gate, these values are as follows:

$$C_{GS} = C_{GSov} + \frac{2}{3}C_{oxt}$$

because we have connected the source and drain and bulk together we can use the formula as follows:

$$C_{GS} = C_{GSov} = C_{ox}WL$$



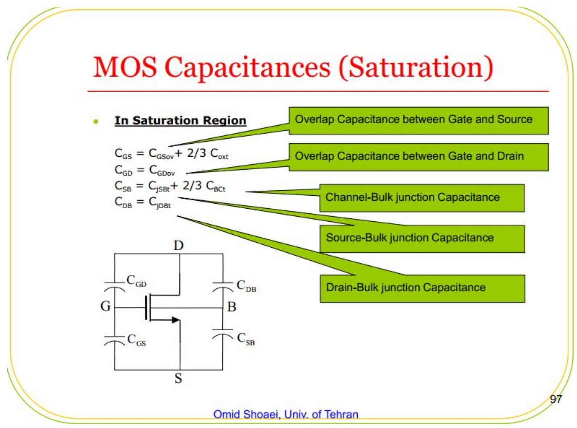



Figure 20: Dr.Shoaei Slides

So our calculations are as follows.

$$2C_{\text{NMOS}} = C_1 \longrightarrow C_{\text{NMOS}} = 1.2665148pF \longrightarrow WLC_{ox} = 1.2665148pF$$
$$\longrightarrow WL = \frac{1.2665148pF}{8.5\frac{fF}{\mu m^2}} = 149.001741176\mu m^2 \xrightarrow{L=0.18\mu m} W = 827.787450978\mu m$$

After this I simulated the oscillator to verify my results accordingly.

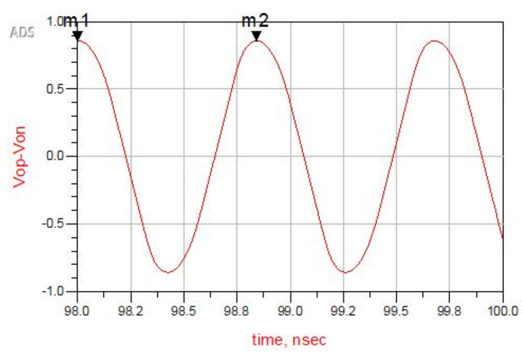



Figure 21: $V_{op} - V_{on}$

I used cursors and the **Eqn** method to calculate the oscillation frequency, the results are quite well.

| time | f | T |
|---|---|---|
| <invalid>sec | 1.190E9 | 8.400E-10 |

Figure 22: Oscillation frequency

# 6 Question 6

In this part we shall perform a sweep on $V_0$ to verify that this oscillator is indeed a **Voltage Controlled Oscillator (VCO)**, the results are as follows.

## 6.1 First Approach

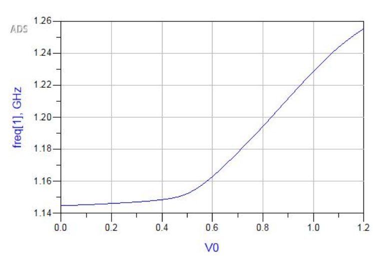



Figure 23: Oscillation frequency plot versus $V_0$ sweep

As we can see by changing the voltage, the oscillation frequency changes, so this oscillator is indeed a **VCO**.

## 6.2 Second Approach

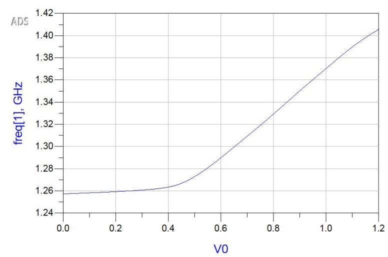



Figure 24: Oscillation frequency plot versus $V_0$ sweep

As we can see by changing the voltage, the oscillation frequency changes, so this oscillator is indeed a **VCO**.

# 7 Final Schematic

The final schematic has the following structure.

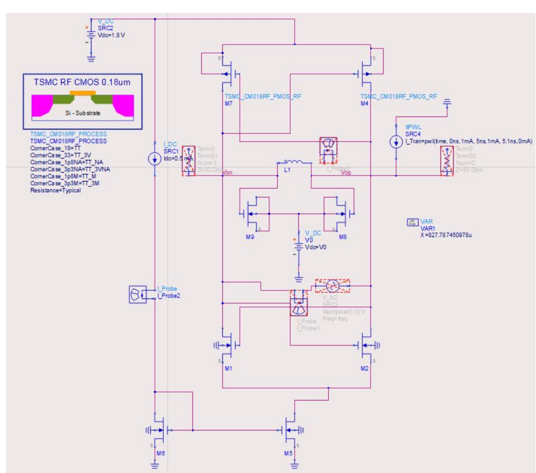



Figure 25: Final Schematic for first approach

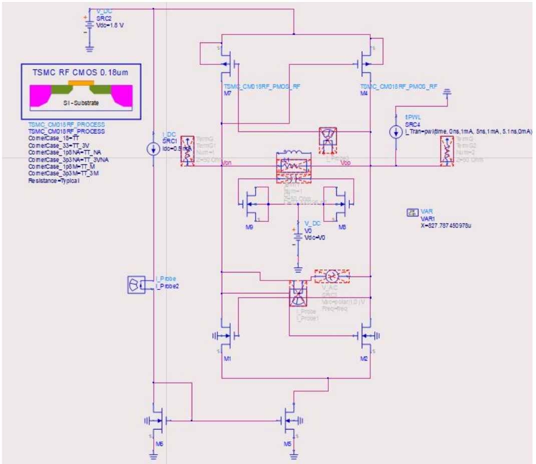


Figure 26: Final Schematic for second approach

# References

[1] Omid Shoaei, *Electronics III, Lecture Notes, Spring 01*

[2] Shaghayegh Vahdat, *Digital Electronic Circuits, Lecture Notes, Fall 01*

[3] Mehdi Kamal, *Digital Electronic Circuits, Lecture Notes, Fall 00*