Lab 1

RC Filter and MOSFET Characteristics

Part 1: RC Filter

$$\tau = R * C = 0.5ns \qquad C = \frac{0.5ns}{1K\Omega} = \mathbf{0.5pF}$$

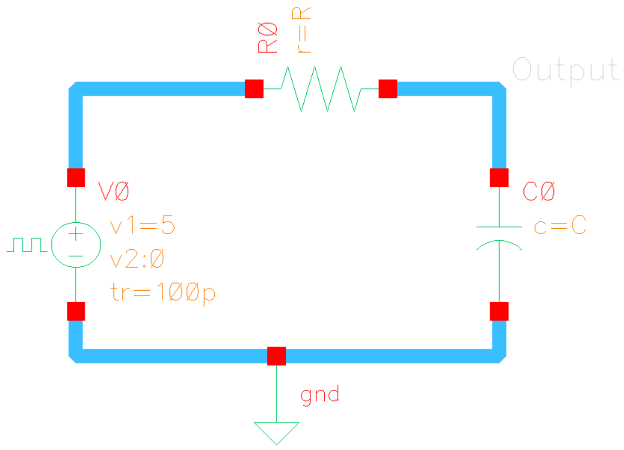

Figure 1 RC Filter Schematic

1. Transient Analysis:

V Out	expr	VT("/Output")
Fall	expr	fallTime(VT("/Output") 0 nil 5 nil 10 90 nil "time")
rise	expr	riseTime(VT("/Output") 0 nil 5 nil 10 90 nil "time")

Figure 2 Output Setup

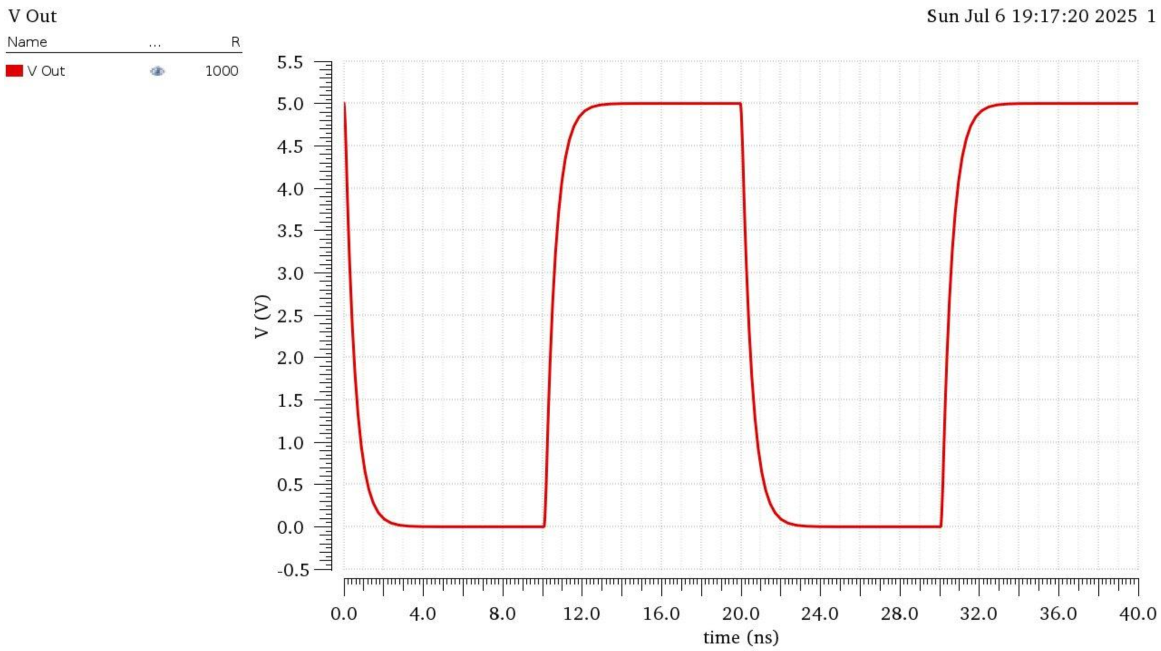

Figure 3 Two Periods of the Filter

Analytic Calculation for Rise and Fall Time:

Charging: $\mathrm{V(t)} = \mathrm{V_0}\left(1 - \mathrm{e}^{\frac{-t}{RC}}\right)$ $\quad\quad$ $\mathbf{V_0 = 5}\boldsymbol{V}$

Discharging: $\mathrm{V(t)} = \mathrm{V_0}.\,\mathrm{e}^{\frac{-t}{RC}}$ $\quad\quad$ $\mathbf{V_0 = 5}\boldsymbol{V}$

$$At\ V(t_1) = 0.1 \cdot V0 \Rightarrow t1 = -RC \cdot \ln(0.9) \qquad At\ V(t_2) = 0.9 \cdot V0 \Rightarrow t2 = -RC \cdot \ln(0.1)$$

$$t_{rise} = t_2 - t_1 \approx 2.2 \cdot RC \qquad t_{rise} \approx t_{fall} \approx 2.2 \cdot RC = \mathbf{1.1}\boldsymbol{ns}$$

1.1 Rise and Fall Time Comparison:

Test	Output	Simulation	Analytic
ITI_Analog:Lab1_RC:1	Fall Time	1.1020E-09	1.1e-09
ITI_Analog:Lab1_RC:1	Rise Time	1.1020E-09	1.1e-09

1.2 Parametric Sweep:

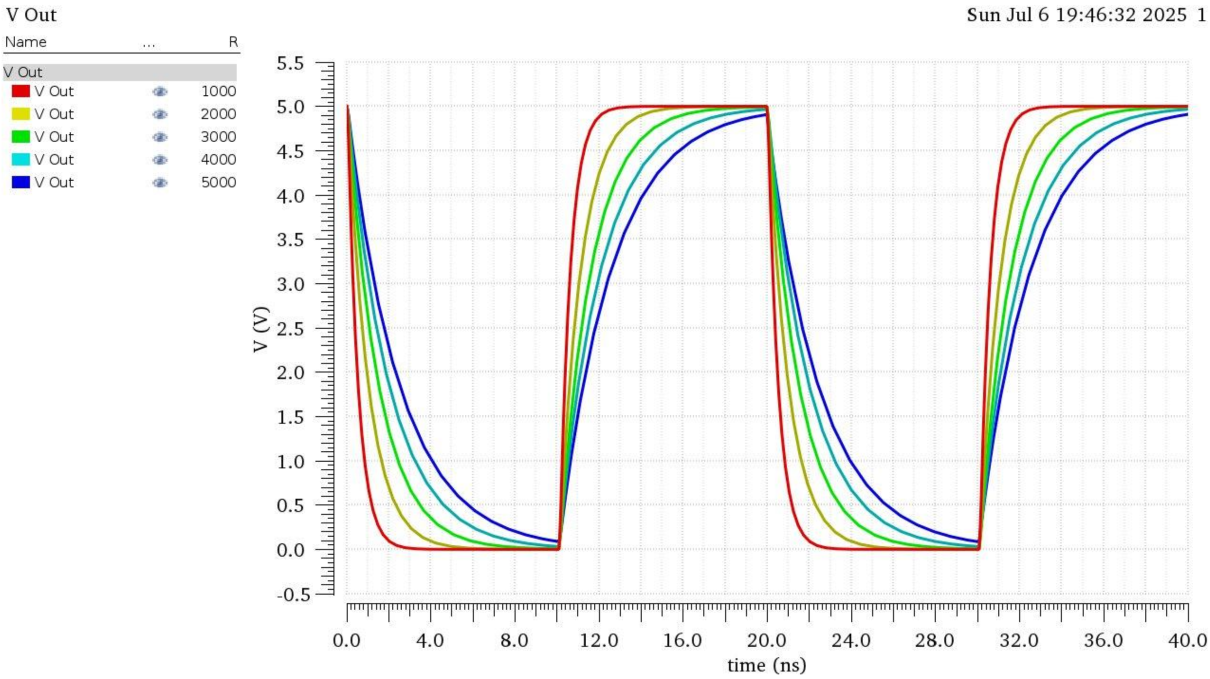

Figure 4 R Parametric Sweep

Comment: Increasing the R increases the time constant thus increasing the rise and fall time, making the square wave less pronounced as R increases.

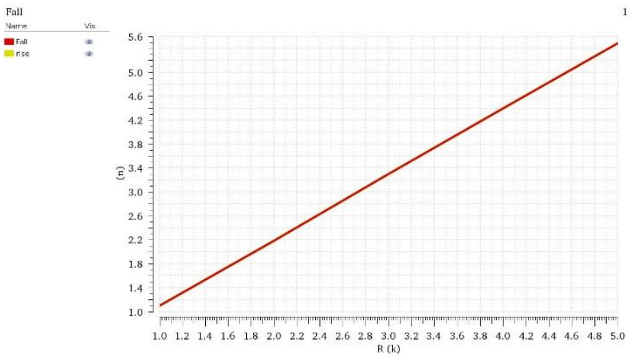

Figure 5 Change of Rise and Fall time with R

2. AC Analysis:

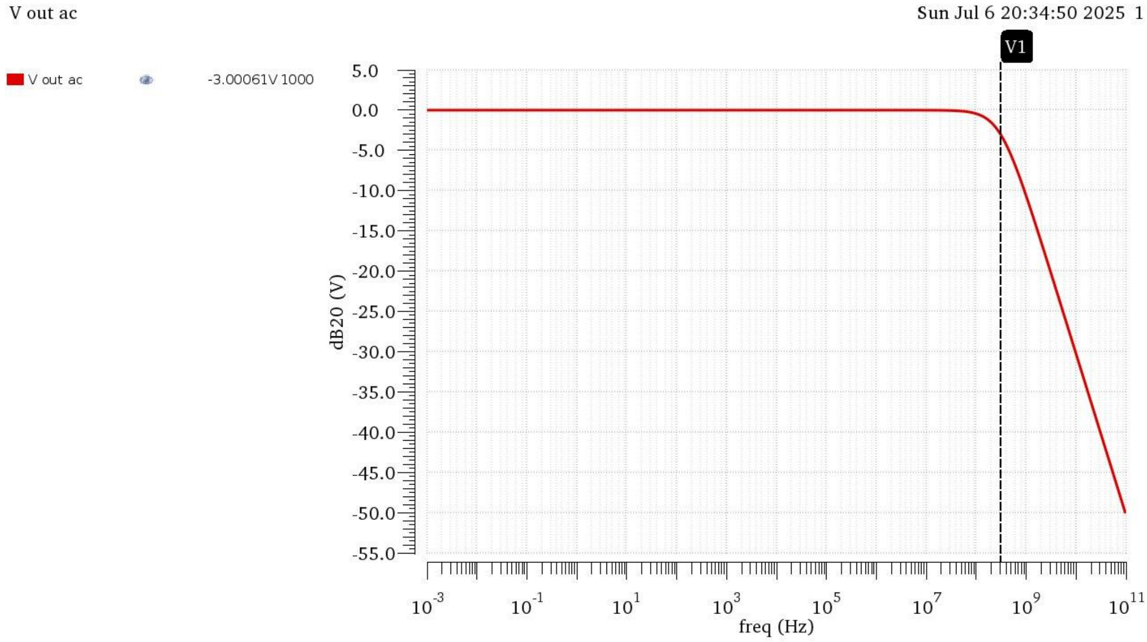

Figure 6 RC Filter Bode Plot (Magnitude)

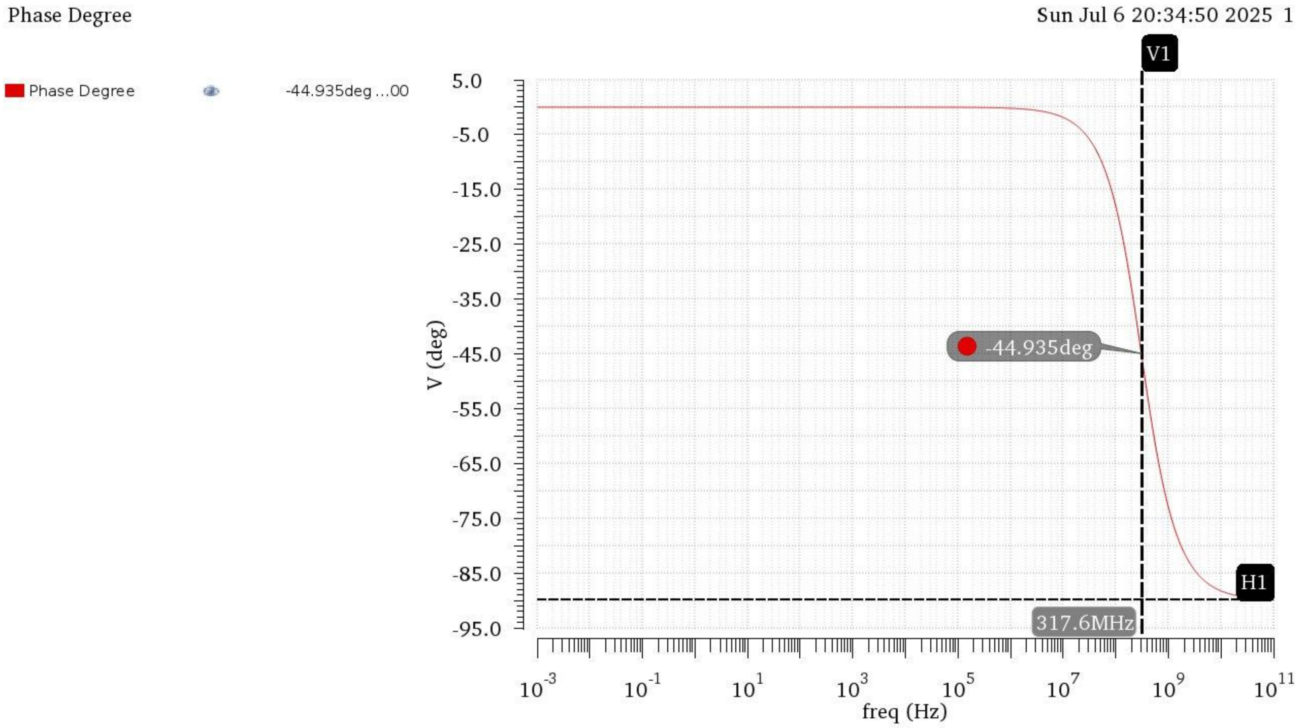

Figure 7 RC Filter Bode Plot (Phase in Degree)

Bandwidth	expr	bandwidth(mag(VF("/Output")) 3 "low")
Ao	expr	ymax(mag(VF("/Output")))

Figure 8 Output Setup for Gain and BW

Analytic Calculation for DC gain and BW:

DC Gain = 1 Cap is O.C in DC, VIN = VOUT

Bandwidth: $\omega_p = \frac{\mathbf{1}}{\boldsymbol{RC}}$ $f_p = \frac{\mathbf{1}}{\boldsymbol{2\pi \times RC}} \approx \mathbf{318.31}\boldsymbol{MHz}$Type equation here.

Test	Output	Simulation	Analytic
ITI_Analog:Lab1_RC:1	Bandwidth	317.6MHz	318.3MHz
ITI_Analog:Lab1_RC:1	Gain	1	1

Parametric Sweep for R = 1,10,100,1000kΩ

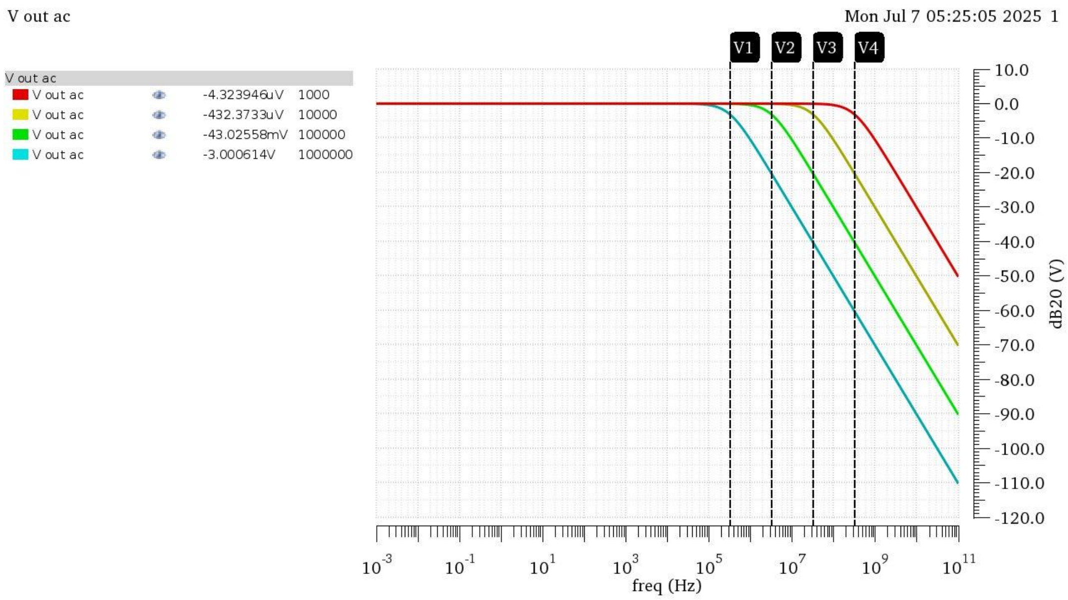

Figure 9 RC Filter Mag Bode Plot with R Parametric Sweep

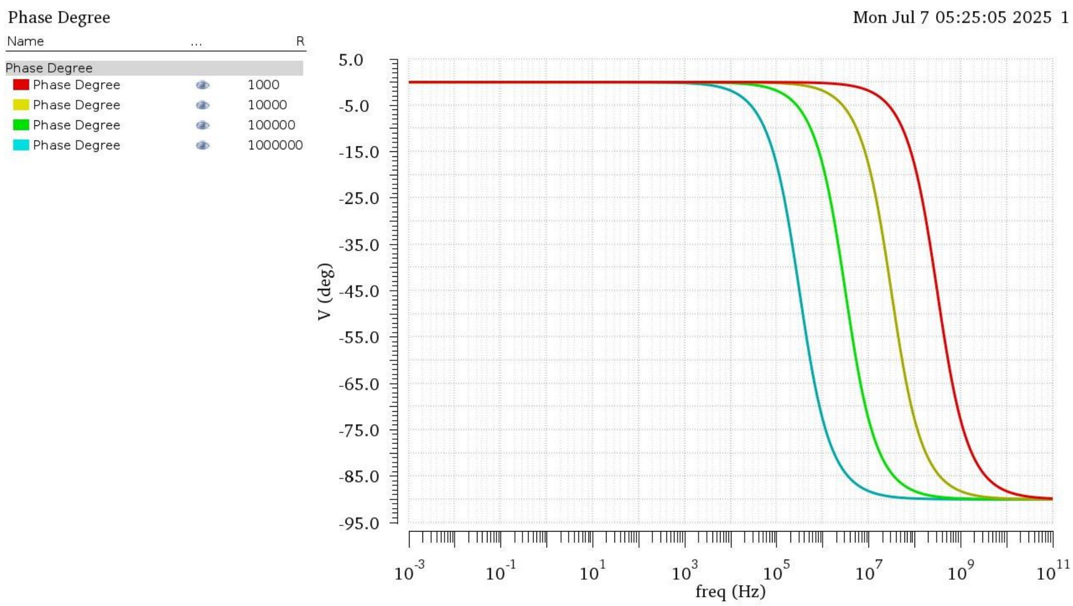

Figure 10 RC Filter Phase Bode Plot with R Parametric Sweep

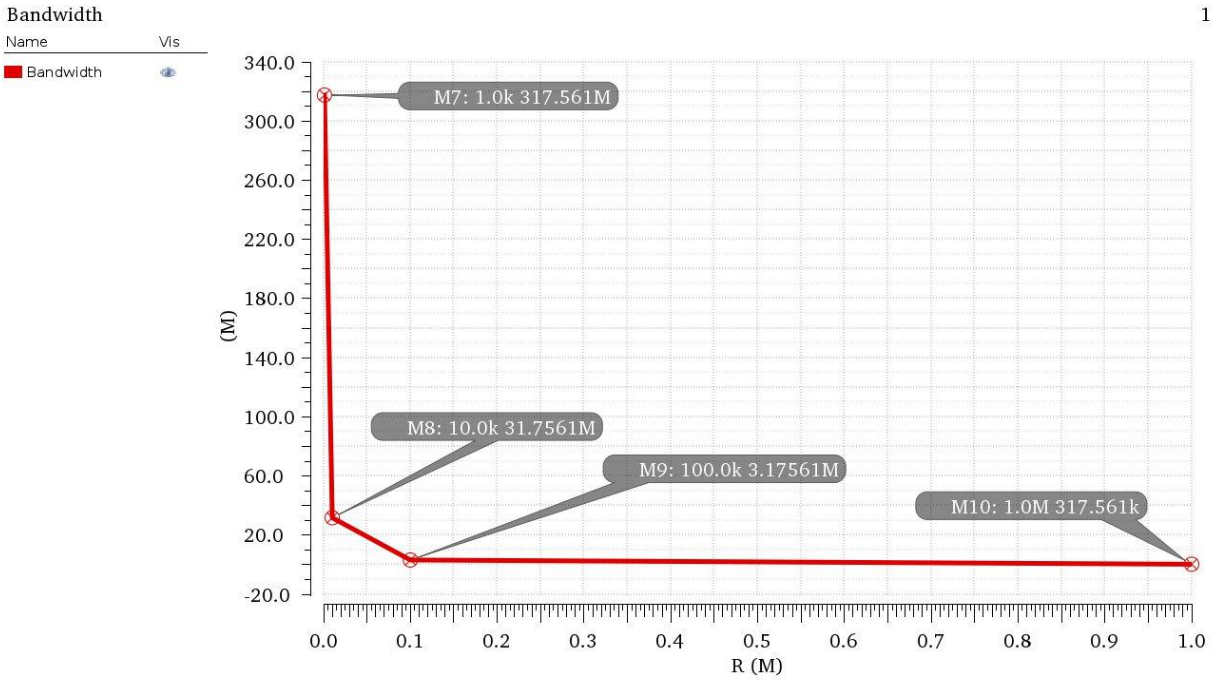

Figure 11 RC Filter Bandwidth Vs R

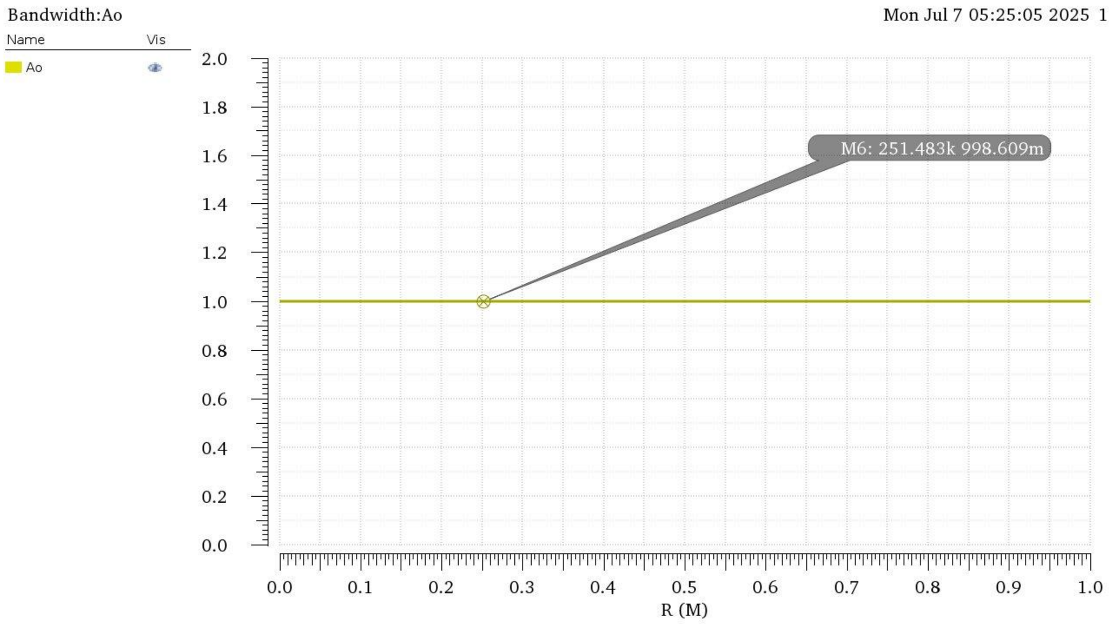

Figure 12 RC Filter DC Gain vs R

Comment: Increasing The Resistance gradually increase the Time Constant this lowering the 3dB cut off frequency decreasing the bandwidth and causing a noticeable shift for both Bode Plot graphs.

DC gain is not affected though as it does not depend on the Time Constant rather on the circuit itself.

Part 2: MOSFET Characteristics

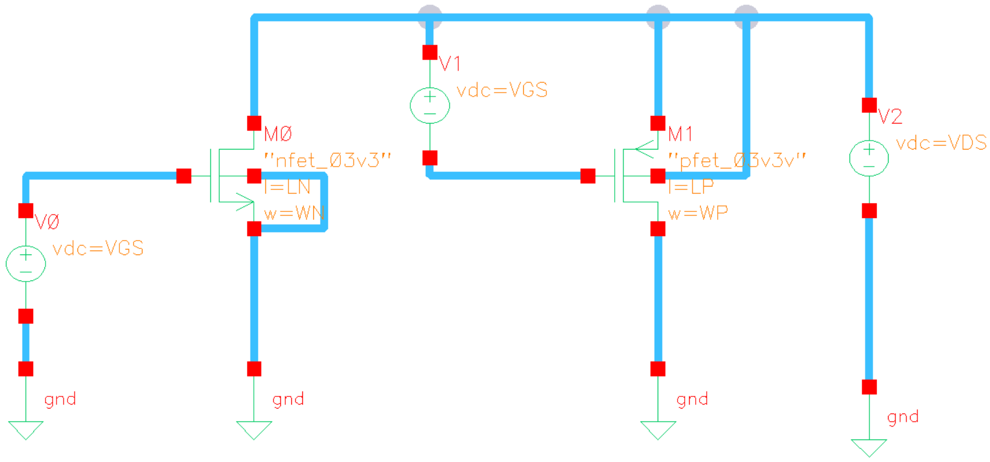

Figure 13 MOSFET Characteristics Schematic Testbench

Using **VDD = 3v,** Short-Channel: **W/L = 6u/300n,** Long-Channel: **W/L = 60u/3u**

1. ID vs VGS

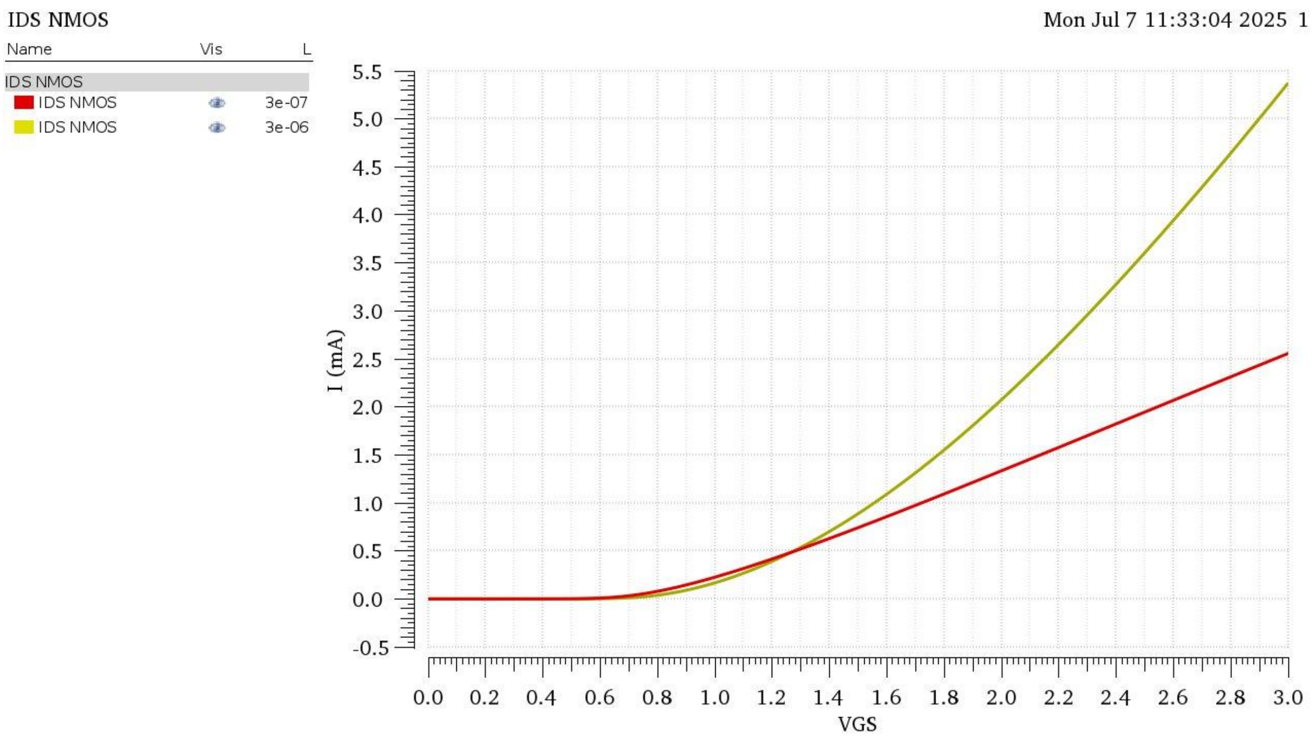

Figure 14 NMOS ID vs VGS, Yellow: Long-Channel, Red: Short-Channel

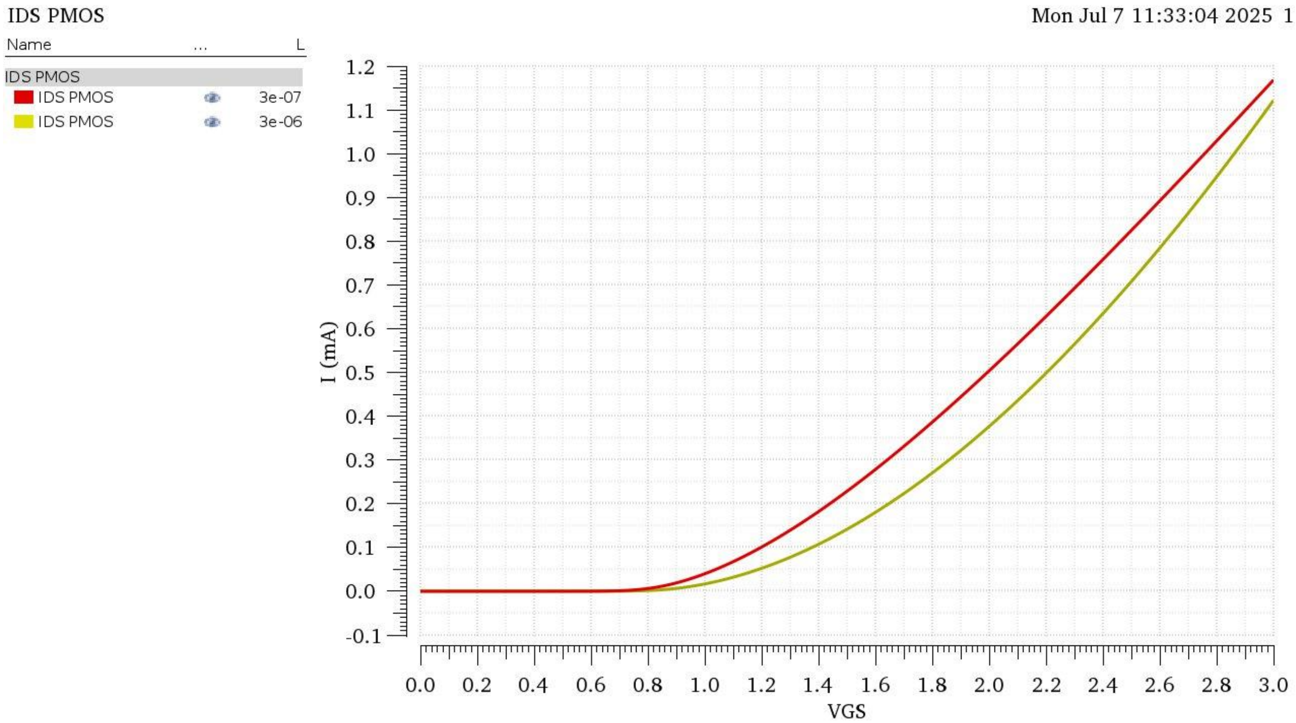

Figure 15 PMOS ID vs VGS, Yellow: Long-Channel, Red: Short-Channel

Comment on the differences between short channel and long channel results.

• Which one has higher current? Why?

The Long Channel Device has higher current, due to the lower electric field in the channel allowing carriers to move more freely, While in short-channel the carriers' velocity saturates limiting the current.

The effect is more noticeable in NMOS devices due to the higher carrier mobility.

• Is the relation linear or quadratic? Why?

Long-Channel: Has a quadratic relation as per the square-law Id = $K*Vov^2/2$

Short-Channel: Has a linear relation as per the velocity saturation law.

Comment on the differences between NMOS and PMOS.

• Which one has higher current? Why?

NMOS, due to the higher mobility of electrons (Majority Carrier).

- **What is the ratio between NMOS and PMOS currents at VGS = VDD?**

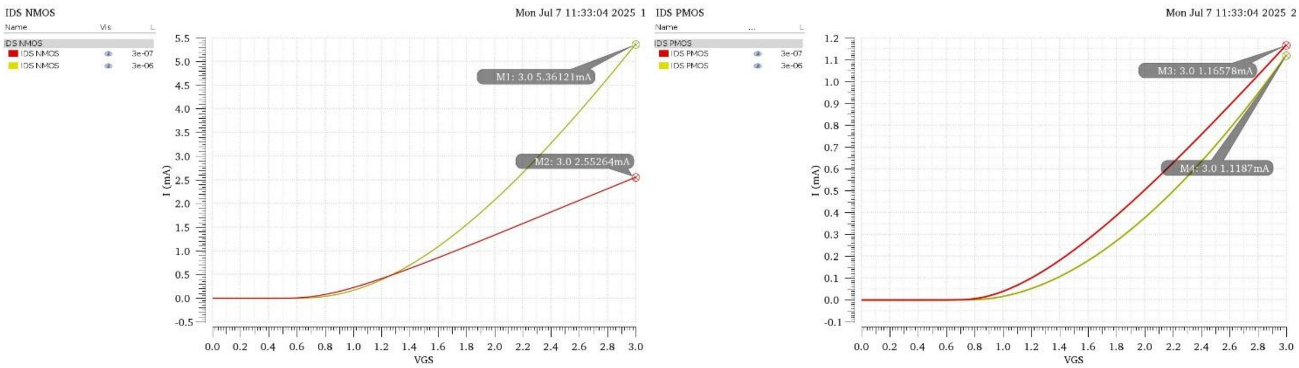

Figure 16 Values of ID at VDD for both NMOS and PMOS

Long-Channel Current Ratio: $ratio = \frac{5.361}{1.1187} = \mathbf{4.79}$

Short-Channel Current Ratio: $ratio = \frac{2.55264}{1.16578} = \mathbf{2.19}$

- **Which one is more affected by short channel effects?**

NMOS is more affected, due to the electrons (NMOS Majority Charge Carrier) having a higher mobility than Holes (PMOS Majority Charge Carrier).

2. gm vs VGS

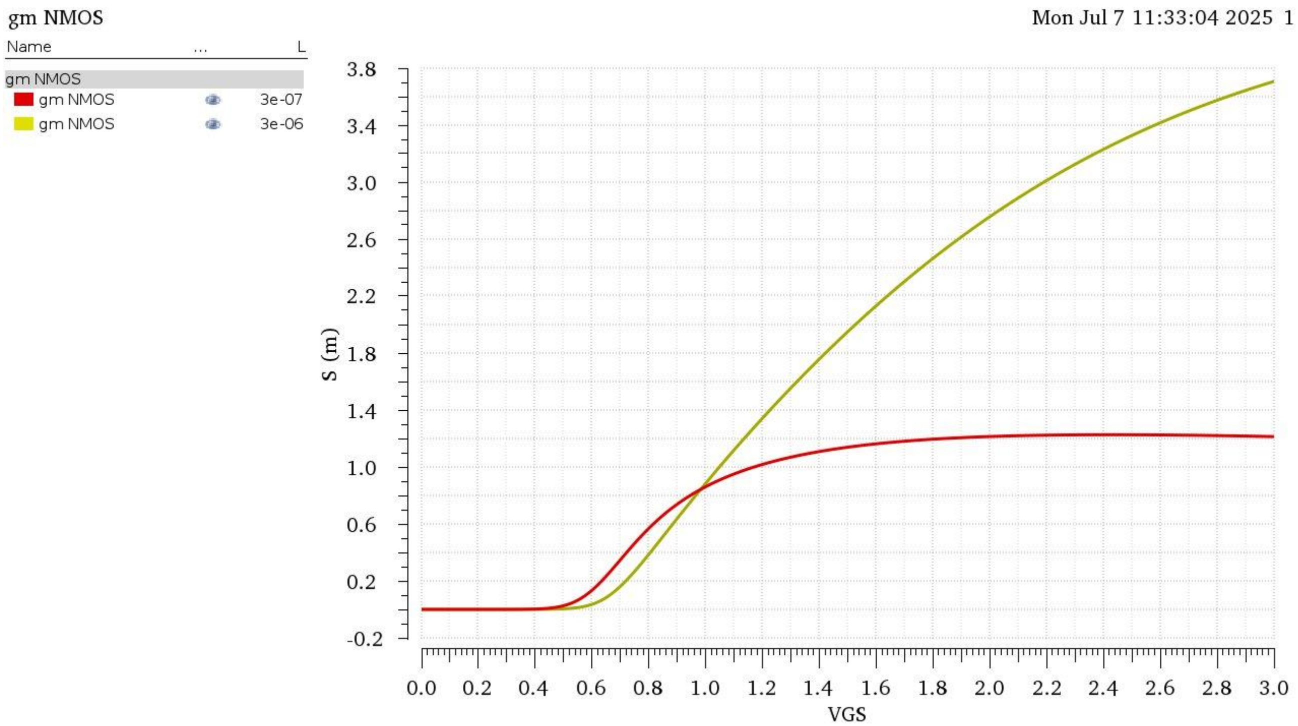

Figure 17 NMOS gm vs VGS, Yellow: Long-Channel, Red: Short-Channel

Comment on the differences between short channel and long channel results.

- **Does gm increase linearly? Why?**

As the device turns on when VGS = Vth, gm starts increasing approximately linearly in both short and long channel as gm = k * (Vgs – Vov), but in short channel the linear increase stops early.

- **Does gm saturate? Why?**

It Does saturate, as Vov increases past VD_{SAT}, gm starts to saturate, its value can be evaluated via $gm = \frac{\partial I}{\partial V_{gs}}$

3. IDS vs VDS

Sweeping over: $\mathbf{V_{DS} = 0:10m:V_{DD}}$, and $\mathbf{V_{GS} = 0:0.2:V_{DD}}$

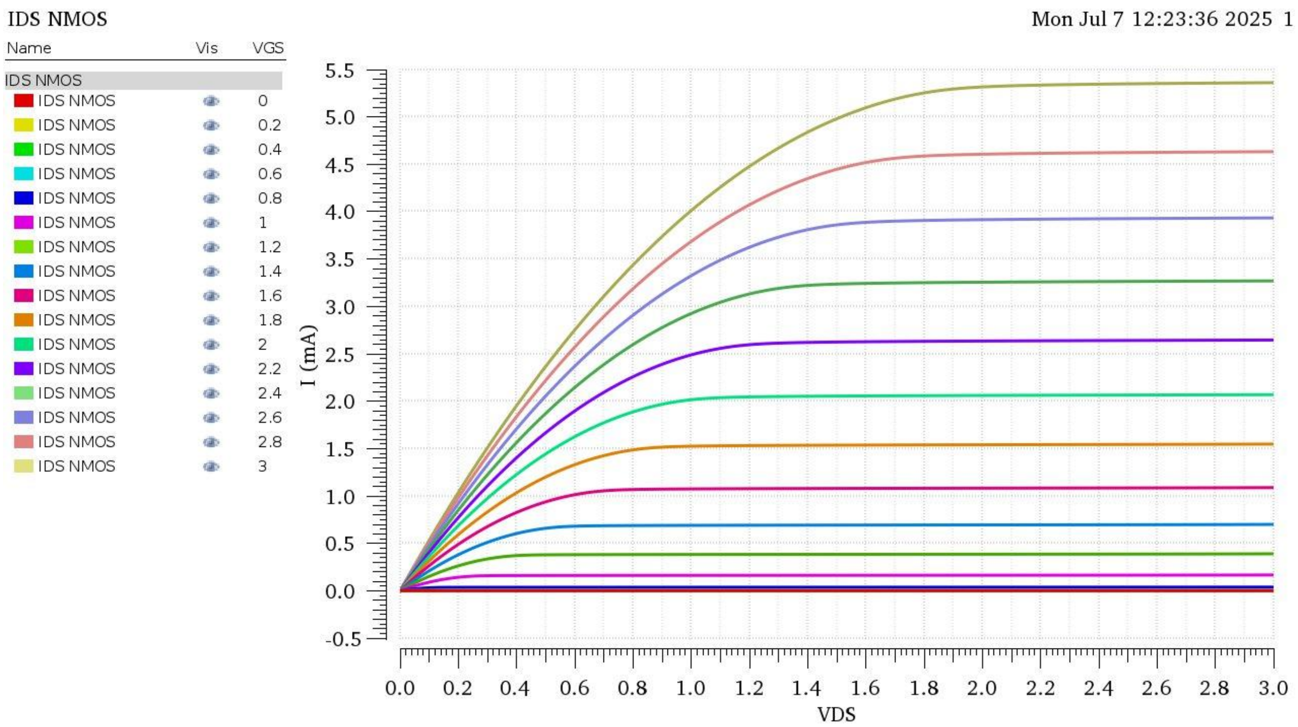

Figure 18 NMOS IDS vs VDS - Long Channel

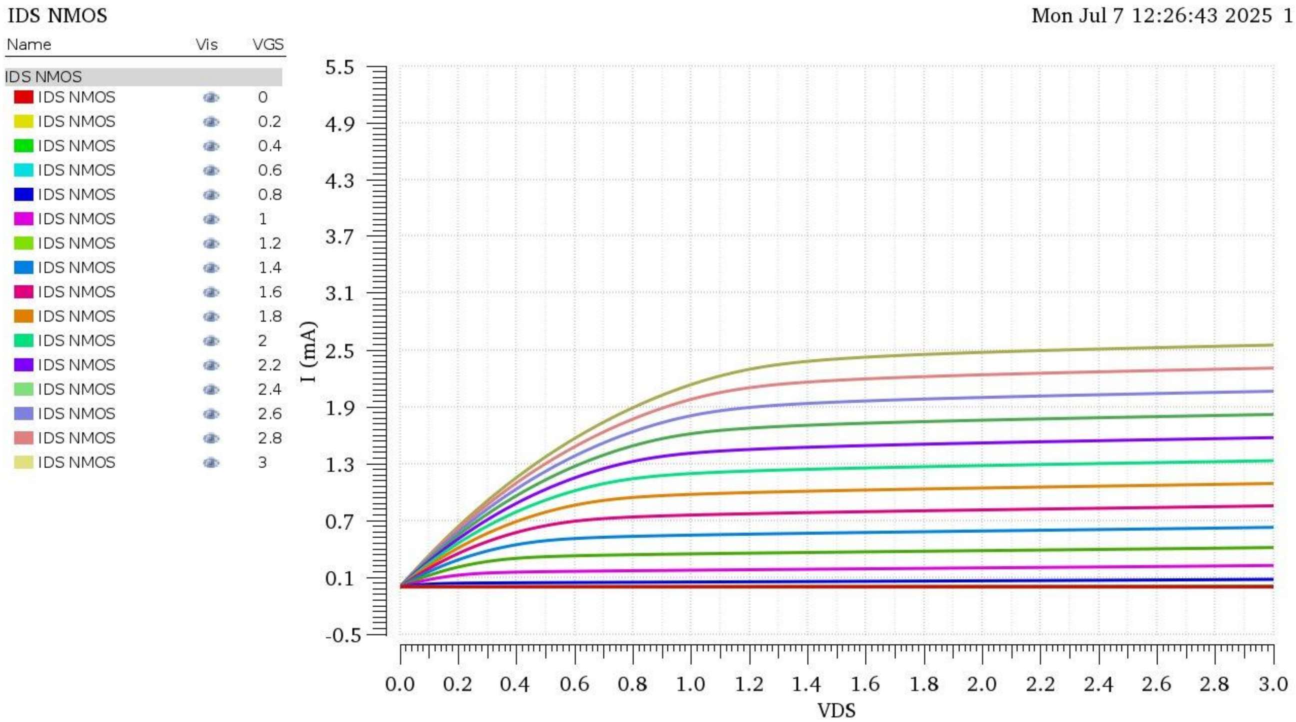

Figure 19 NMOS IDS vs VDS - Short Channel

Comment on the differences between short channel and long channel results.

• Which one has higher current? Why?

Long-Channel has noticeably higher current, This is due to it operating in Pinch-Off saturation which has a quadratic relation for the current as opposed to the Short-Channel NMOS which operate in Velocity Saturation which has a linear relation for the current.

• Which one has higher slope in the saturation region? Why?

Short-Channel has a higher slope in the saturation region, Due to the effect of ro.

As the length of the channel decreases the resistance between the drain and source decreases and becomes more noticeable in the short channel device.

But in the long channel device this resistance is very large, approximately infinite. resulting in no slope appearing in the saturation region.