INTEGRATED CIRCUITS 1

LAB01

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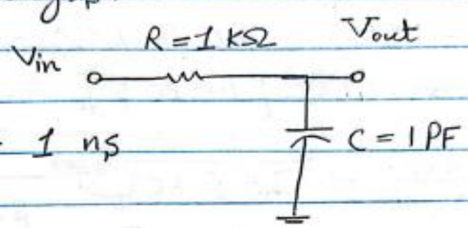
PART 1: LOW PASS FILTER SIMULATION:

1. Transient Analysis

1) Design a first order low pass filter that has $R = 1k\Omega$ and 1ns time constant.
2) Apply a square wave input with $T_{high} = Pulse\ Width = 10ns$, $T_{clk} = Period = 20ns$, and $T_{rise} = T_{fall} = 100ps$.
3) Report transient analysis results for two periods (use max time step = $T_{clk}/100$).
4) Calculate rise and fall time (10% to 90%) using Cadence calculator expressions. Export the expressions to adexl.
5) Compare simulation with analytical results in a table.
6) Do parametric sweep for $R = 1:1:5k\Omega$. Report overlaid results. Comment on the results.

① transient analysis:

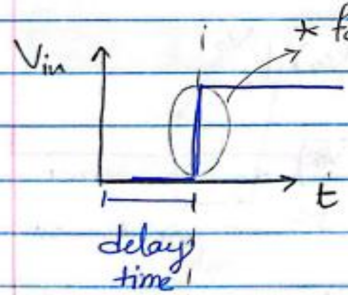


$\tau = RC$

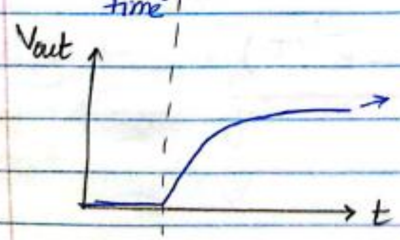
$= 10^3 \times 10^{-12} = 1\ ns$

* 1^{st} order Low pass;

→ we will add Vpulse with the given characteristics



* for the output to respond to this stimulant it will take * time $= \tau = RC$ * and about 5τ to reach within $\boxed{1\%}$ of final value



Some Calculations:

$\tau = 1$ ns

$t_{rise} = t_{90\%} - t_{10\%}$

$\because V_o = V_{in}(1 - e^{-t/\tau})$

$0.9 \cancel{V_{in}} = \cancel{V_{in}}(1 - e^{-T/\tau})$

$\cancel{-}0.1 = \cancel{-} e^{-T/\tau}$

$-\ln 10 = -T/\tau \quad \therefore \boxed{T_{90\%} = 2.3\tau = 2.3 \text{ nm}}$

at 10 %

$\because 0.1 \cancel{V_{in}} = \cancel{V_{in}}(1 - e^{-T/\tau})$

$\cancel{-}0.9 = \cancel{-} e^{-T/t}$

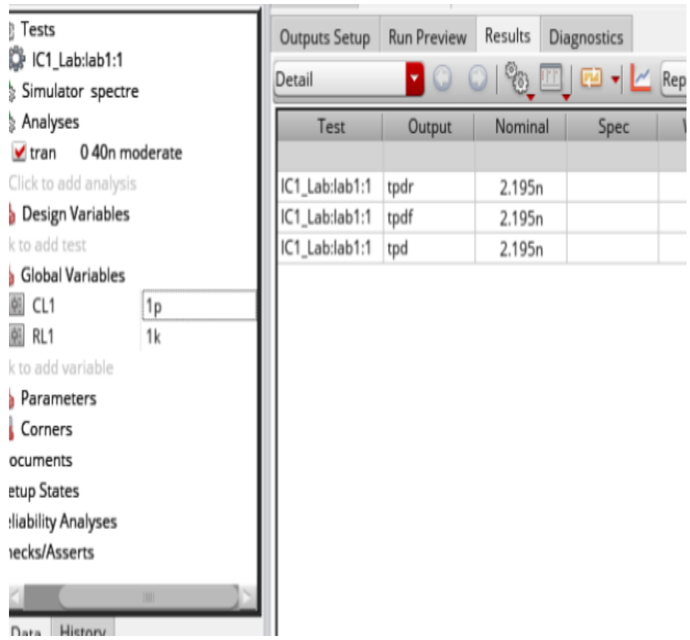
$T_{10\%} = 0.105\tau \quad \therefore T_{rise} = T_{90\%} - T_{10\%}$

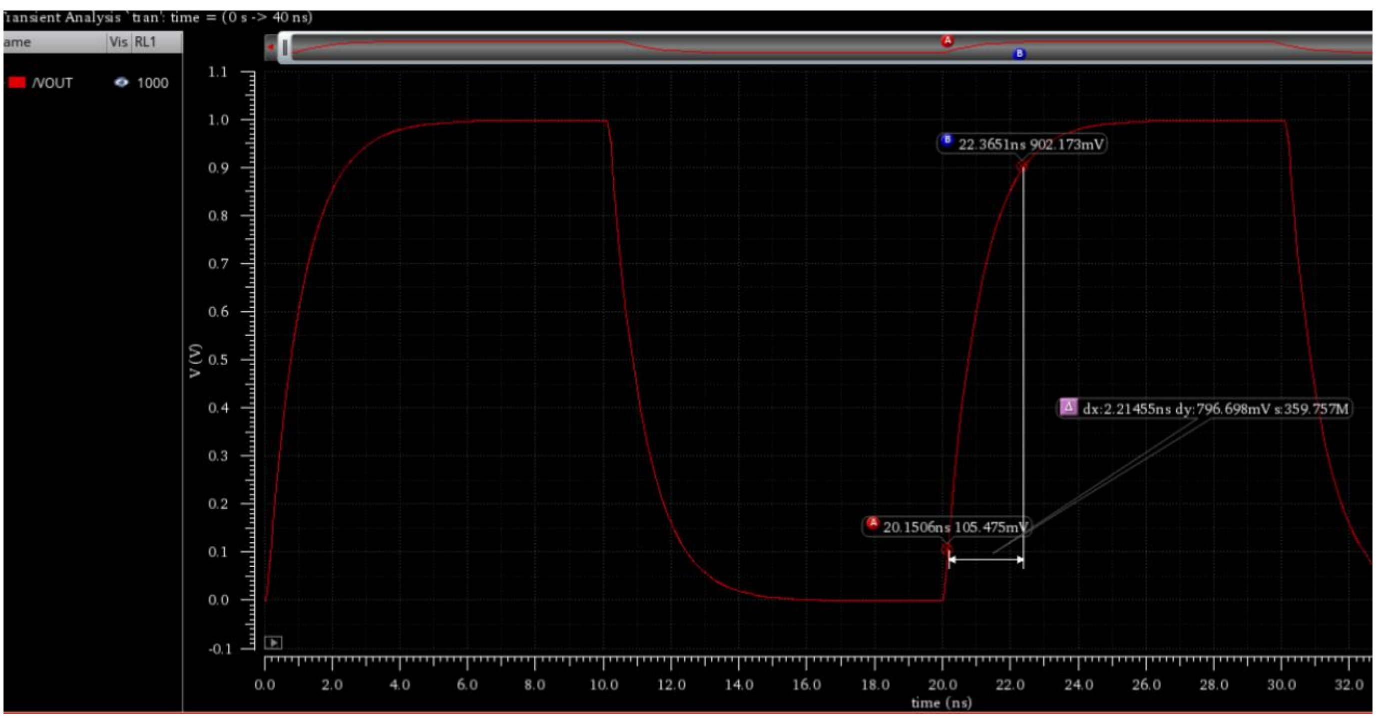
$\therefore T_{rise} = T_{fall} = 2.3\tau - 0.105\tau = \boxed{2.195 \text{ nm}}$

$= 2.195\,\tau$

Using The Simulation we compared and found That Tpd rise = fall time = 2.195 ns

→ Also using The A-B Cursor on The Simulation we found That, rise time and fall time to be 2.2 ns





→ Parametric sweep $\tau = RC$

as $R\uparrow$ $\tau\uparrow$

at $R = 1k\Omega$ $\tau = 1nm$

$t_{rise} = t_{fall} = 2.195$ ns

at $R = 3k\Omega$ $\tau = 3$ nm

$t_{rise} = t_{fall} = 2.195\tau = 2.195 \times 3$

$= 6.589$ ns

at $R = 5k\Omega$ τ is very Large

$\tau = 5$ nm

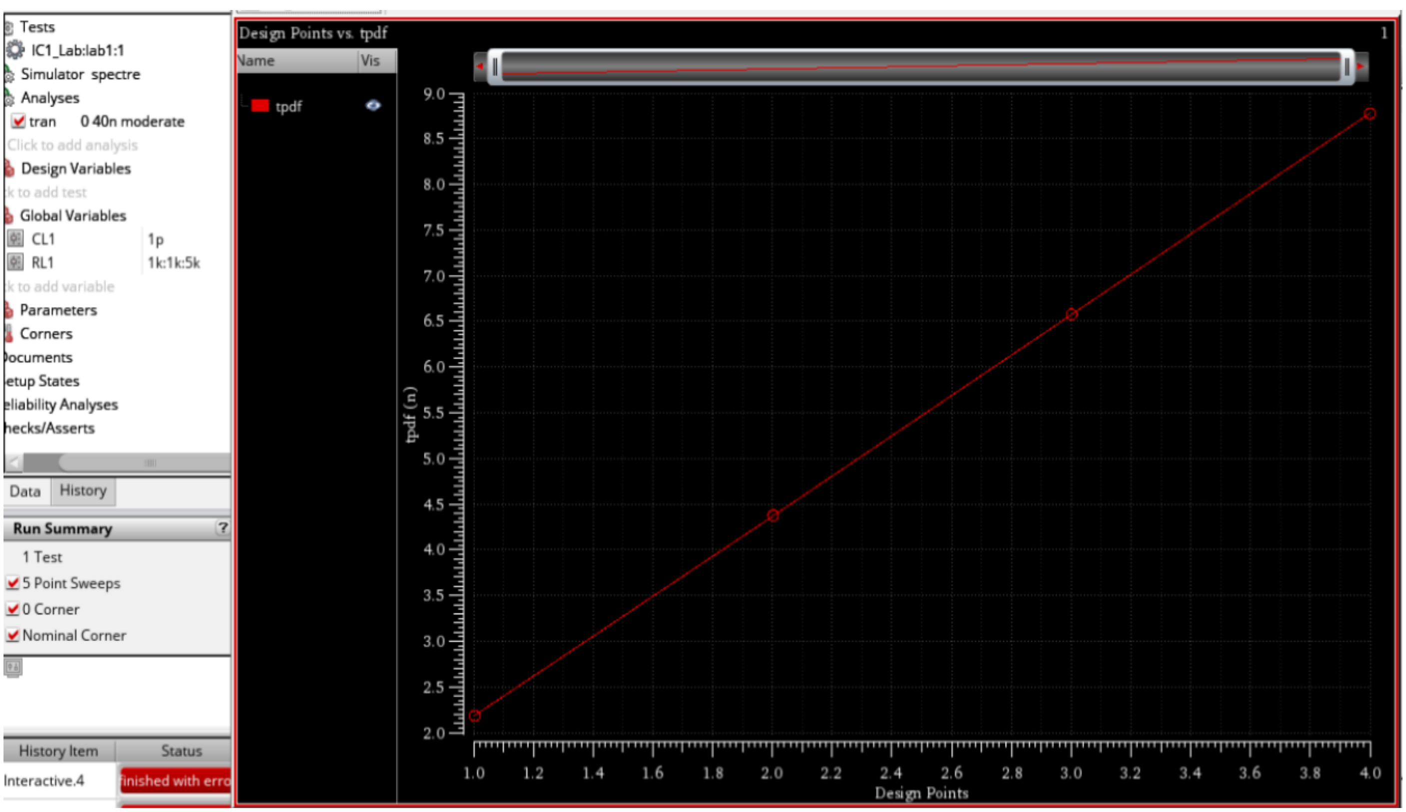
The V_{out} will not reach either 90% or 10% This will lead to evaluation error.

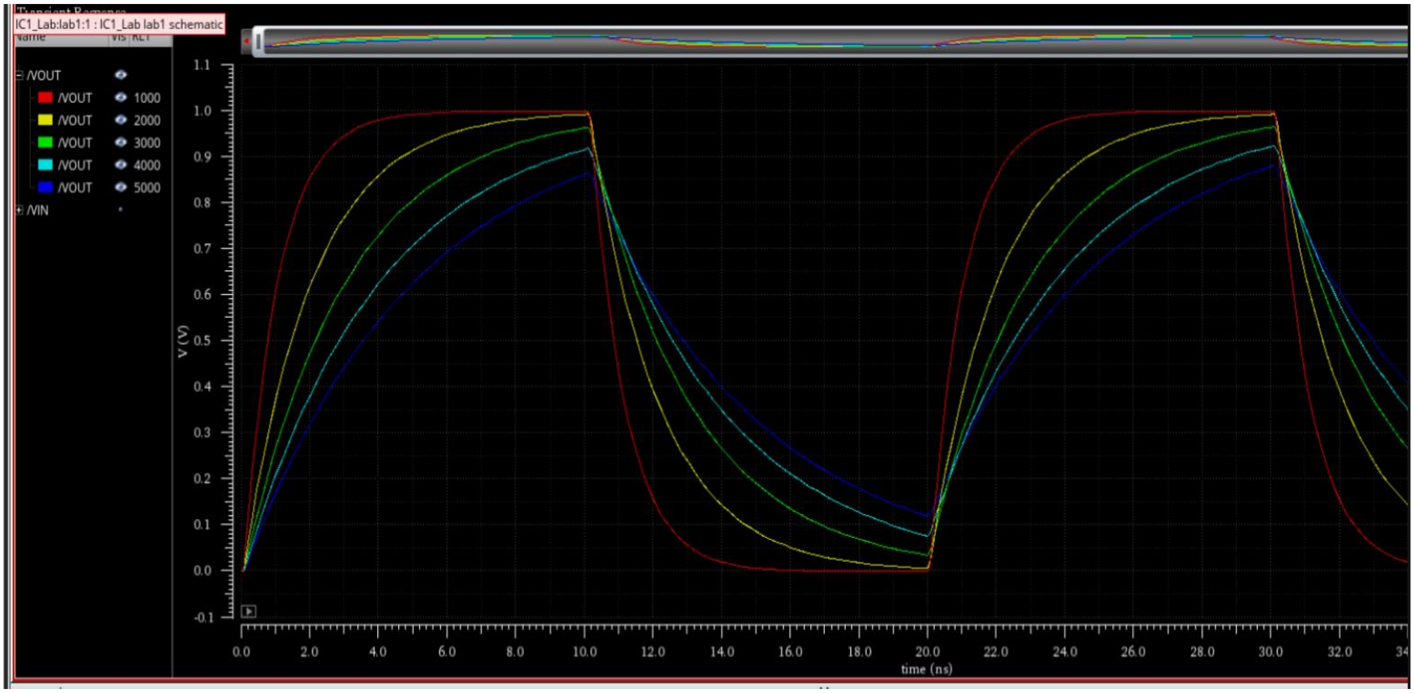
→ From the graph shown in The Fig. as R_L increas $\tau\uparrow$ and The time it takes to reach 90% or 10% at $5k\Omega$ The Vout will not reach 90% or 10% leading to evaluation error.

Outputs Setup | Run Preview | Results | Diagnostics

Detail · Replace

Point	Test	Output	Nominal	Spec
1	IC1_Lab:lab1:1	tpdf	2.195n	
1	IC1_Lab:lab1:1	tpd	2.195n	
1	IC1_Lab:lab1:1	/VOUT		
1	IC1_Lab:lab1:1	/VIN		
Parameters: RL1=2k				
2	IC1_Lab:lab1:1	tpdr	4.391n	
2	IC1_Lab:lab1:1	tpdf	4.391n	
2	IC1_Lab:lab1:1	tpd	4.391n	
2	IC1_Lab:lab1:1	/VOUT		
2	IC1_Lab:lab1:1	/VIN		
Parameters: RL1=3k				
3	IC1_Lab:lab1:1	tpdr	6.589n	
3	IC1_Lab:lab1:1	tpdf	6.589n	
3	IC1_Lab:lab1:1	tpd	6.589n	
3	IC1_Lab:lab1:1	/VOUT		
3	IC1_Lab:lab1:1	/VIN		
Parameters: RL1=4k				
4	IC1_Lab:lab1:1	tpdr	8.787n	
4	IC1_Lab:lab1:1	tpdf	8.787n	
4	IC1_Lab:lab1:1	tpd	8.787n	
4	IC1_Lab:lab1:1	/VOUT		
4	IC1_Lab:lab1:1	/VIN		
Parameters: RL1=5k				
5	IC1_Lab:lab1:1	tpdr	eval err	
5	IC1_Lab:lab1:1	tpdf	eval err	
5	IC1_Lab:lab1:1	tpd	eval err	
5	IC1_Lab:lab1:1	/VOUT		
5	IC1_Lab:lab1:1	/VIN		



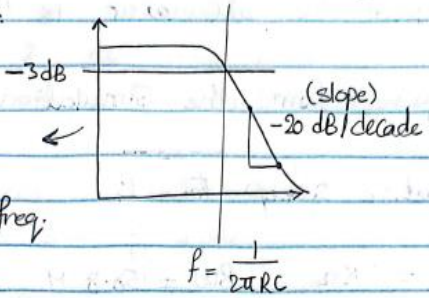


2. AC Analysis

1) Report Bode Plot (magnitude and phase) for the previous LPF.
2) Calculate DC gain and 3dB bandwidth using Cadence calculator expressions. Export the expressions to adexl.
3) Compare simulation with analytical results in a table.
4) Do parametric sweep for $R = 1,10,100,1000k\Omega$. Report overlaid results. Comment on the results.

AC_analysis:

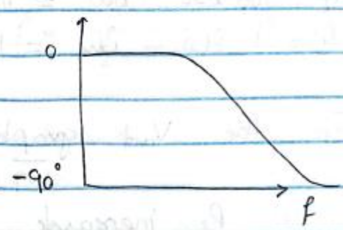
Theoritically:



Magnitude (low pass)
Passes low freq.

As for phase plot as freq increase phase angle dec.

$$H(s) = \frac{\frac{1}{sC}}{R + \frac{1}{sC}} = \frac{1}{1 + RSC}$$

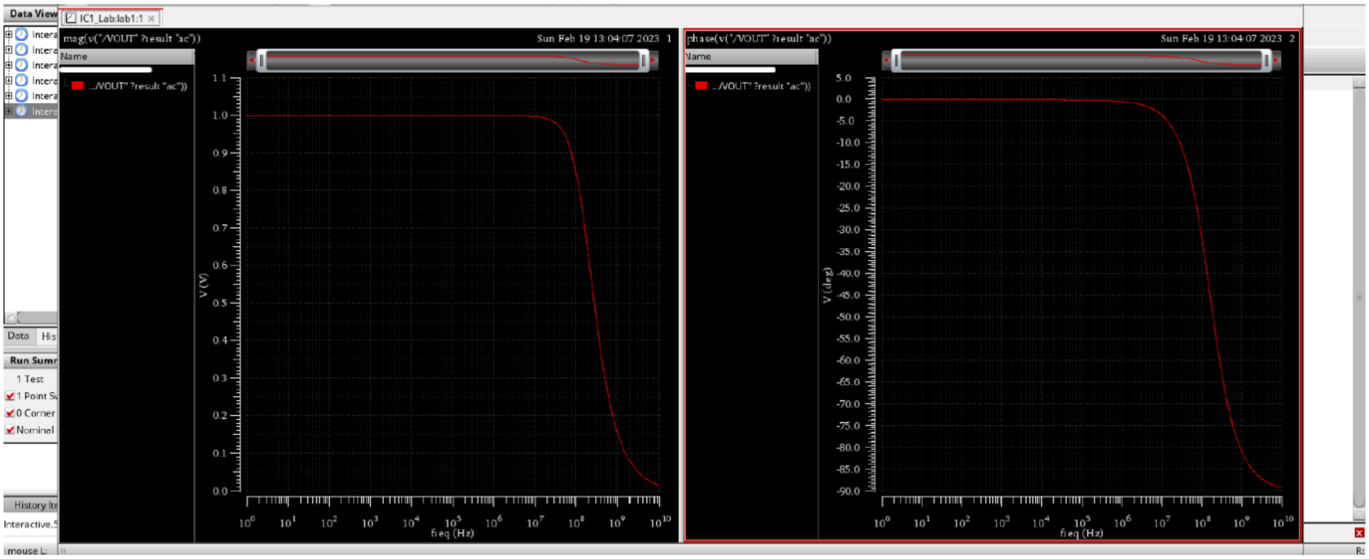


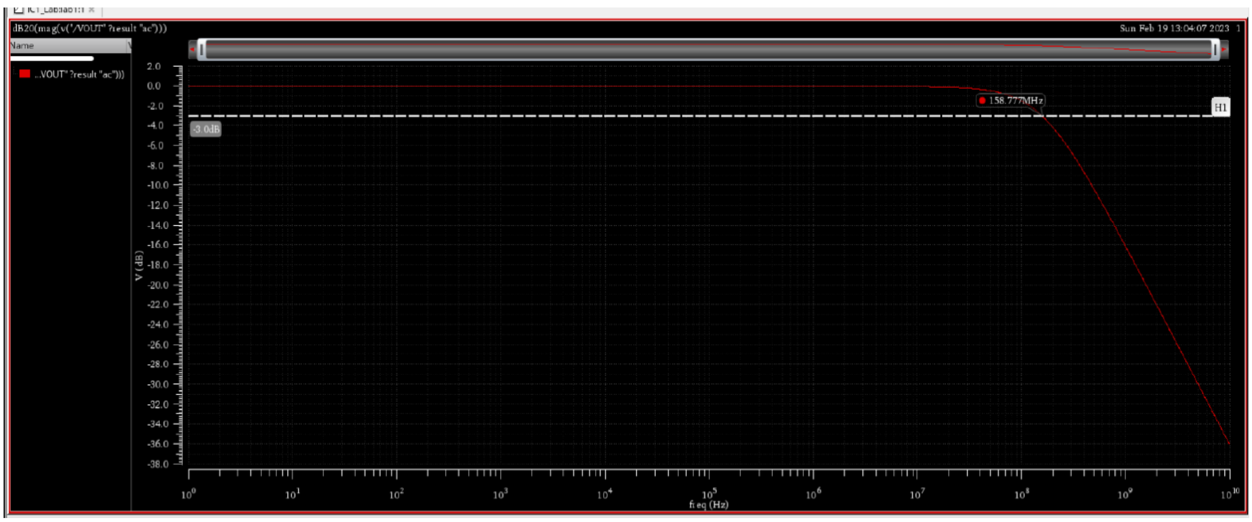
$$H(jw) = \frac{1/RC}{1/RC + (jw)}$$ as $f\uparrow$ $\angle H(jw)$ decrease from 0° to -90°

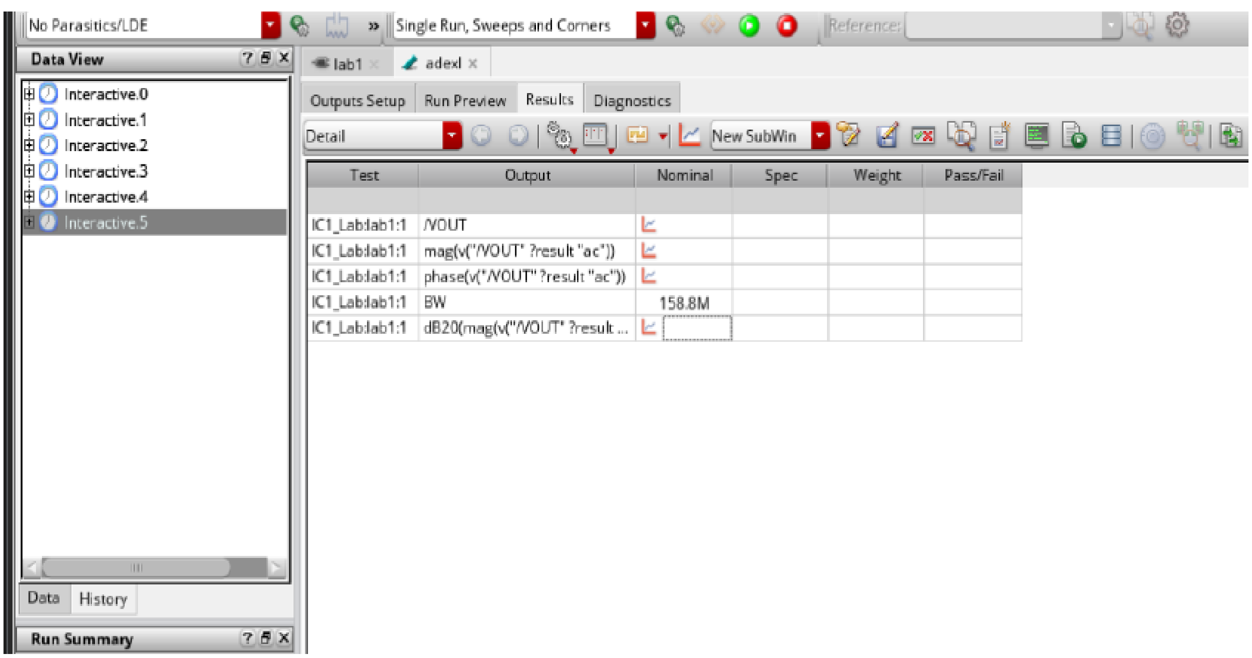
DC gain at freq = zero ⇒ The capictor is open circuit then $V_{out} = V_{in}$

gain = 1

DC gain = 0 dB from the graph


mag(v("/VOUT" ?result "ac"))
phase(v("/VOUT" ?result "ac"))
Sun Feb 19 13:04:07 2023
V (V)
V (deg)
freq (Hz)


dB20(mag(v("/VOUT" ?result "ac")))
Sun Feb 19 13:04:07 2023
158.777MHz
-3.0dB
H1
V (dB)
freq (Hz)


No Parasitics/LDE
Single Run, Sweeps and Corners
Reference:
Data View
Interactive.0
Interactive.1
Interactive.2
Interactive.3
Interactive.4
Interactive.5
lab1
adexl
Outputs Setup
Run Preview
Results
Diagnostics
Detail
New SubWin
Test
Output
Nominal
Spec
Weight
Pass/Fail
IC1_Lab:lab1:1
/VOUT
mag(v("/VOUT" ?result "ac"))
phase(v("/VOUT" ?result "ac"))
BW
158.8M
dB20(mag(v("/VOUT" ?result ...
Data
History
Run Summary

Bode plot → right click → Direct plot → AC mag & Phase

From the Simulation Bandwidth is 158.77 MHz and from the Calculator is 158.8 MHz

Dc gain from the Simulation is 0 dB

parametric sweep for R_L

at $R_L = 1\,K\Omega$ BW = 158.8 M
$R_L = 10\,K\Omega$ BW = 15.88 M
$R_L = 100\,K\Omega$ BW = 1.588 M
$R_L = 1\,M\Omega$ BW = 158.8 K

From the Vout graph

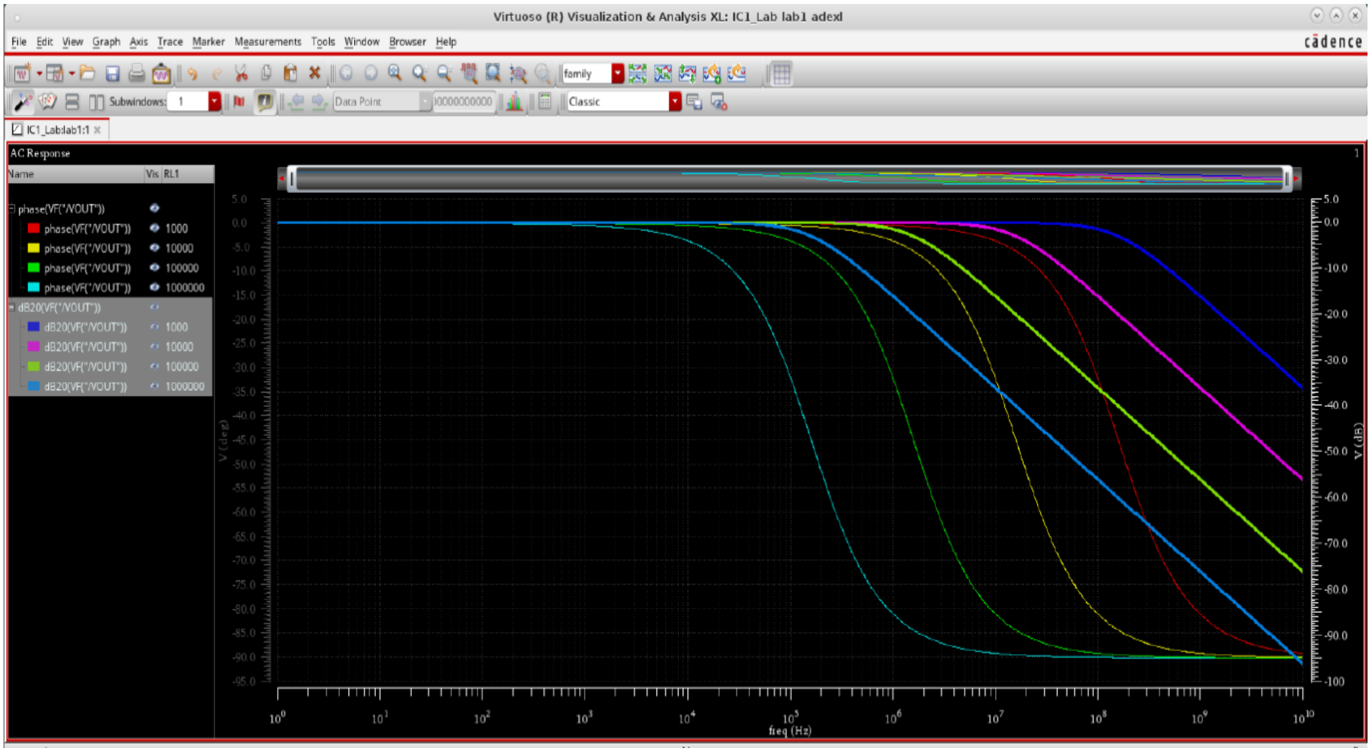
as R_L increases the 3dB freq decrease. ↓ Band width in this case

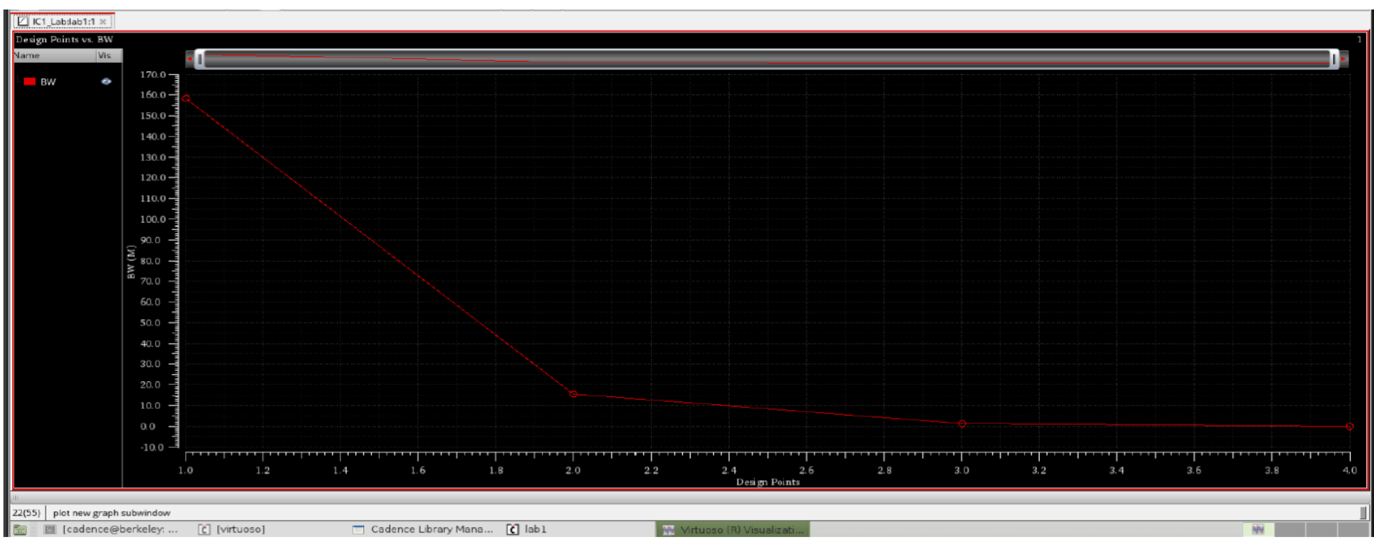
which can be ← seen from the graph

these results can also be validated from the Func.

$$H(s) = \frac{1}{1+RSC}, \quad H(jw) = \frac{1}{1+RC(jw)}$$

Point	Test	Output	Nominal
Parameters: RL1=1k			
1	IC1_Lab:lab1:1	/VOUT	
1	IC1_Lab:lab1:1	mag(v("/VOUT" ?result "ac"))	
1	IC1_Lab:lab1:1	phase(v("/VOUT" ?result "ac"))	
1	IC1_Lab:lab1:1	BW	158.8M
1	IC1_Lab:lab1:1	dB20(mag(v("/VOUT" ?result ...	
Parameters: RL1=10k			
2	IC1_Lab:lab1:1	/VOUT	
2	IC1_Lab:lab1:1	mag(v("/VOUT" ?result "ac"))	
2	IC1_Lab:lab1:1	phase(v("/VOUT" ?result "ac"))	
2	IC1_Lab:lab1:1	BW	15.88M
2	IC1_Lab:lab1:1	dB20(mag(v("/VOUT" ?result ...	
Parameters: RL1=100k			
3	IC1_Lab:lab1:1	/VOUT	
3	IC1_Lab:lab1:1	mag(v("/VOUT" ?result "ac"))	
3	IC1_Lab:lab1:1	phase(v("/VOUT" ?result "ac"))	
3	IC1_Lab:lab1:1	BW	1.588M
3	IC1_Lab:lab1:1	dB20(mag(v("/VOUT" ?result ...	
Parameters: RL1=1M			
4	IC1_Lab:lab1:1	/VOUT	
4	IC1_Lab:lab1:1	mag(v("/VOUT" ?result "ac"))	
4	IC1_Lab:lab1:1	phase(v("/VOUT" ?result "ac"))	
4	IC1_Lab:lab1:1	BW	158.8k
4	IC1_Lab:lab1:1	dB20(mag(v("/VOUT" ?result ...	





3. [Optional] Pole Zero Analysis

1) Report pole zero analysis results.
2) Find the pole frequency and compare it with the bandwidth calculated from AC analysis.

* هاتها من ال results browser

Pole-Zero analysis:
no Zeros where found
according to Simulation:
→ no zeros were found

Pole at $P_1 = -1.5915 \times 10^8$

However since: $H(s) = \dfrac{1}{1 + RSC}$

$\therefore \; S = -\dfrac{1}{RC} \rightarrow$ pole

$P_1 = S = -\dfrac{1}{10^3 \times 10^{-12}} = -10^9$

$\therefore \; f = \dfrac{-10^9}{2 \times \pi} = -1.59 \times 10^8$ Hz

↓ Approximately The Same Answer

As for The Comparison between The Bandwidth and pole

158.8 MHz , pole = $-$159.15 MHz

$f_{3dB} = \dfrac{1}{2\pi RC} \simeq 159.15$ MHz

Simulation ⇒ 158.8 MHz

* They are supposidly equal to each other.

$1 + RC(j\omega) = 0$

$RC(j\omega) = -1$

$j\omega = -\dfrac{1}{RC} j^2$

$\omega = \left(\dfrac{1}{RC}\right) j$

$f = \dfrac{1}{2\pi RC} j$

```
            .probe 0
          .measure 0
             save 0

Time for parsing: CPU = 0 s, elapsed = 15.439 ms.
Time accumulated: CPU = 152 ms, elapsed = 157.483 ms.
Peak resident memory used = 81.1 Mbytes.

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Pre-Simulation Summary
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Warning from spectre.
    WARNING (SPECTRE-16707): Only tran supports psfxl format, result of othe

****************
PZ Analysis 'pz'
****************
DC simulation time: CPU = 0 s, elapsed = 431.061 us.
DC simulation time: CPU = 0 s, elapsed = 77.0092 us.
                   Poles (Hz)

         Real                  Imaginary                Qfactor

  1   -1.59155e+08            0.00000e+00            5.00000e-01

 No zero is found

Accumulated DC solution time = 38.4519 ms.
```
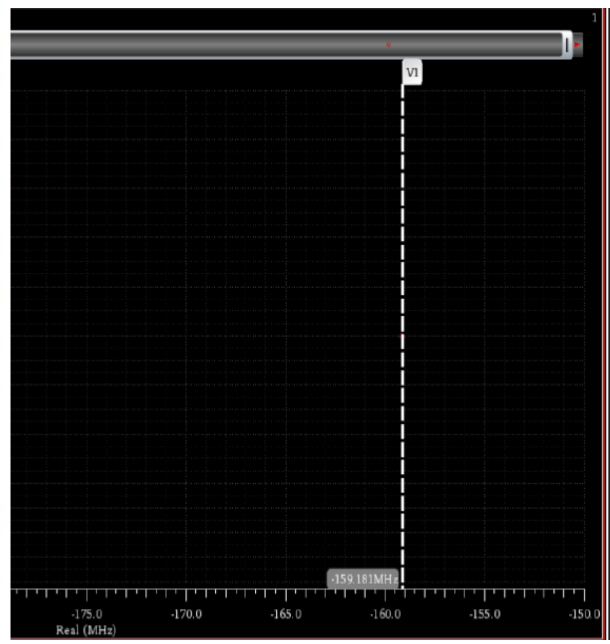
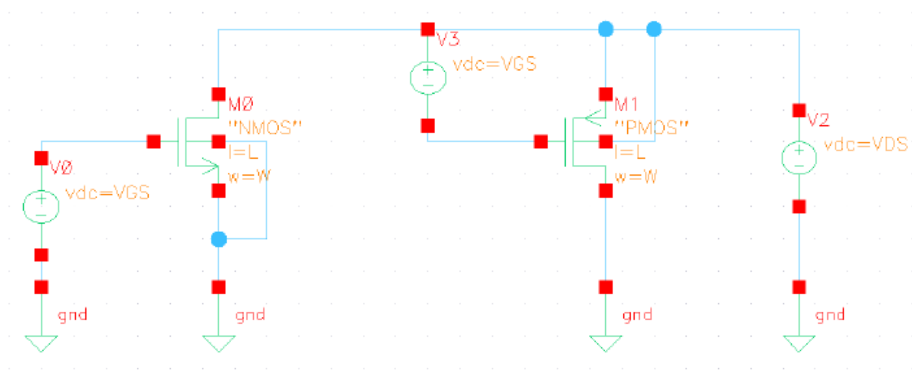



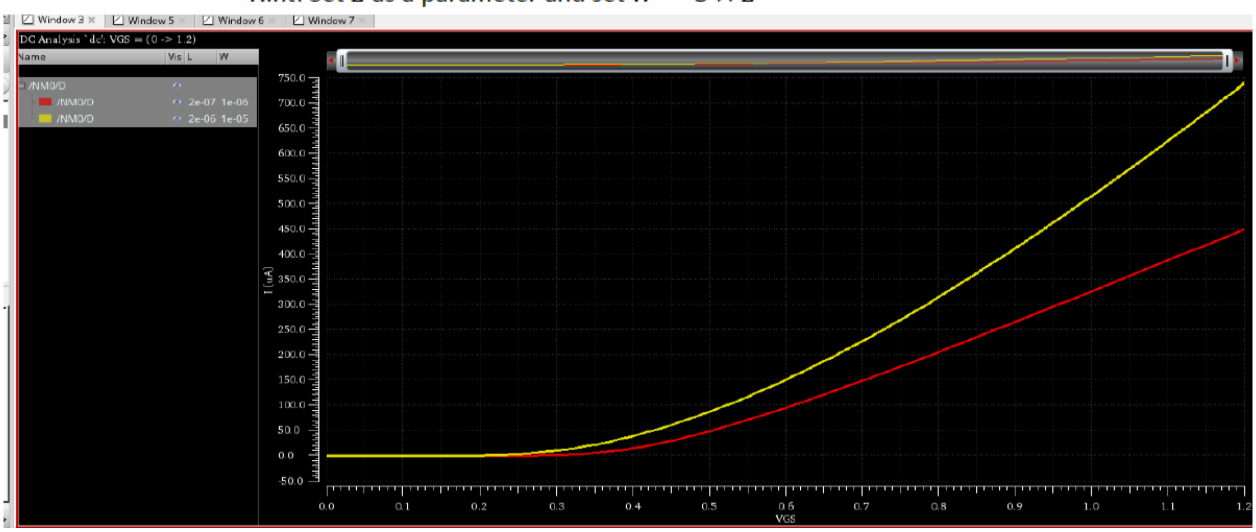
PART 2: MOSFET CHARACTERISTICS:

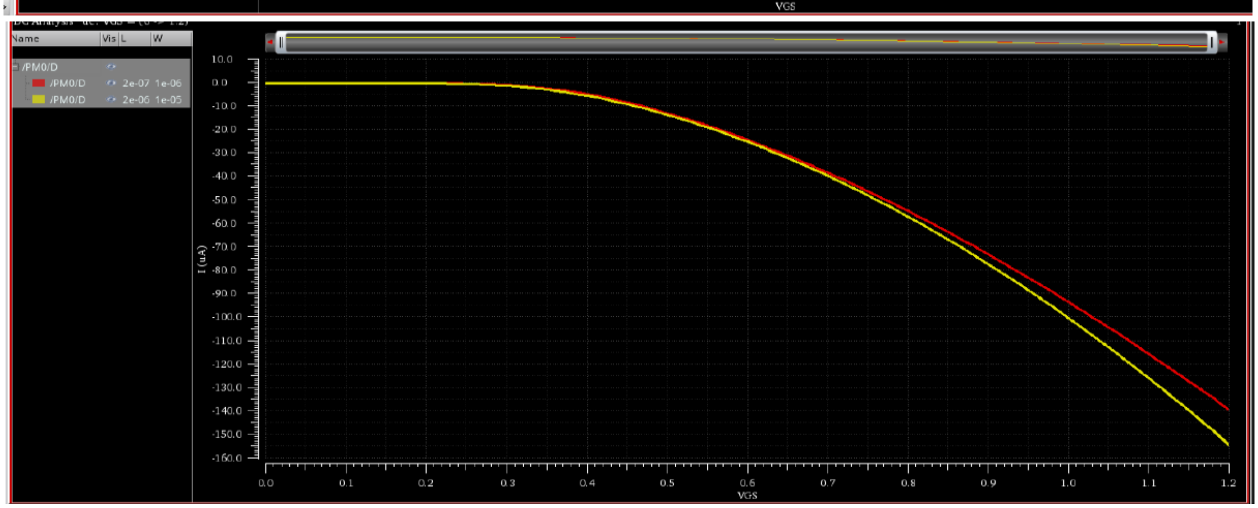


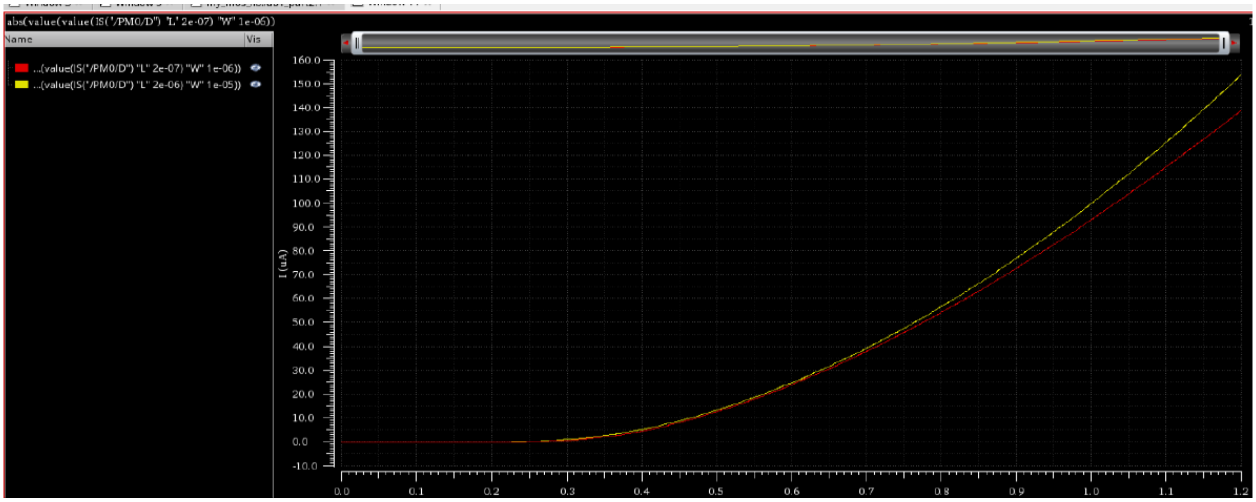
1. ID vs VGS

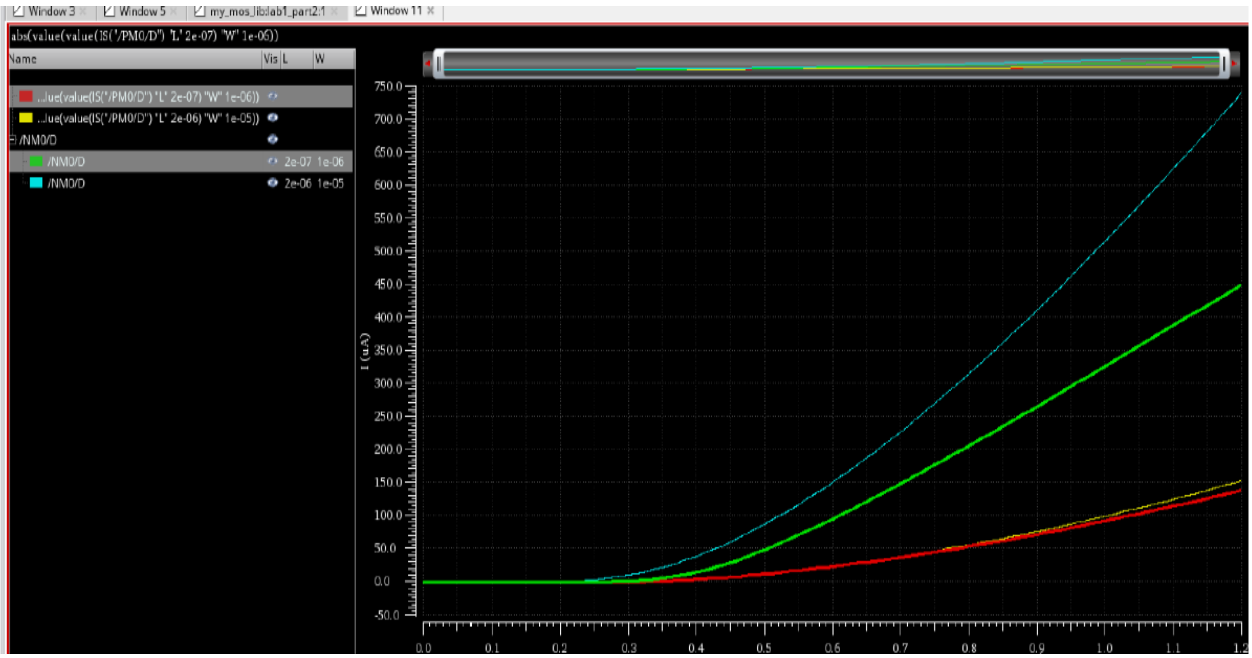
1) Plot $I_D - V_{GS}$ characteristics for NMOS and PMOS devices. Set $V_{DS} = V_{DD}$, and $V_{GS} = 0{:}\,10m{:}\,V_{DD}$. Use $V_{DD} = 1.2V$ for 130nm technology and $V_{DD} = 1.8V$ for 180nm technology. Plot the results overlaid for the following:
   - Short channel device: $W = 1\mu m$ and $L = 200nm$
   - Long channel device: $W = 10\mu m$ and $L = 2\mu m$.

   Hint: Set L as a parameter and set $W = 5 \times L$









2) Comment on the differences between short channel and long channel results.
   - Which one has higher current? Why?
   - Is the relation linear or quadratic? Why?
3) Comment on the differences between NMOS and PMOS.
   - Which one has higher current? Why?
   - What is the ratio between NMOS and PMOS currents at VGS = VDD?
   - Which one is more affected by short channel effects?

→ from The graphs we find that:

2)

as for NMOS: long channel NMOS has higher current Than short channel (as expected) That is because of The short channel effects (velocity saturation and mobility degradation)

→ long channel is quadratic while Short channel is linear That's because of velocity sat.

pinch off sat. (in long channel) → $I_D \propto V_{GS}^2$

Velocity sat. (in short channel) → $I_D \propto V_{GS}$

PMOS has much less effects which we will discuss on The 2nd point-

3-

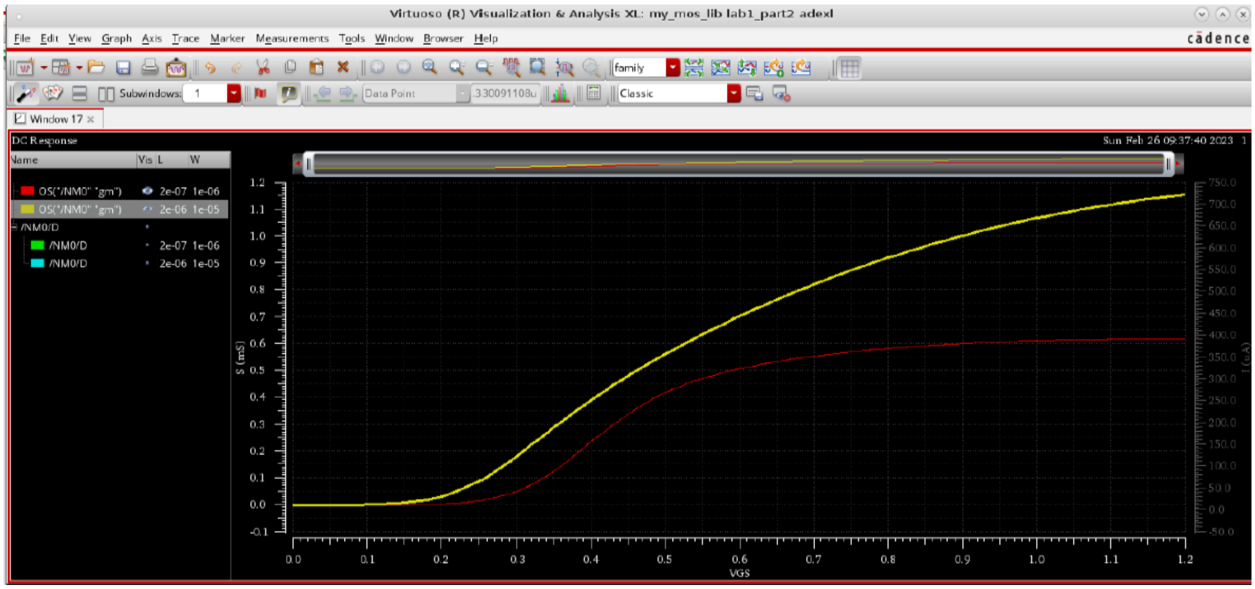
① NMOS has higher current because of The diff. in mobility Ratio electrons have higher mobility than holes

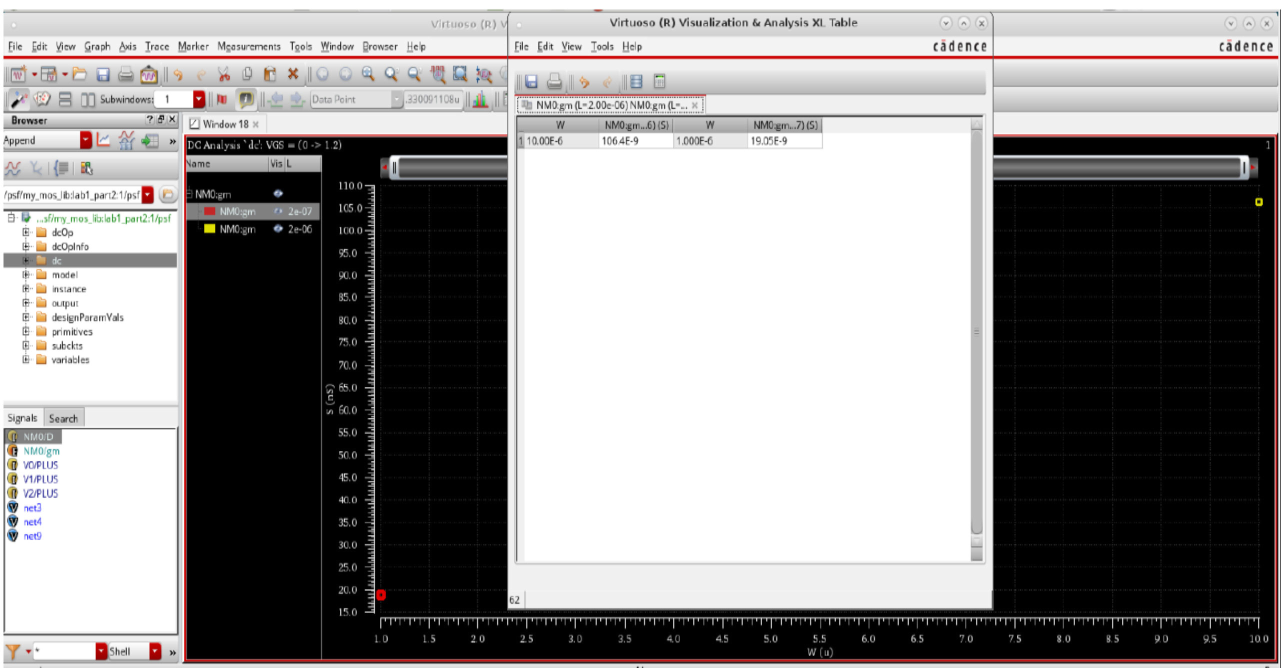
② at $V_{GS} = V_{DD}$ The Ratio between at V_{DD} NMOS and PMOS is mobility Ratio, which is $\frac{739.3 \times 10^{-6}}{153.9 \times 10^{-6}} = 4.8$ at Const. other Factors

- NMOS is more affected by short channel effects because of The mobility Ratio, The mobility of holes is small when Compared to electrons So it doesn't saturate as fast as electrons (NMOS)

✓. g_m vs VGS

1) Plot g_m vs V_{GS} for NMOS device. Set $V_{DS} = V_{DD}$, and $V_{GS} = 0\!:10m\!:V_{DD}$. Plot the results overlaid for the following:
    - Short channel device: $W = 1\mu m$ and $L = 200nm$
    - Long channel device: $W = 10\mu m$ and $L = 2\mu m$.





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

- Does g_m increase linearly? Why?
- Does g_m saturate? Why?

② g_m is the derivative of I_D

$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$

g_m increases semi linearly in long channel
That's because

$$I_D = \frac{1}{2} k_n V_{ov}^2$$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = k_n V_{ov} \qquad g_m \propto V_{GS}$$

as for the short channel g_m will saturate much earlier that is due to velocity saturation where,

$$I_D = \cancel{k_n}\ \mu_n C_{ox} \frac{W}{L} \left(V_{ov} - \frac{V_{DSsat}}{2} \right) V_{DSsat}$$

$$I_D = C_{ox} W v_{sat} \left(V_{ov} - \frac{V_{DSsat}}{2} \right)$$

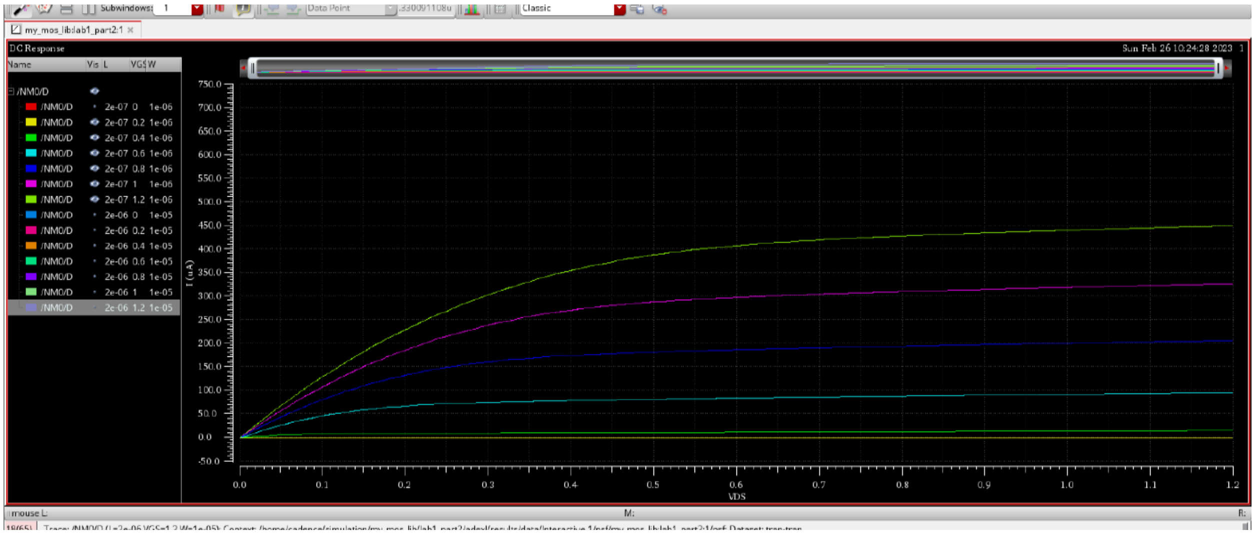
$$I_D \propto V_{GS}$$

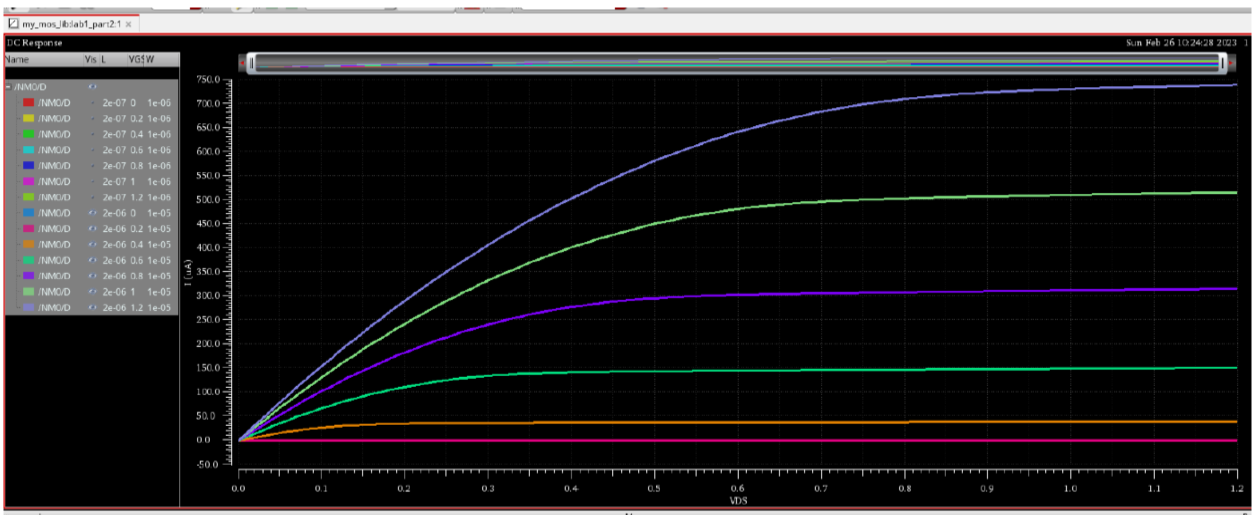
$\therefore$ g_m is const.

from the table you will find that g_m will saturate much earlier in case of short than long channel

3. ID vs VDS

1) Plot $I_D - V_{DS}$ characteristics for NMOS device. Set $V_{DS} = 0{:}\,10m{:}\,V_{DD}$, and $V_{GS} = 0{:}\,0.2{:}\,V_{DD}$ (nested sweep). Plot the results overlaid for the following:
   - Short channel device: $W = 1\mu m$ and $L = 200nm$
   - Long channel device: $W = 10\mu m$ and $L = 2\mu m$.





ID Vs VDs

→ long channel has higher current than short channel That is because of The short channel effects like velocity saturation and mobility degradation and Drain induced barrier lowering as it decreases V_{th} thus V_{ov} inc. giving V_{DS} enough time to reach V_{DSsat} first and saturating at lower current.

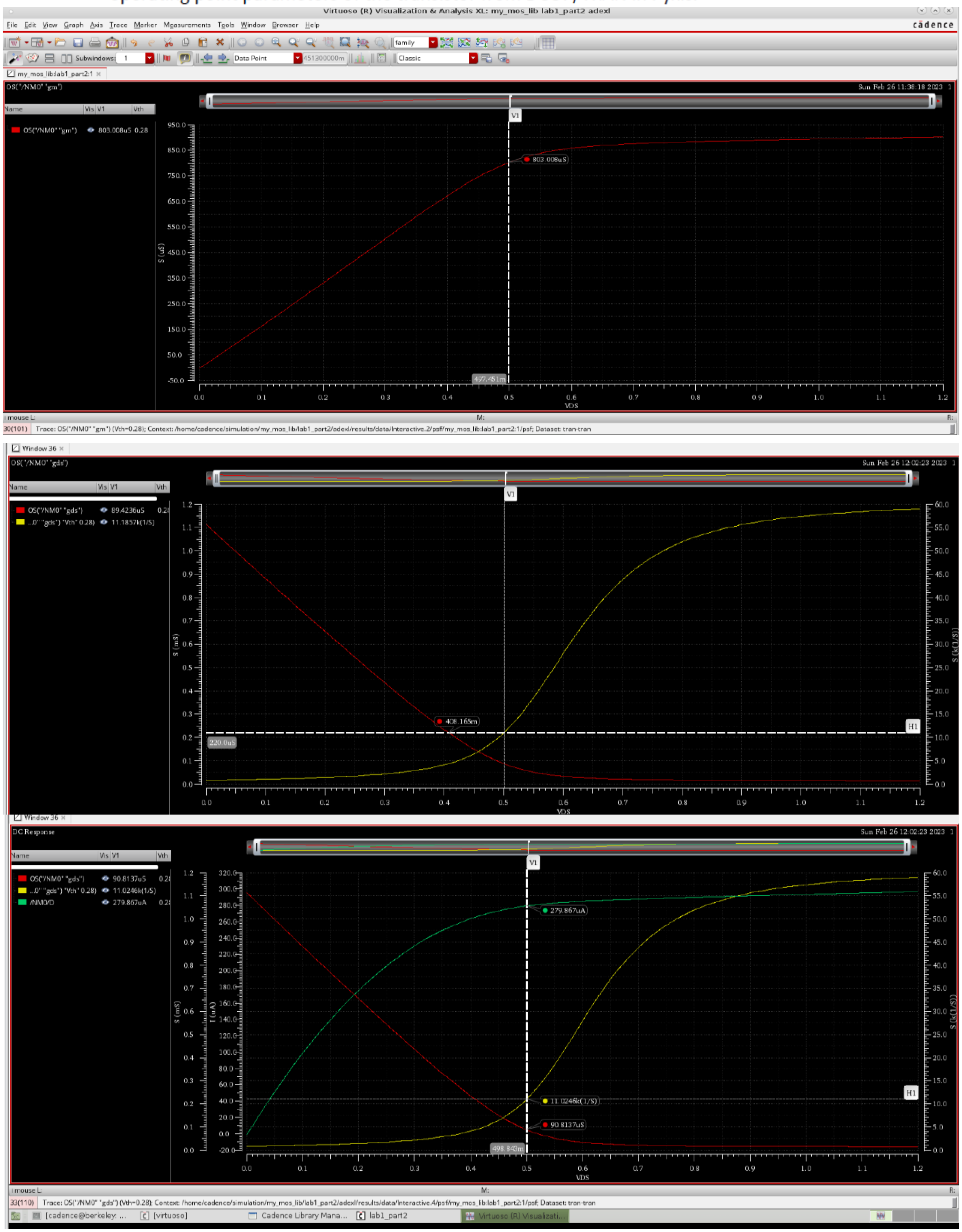
Short

→ ~~long~~ channel has higher slope in saturation region than long channel That is because of The channel length modulation effect is more in case short than long channel because the dependence of the current on V_{DS} in short channel is larger than in long channel.

4. [Optional] g_m and r_o in Triode and Saturation

1) Plot g_m and r_o vs V_{DS} for NMOS device. Use $W = 10\mu m$ and $L = 2\mu m$, $V_{DS} = 0{:}\,10m{:}\,V_{DD}$, and $V_{GS} \approx V_{TH} + 0.5V$.

   Hint: You can get an estimate of V_{TH} from the I_D vs V_{GS} characteristics, or you can print the operating point parameters of the transistor from DCOP/TRAN in Pyxis.



2) Comment on the variation of g_m vs V_{DS}.

- In the first part of the curve, is the relation linear? Why?
- Does g_m saturate? Why?
- Where do you want to operate the transistor for analog amplifier applications? Why?

4) from The graph ID Vs VGS we find that $V_{Th} = 0.28$ v

2- • The relation is linear in The first part of The Curve, before $V_{DS} = 0.5$ v The transis. was in The triode region where $I_D \propto V_{DS}^2$. Quadratic relation

$$I_D = K_n \left(V_{ov} V_{DS} - \frac{V_{DS}^2}{2} \right)$$

Thus gm is always derivative of I_D then g_m is linear with V_{DS}

• Then gm saturates eventually because I_D gets in the saturation region

$$I_D = \tfrac{1}{2} K_n V_{ov}^2 (1 + \lambda V_{DS})$$

at some point The dependence of I_D on V_{DS} is semi linear and thus g_m becomes constant

→ Saturation Region — as it can be used as VCCS, where I_D is dependent on V_{GS} mostly with a little effect from V_{DS}.

3) Comment on the variation of r_o vs V_{DS}.

- Does r_o saturate just after the transistor enters saturation similar to gm? Why?
- Does r_o increase if the transistor is biased more into saturation?
- Should we operate the transistor at the edge of saturation?
- Where do you want to operate the transistor for analog amplifier applications? Why?

$\frac{1}{g_{ds}}$ in simulation

There is a little amount of V_{DS} dependence before it saturates

3) r_o takes time before it saturates because of CLM, r_o increase with CLM until other short channel effects kicks in r_o starts decreasing.

- r_o will ~~decrease~~ increase as we further go into saturation due to other channel length modulation

Quadratic dependence on V_{DS}

- The Edge of saturation will satisfy both Regions it might have properties of both.
- Saturation Region as it's used as VCCS

↳ at The Region where r_o is almost constant before it starts decreasing. to give a stable gain.

Least V_{DS} dependence

r_o will increase as we go further into saturation due to CLM until a point comes where The effect of other factors of short channel effects makes it decrease. ↳ DIBL, SCBE

Ultimately it depends on the application

at The Edge of saturation there, the eq. of The triode ~~with~~ will hold and thus the current will depend on V_{DS} (Quadratic relation region) which will not be ideal if we want to use it as a VCCS. (Thus No, we shouldn't)

The End