Cadence Virtuoso LAB (4) Report

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Analog Electronics Workshop

Common Drain Amplifier Frequency Response

Part 1

Sizing Chart

P1:

$\rightarrow$ **Square Law.**

$$|A_v| \approx g_m r_o = \frac{2I_D}{V_{ov}} \times \frac{V_A}{I_D} = \frac{2V_A}{V_{ov}} \rightarrow \text{We used } g_m = \frac{2I_D}{V_{ov}}, V_{ov} = \frac{2I_D}{g_m}$$

$$V^* = V_{ov}$$

$\rightarrow$ **For Real MOSFET.**

$$V_{ov} \neq \frac{2I_D}{g_m} \rightarrow \text{Define } V^* = \frac{2I_D}{g_m} \Leftrightarrow g_m = \frac{2I_D}{V^*}, |A_v| \approx \frac{2V_A}{V^*}$$

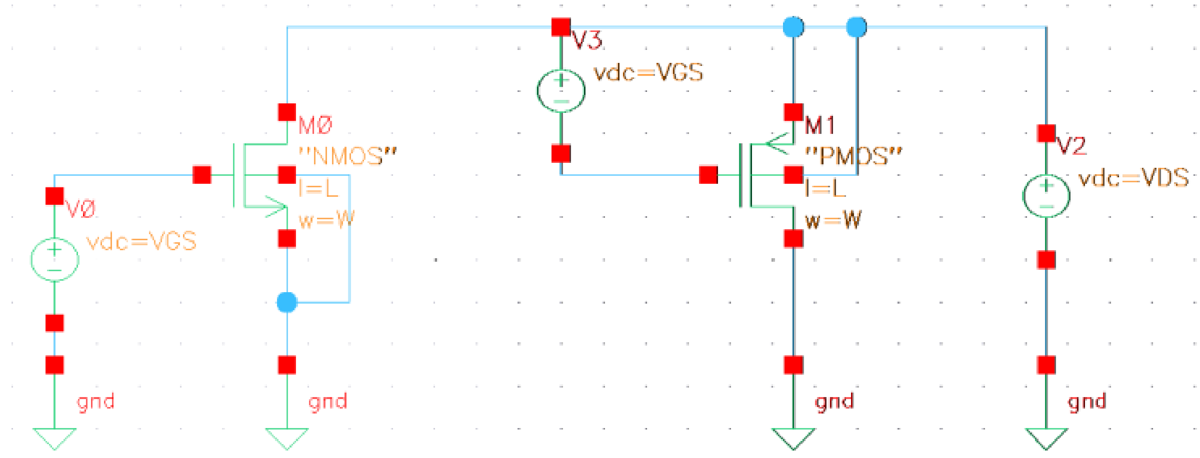
P2:

We want to design a CD amplifier with the parameters below.

Specs (Specifications) M_1 =PMOS

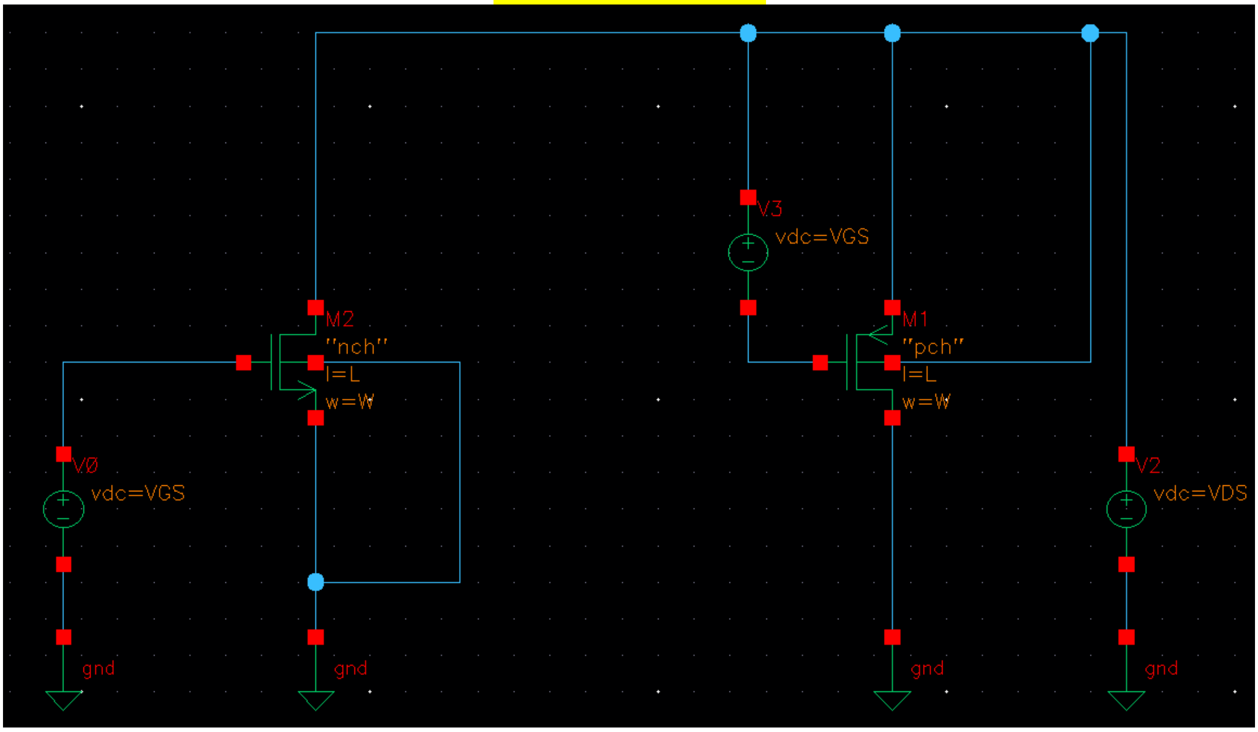
$V_{Star}\ (V^*)$	$200\ mV.$
Supply (V_{DD})	$1.8\ V.$
Current Consumption (I_D)	$10\ \mu A.$
Length (L)	$1\ \mu m.$
Width (W)	$10\ \mu m.$

Circuit



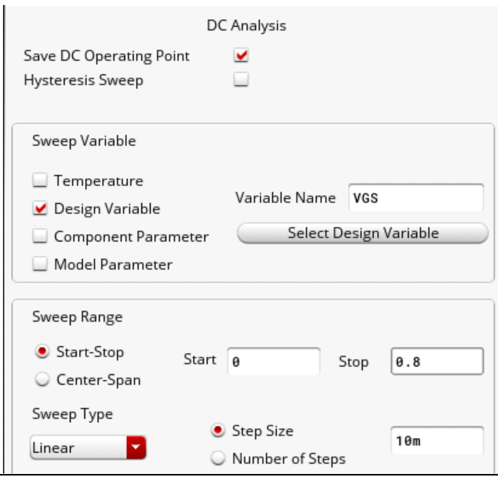
P3

Schematic



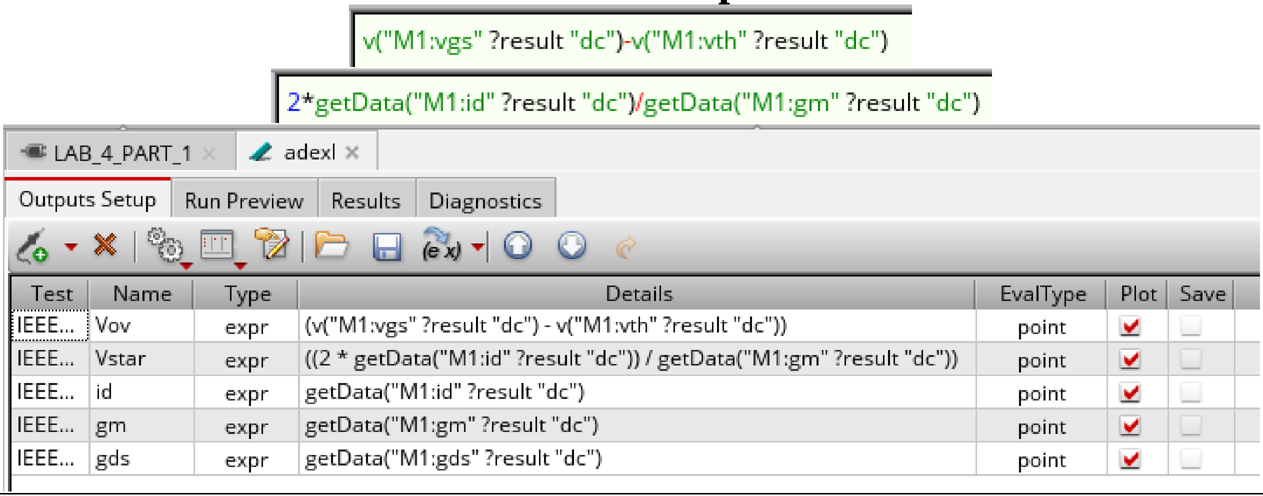
P4

Sweep V_{GS} from 0 to $\approx V_{TH} + 0.4V = 0.8$ with 10 mV step. Set $V_{DS} = \frac{V_{DD}}{2}$.



P5

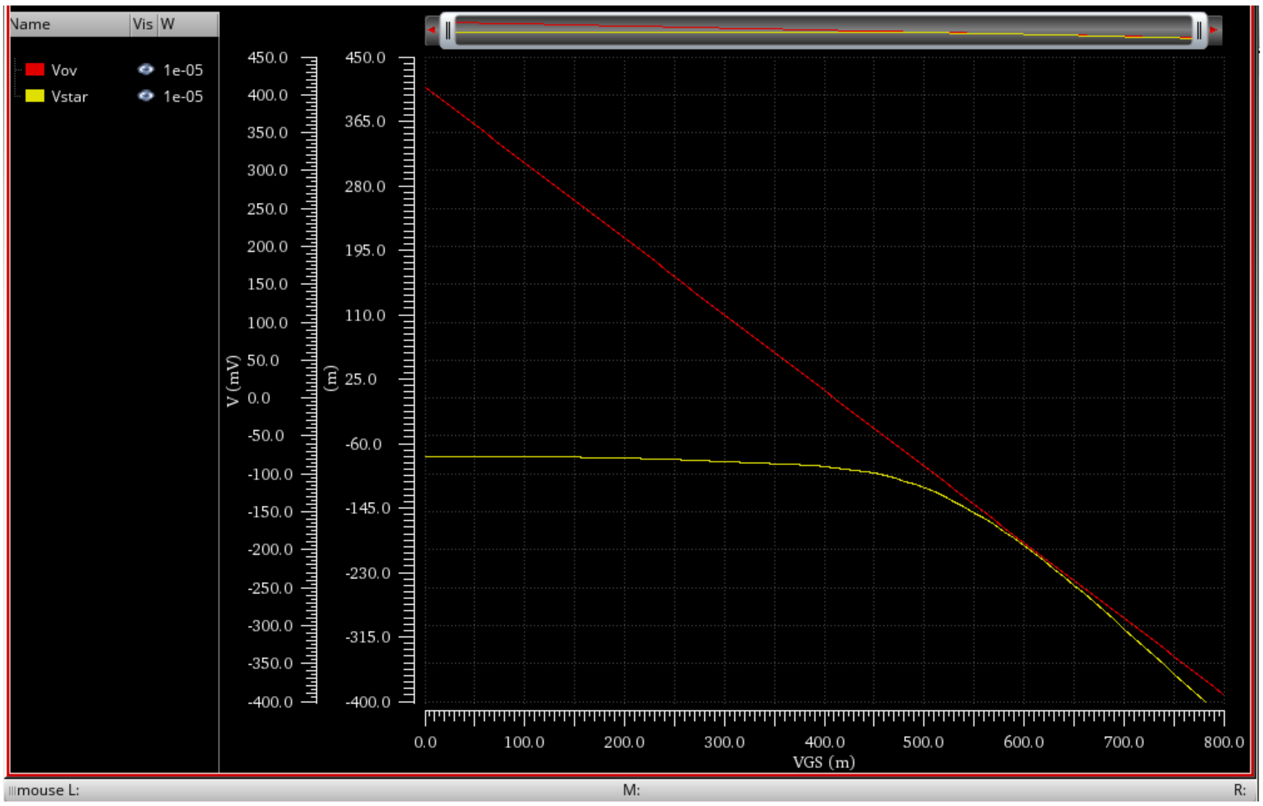
We want to compare $V^* = \frac{2I_D}{g_m}$ and $V_{ov} = V_{GS} - V_{TH}$ by plotting them overlaid. Use the calculator to create expressions for V^* and Vov .



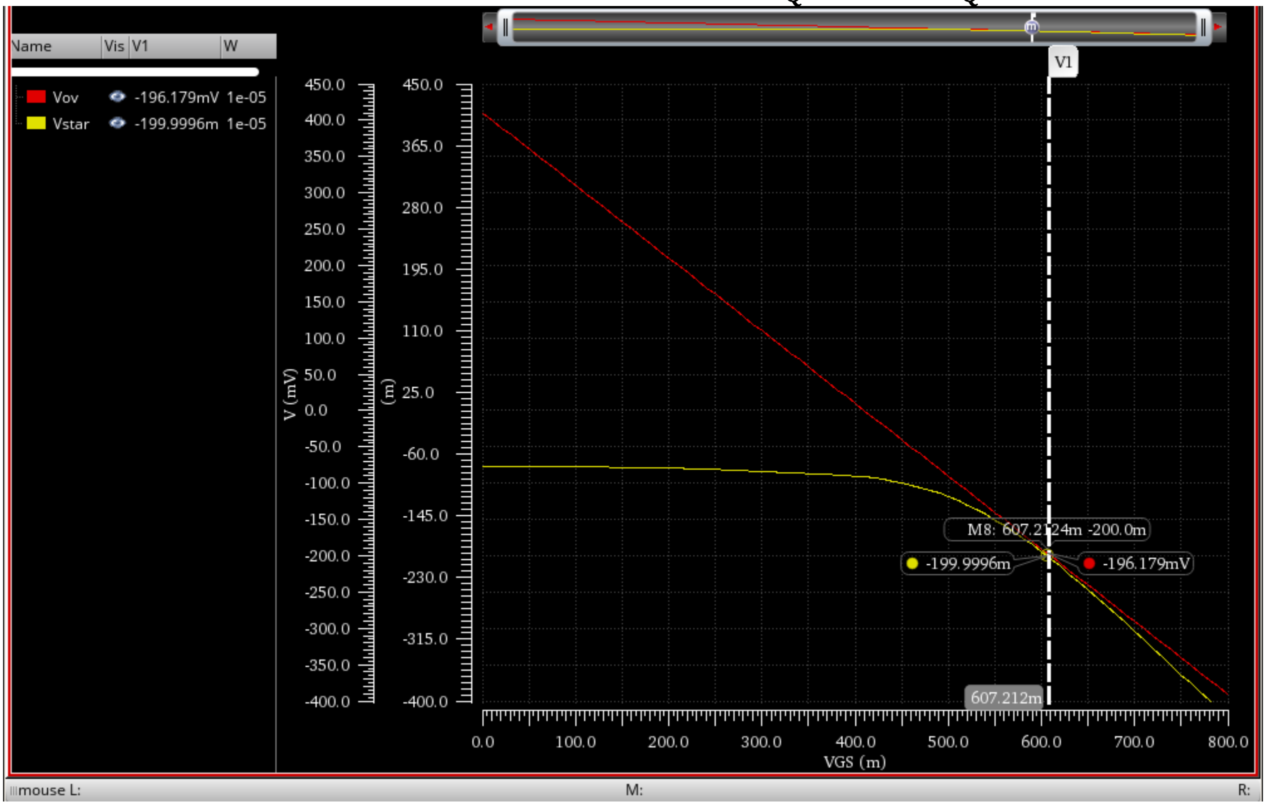
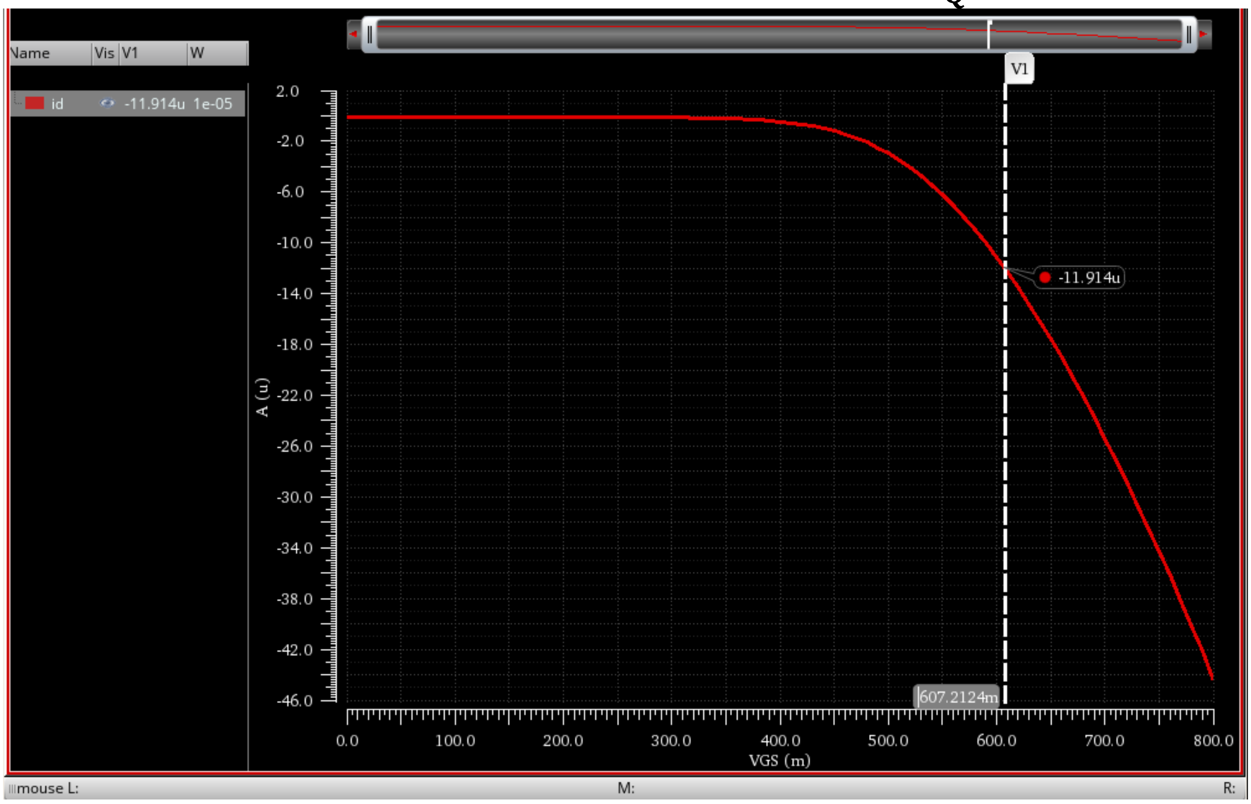
Test	Name	Type	Details	EvalType	Plot	Save
IEEE...	Vov	expr	(v("M1:vgs" ?result "dc") - v("M1:vth" ?result "dc"))	point	✓	
IEEE...	Vstar	expr	((2 * getData("M1:id" ?result "dc")) / getData("M1:gm" ?result "dc"))	point	✓	
IEEE...	id	expr	getData("M1:id" ?result "dc")	point	✓	
IEEE...	gm	expr	getData("M1:gm" ?result "dc")	point	✓	
IEEE...	gds	expr	getData("M1:gds" ?result "dc")	point	✓	

P6

Plot V^* and V_{ov} Overlaid vs V_{GS}
Y-axis of Both Curves Has Same Range

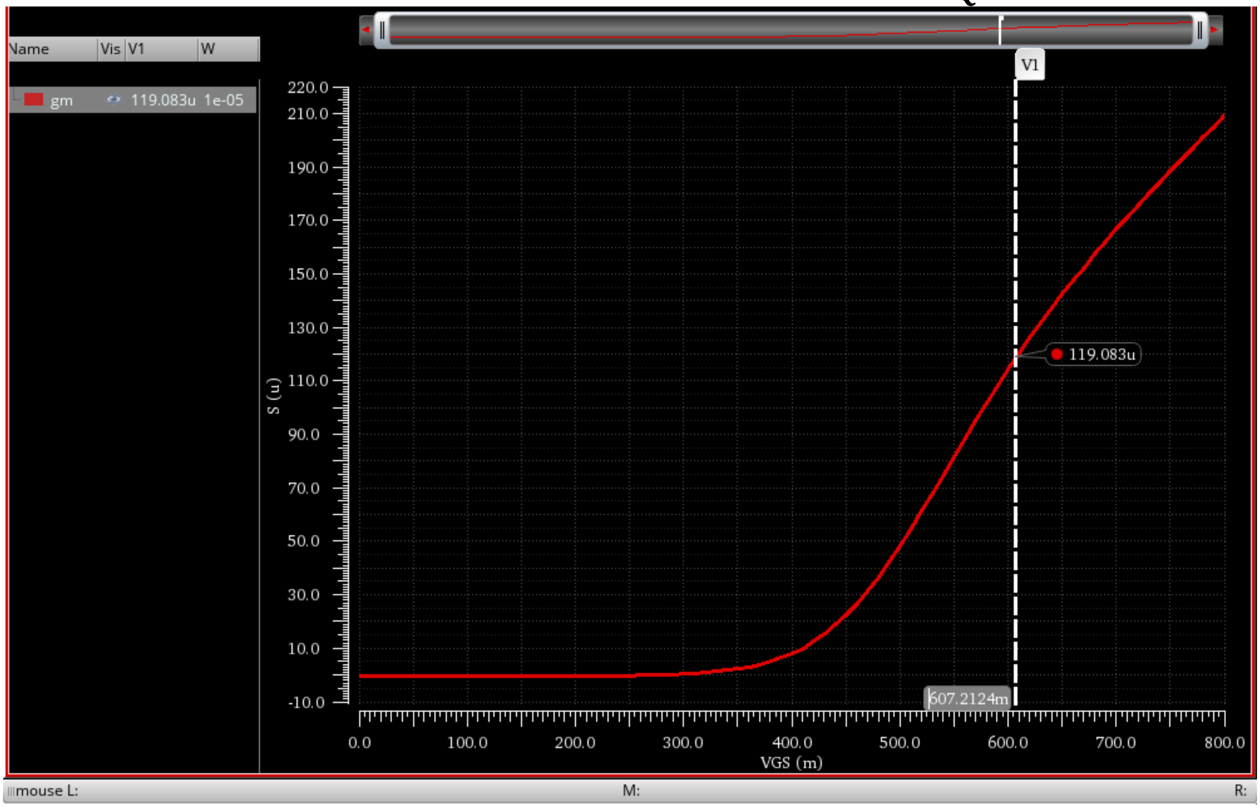


We will notice that at the beginning of the strong inversion region, V^* and V_{ov} are relatively close to each other (i.e., square – law is relatively valid). For deep strong inversion (large V_{ov}: velocity saturation and mobility degradation) or weak inversion (near – threshold and subthreshold operation) the behavior is quite far from the square-law.

P7	**On the V^* and V_{ov} Chart Locate the Point at Which $V^* = 200$ mV. Find the Corresponding V_{ov_Q} and V_{GS_Q}.**  $@\ V^*_Q = -200\text{ mV} \rightarrow V_{ov_Q} = -196.179\text{ mV}.$ $\rightarrow V^* = -199.9996\text{ mV} \rightarrow V_{GS_Q} = 607.2124\text{ mV}.\ @\ V_{TH} \approx 0.4\text{ V}.$
P8	**Plot I_D vs V_{GS}. Find its Values at V_{GS_Q}**  $@V_{GS_Q} = 607.2124\text{ mV} \rightarrow I_{D_X} = -11.914\ \mu\text{A}.$

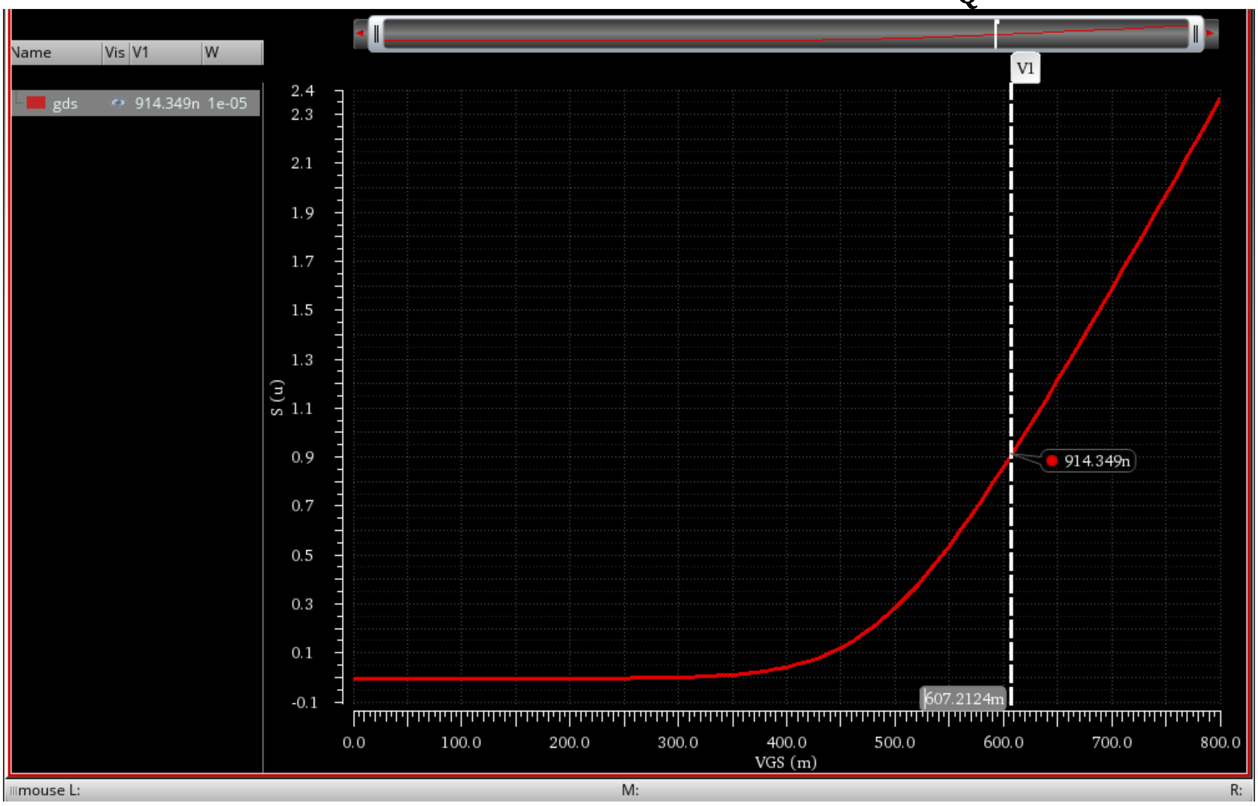
P8

Plot g_m vs V_{GS}. Find its Values at V_{GS_Q}



$$@V_{GS_Q} = 607.2124\ mV \rightarrow g_{m_X} = 119.083\ \mu S.$$

Plot g_{ds} vs V_{GS}. Find its Values at V_{GS_Q}



$$@V_{GS_Q} = 607.2124\ mV \rightarrow g_{ds_X} = 914.349\ nS \rightarrow r_o = \frac{1}{g_{ds_X}} = 1.1\ M\Omega$$

P9	**Now back to the assumption that we made that $W = 10\ \mu m$.** **This is not the actual value that we will use for our design.** **But the good news is that I_D is always proportional to W irrespective of the operating region and the model of the MOSFET (regardless square – law is valid or no). Thus, we can use ratio and proportion (cross – multiplication) to determine the correct width at which the current will be $I_{D_Q} = 10\ \mu A$ as given in the specs.** **Calculate W as shown below.**

W	I_D
$W_{assumed} = 10\ \mu m$	I_{D_X} @ V_Q^* (From The Chart)
$W_{required} = ?$	$I_{D_Q} = 10\ \mu A$ (From The Specs)

W	I_D
$W_{assumed} = 10\ \mu m$	I_{D_X} @ V_Q^* (From The Chart) $= 11.914\ \mu A$
$W_{required} = ?$	$I_{D_Q} = 10\ \mu A$ (From The Specs)

$$W_{required} = 8.393\ \mu m.$$

P10	**Now we are almost done with the design of the amplifier.** **Note that g_m is also proportional to W as long as V_{ov} is constant.** **On the other hand, $r_o = \frac{1}{g_{ds}}$ is inversely proportional to W (I_D) as long as L is constant. Before leaving this part, calculate g_{m_Q} and g_{ds_Q} using ratio and proportion (cross multiplication).**

g_m	W
$g_{m_X} = 119.083\ \mu S.$	$W_{assumed} = 10\ \mu m$
$g_{mQ_{required}} = ?$	$W_{required} = 8.393\ \mu m$

$$g_{mQ_{required}} = 99.946\ \mu S.$$

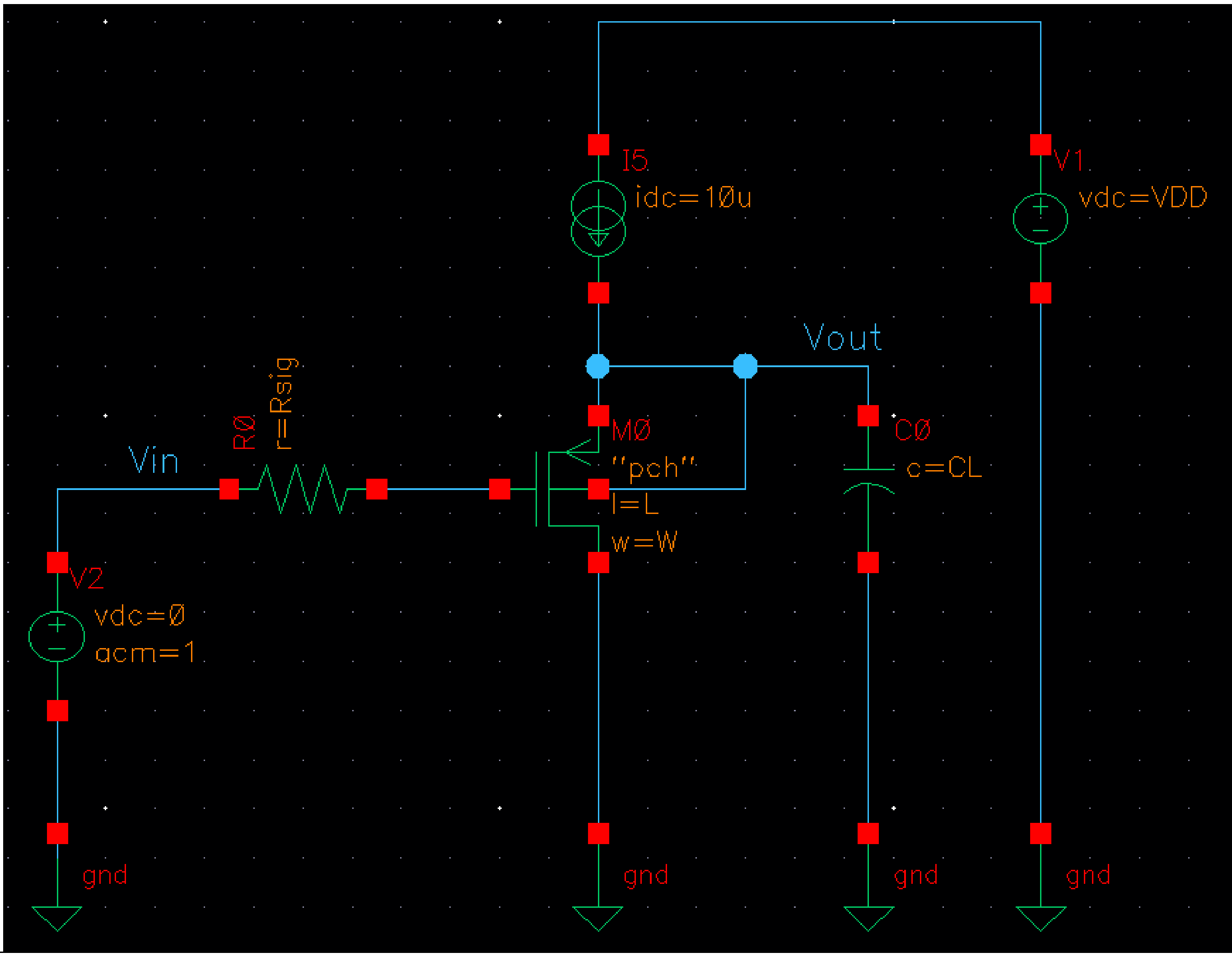
g_{ds}	W
$g_{ds_X} = 914.349\ nS.$	$W_{assumed} = 10\ \mu m$
$g_{ds_{required}} = ?$	$W_{required} = 8.393\ \mu m$

$$g_{dsQ_{required}} = 767.413\ nS \rightarrow r_o = 1.3\ M\Omega$$

Part 2

CD Amplifier

Schematic



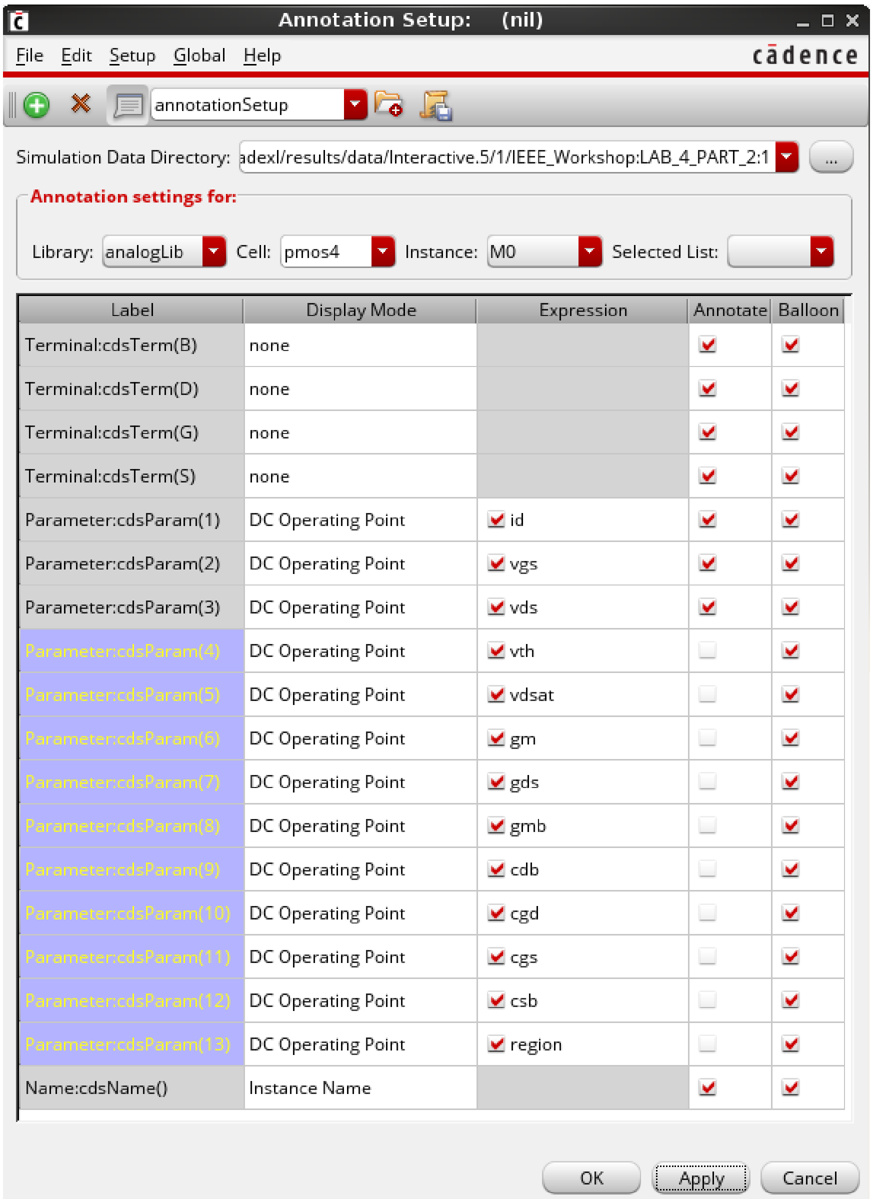
OP (Operating Point) Analysis

Q1

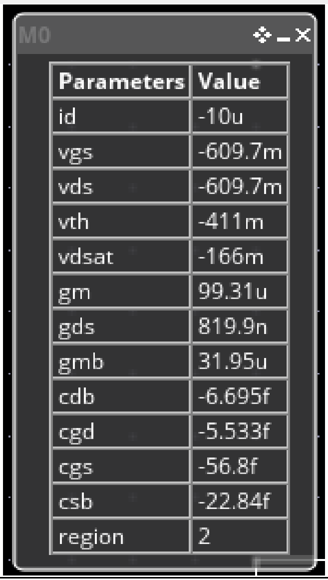
Global Variables	
CL	2p
L	1u
Rsig	2M
VDD	1.8
W	8.393u
Click to add variable	

Q2

Simulate the OP point. Report a snapshot clearly showing the following parameters (add a filter to your monitor).

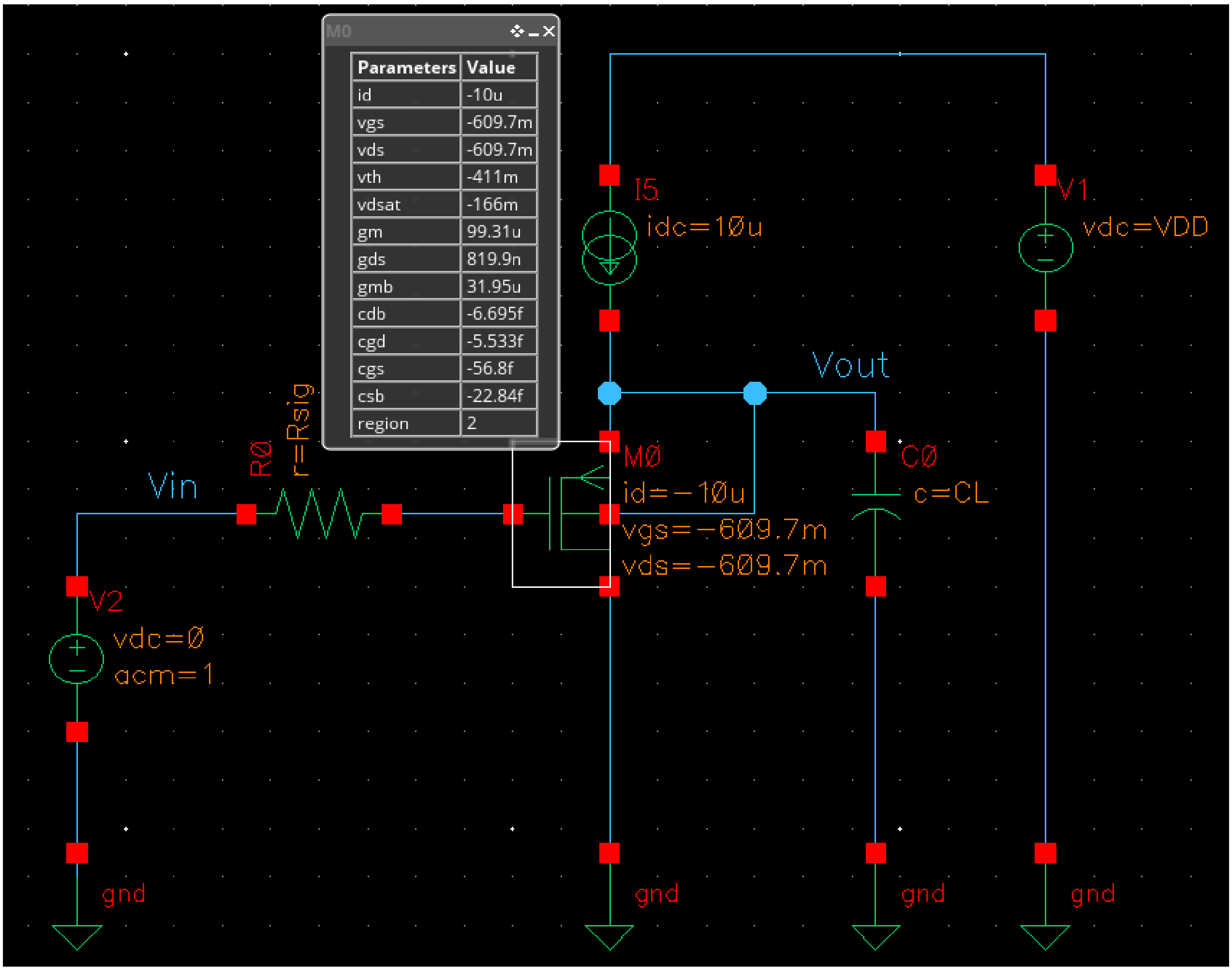


ID
VGS
VDS
VTH
VDSAT
GM
GDS
GMB
CDB
CGD
CGS
CSB
Region


M0

Parameters	Value
id	-10u
vgs	-609.7m
vds	-609.7m
vth	-411m
vdsat	-166m
gm	99.31u
gds	819.9n
gmb	31.95u
cdb	-6.695f
cgd	-5.533f
cgs	-56.8f
csb	-22.84f
region	2

Q2



Q3

Check that the transistor operates in saturation.

→ **From Simulation (Above).**

- **Hint: The "region" meaning is as follows:**
  (0 cut-off, 1 triode, 2 sat, 3 sub – threshold, and 4 breakdown).
- **Region = 2 = Saturation.**

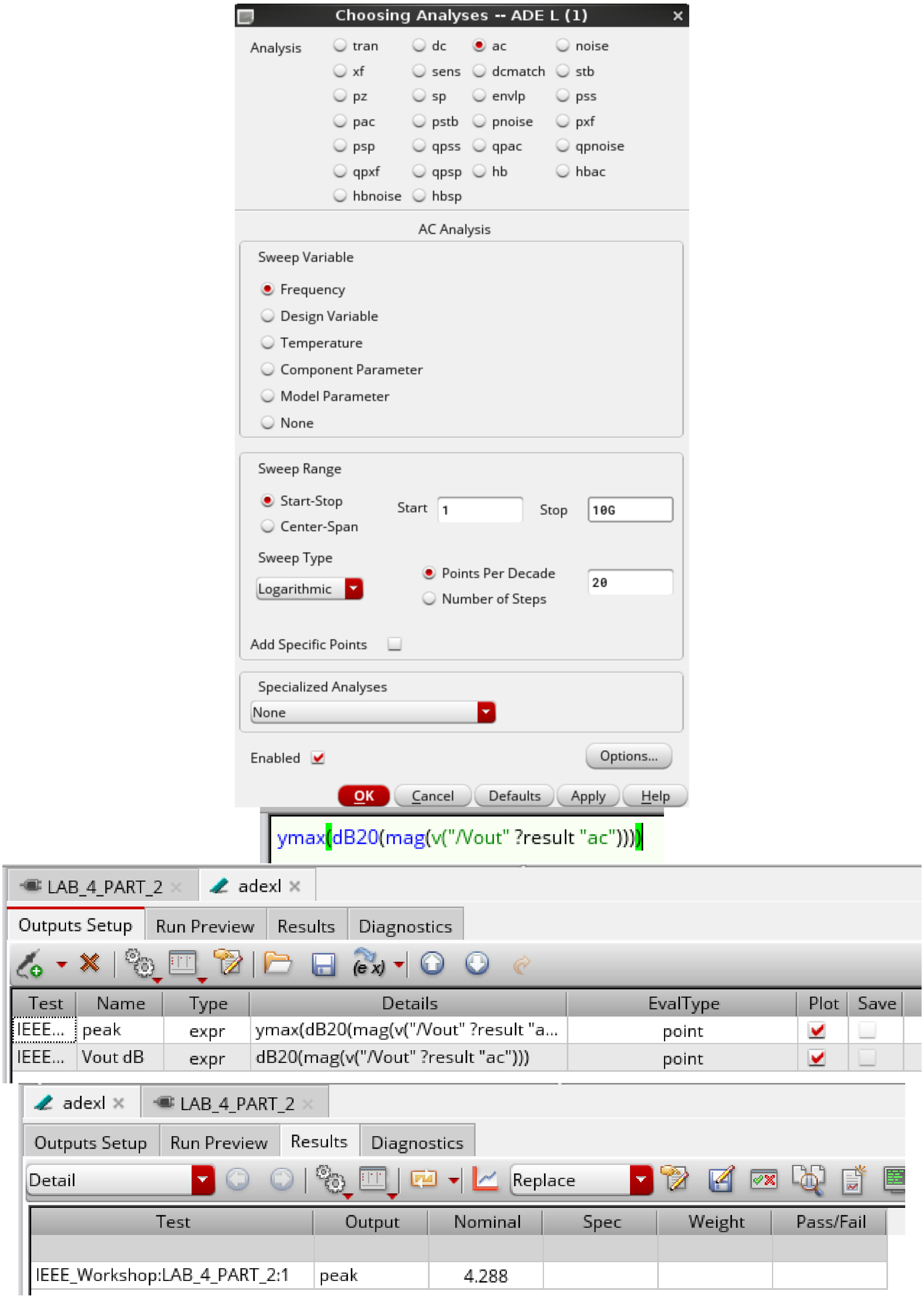
→ **From Hand Analysis:**

- $|V_{TH}| = 411\ mV$, $V_{sg} = 609.7\ mV > |V_{TH}|$ **(Transistor ON)**
- $V_{sd} = 609.7 > V_{sg} - |V_{TH}|$, ∴ **Trans. In Saturation.**

AC Analysis

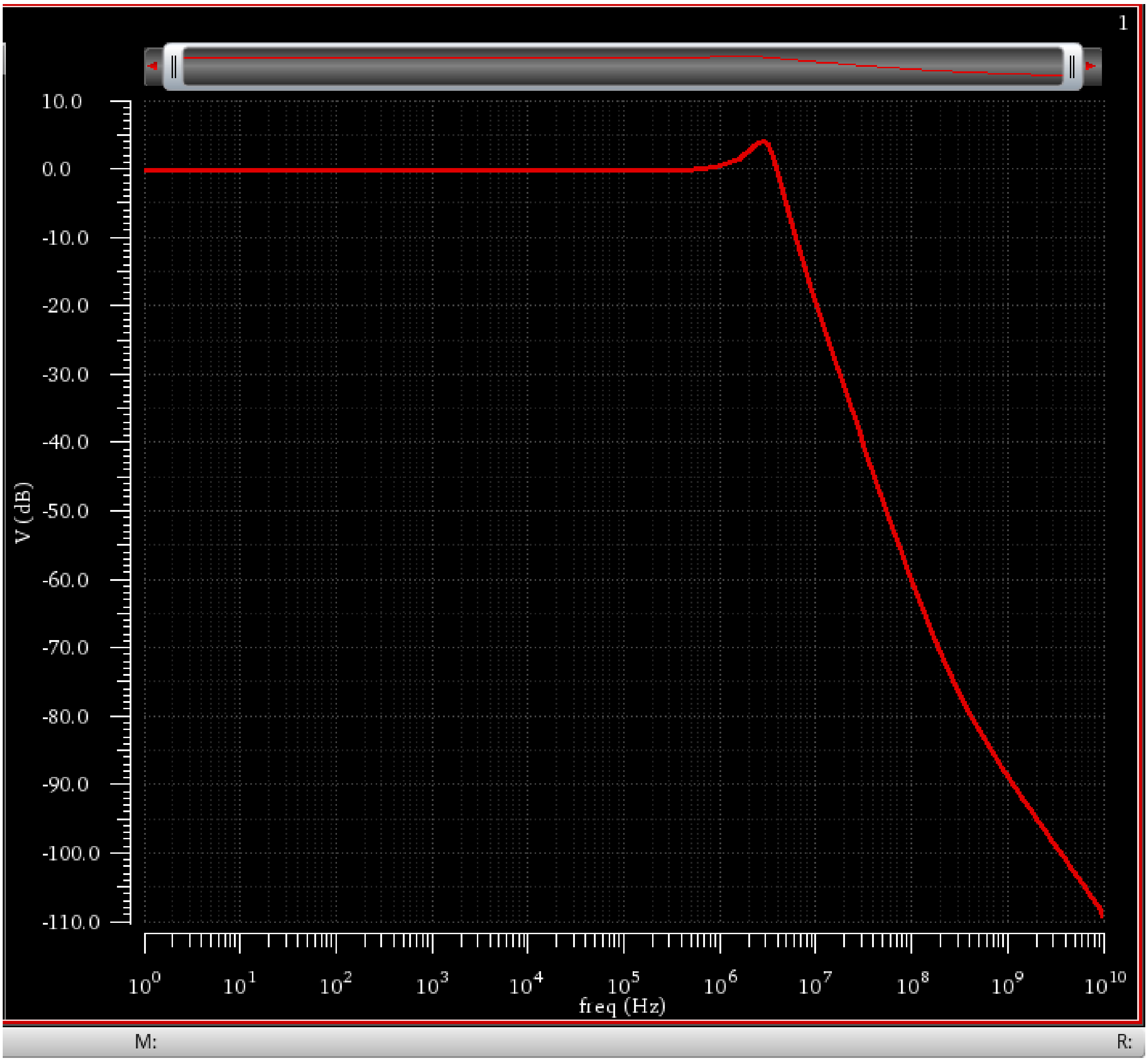
Q1

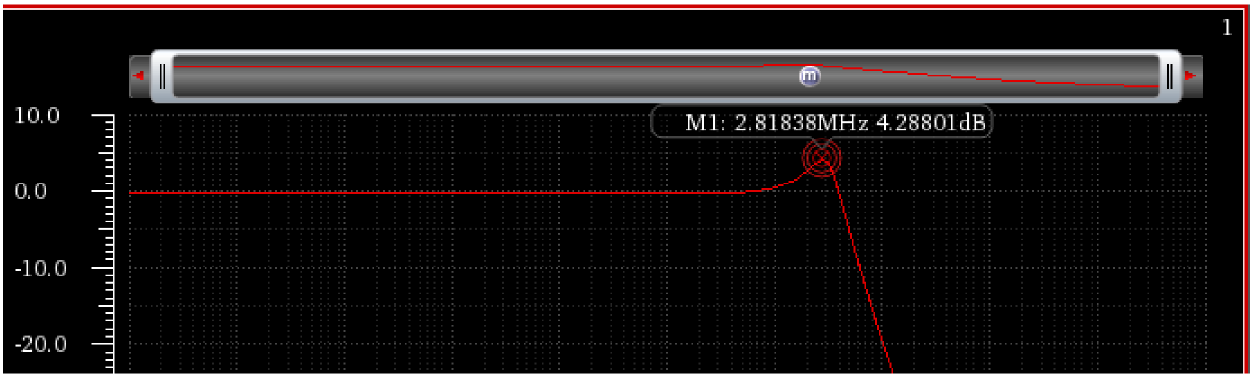
(1Hz: 10GHz, logarithmic, 20points/decade) to investigate the frequency domain peaking.



frequency domain peaking = 4.288 dB.

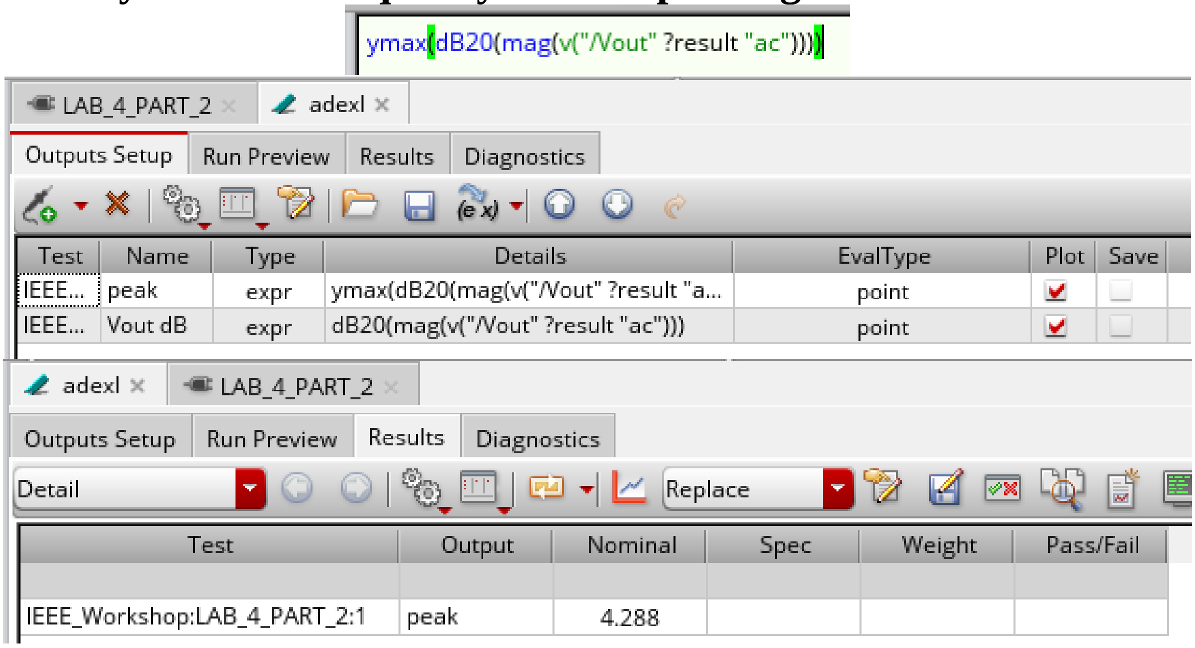
Q2	**Report the Bode plot magnitude V(dB).**





Q3

- **Do you notice frequency domain peaking?**



frequency domain peaking $= 4.288$ dB.

Q4

- **Analytically calculate quality factor (use approximate expressions).**

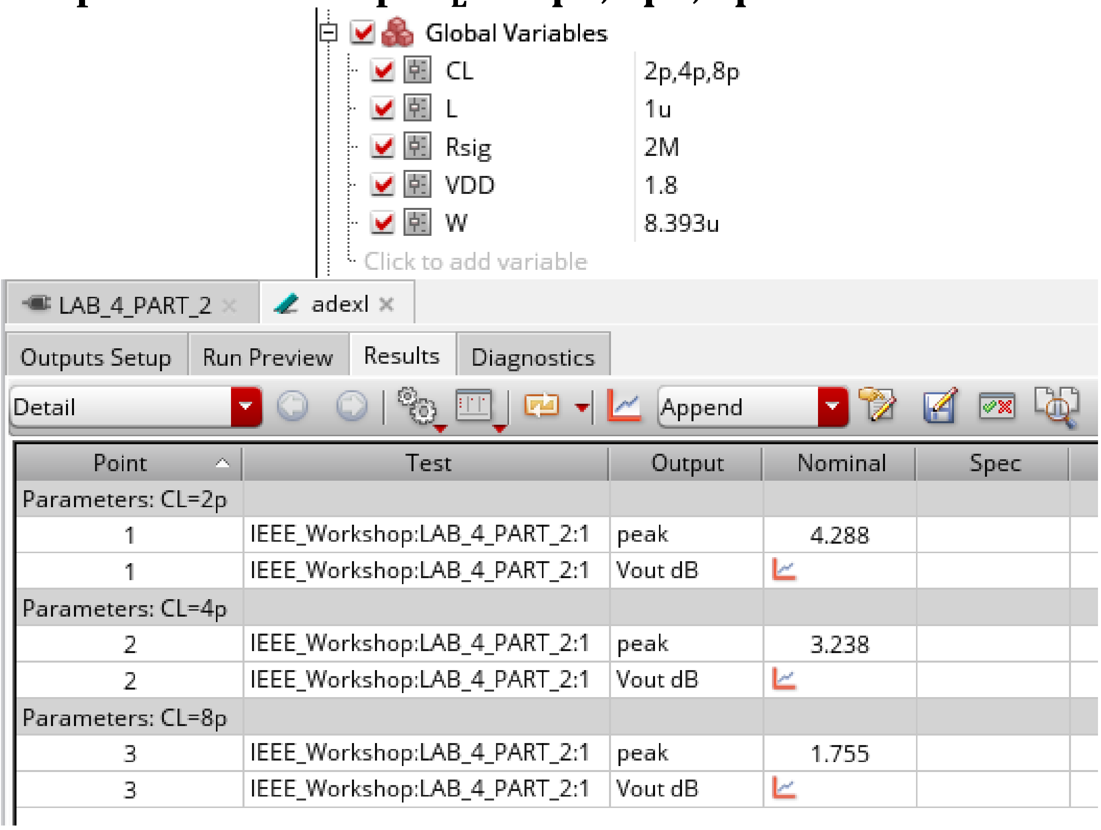
  - **From Simulation:**
  -

g_m	$99.31\ \mu S$
C_{gs}	$56.8\ fF$
C_{gd}	$5.533\ fF$
C_L	$2\ pF$
R_{sig}	$2\ M\Omega$
$Q = \sqrt{\dfrac{g_m(C_{gs}+C_{gd})R_{sig}}{C_L}}$	2.488

  - **Is the system underdamped or overdamped?**

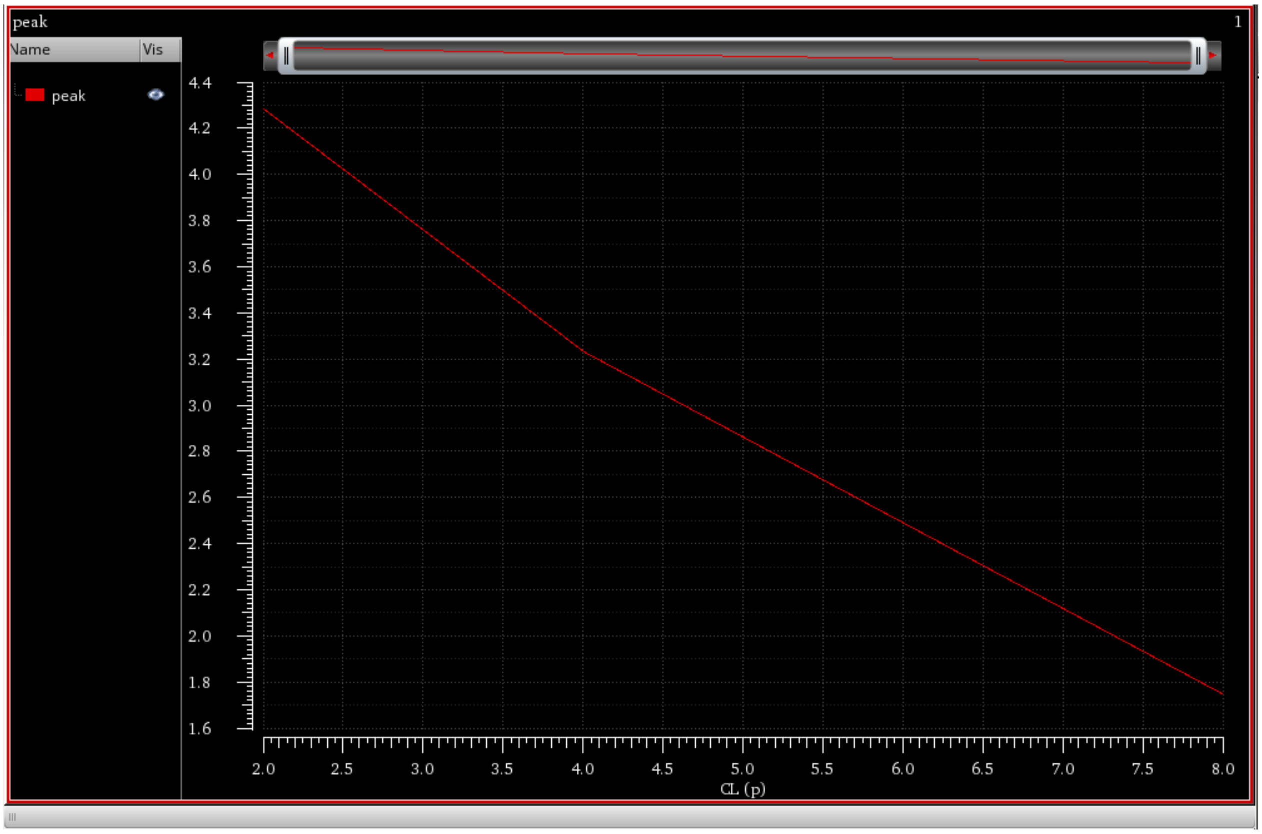
$\rightarrow$ Since, $Q > 0.5$, $\therefore$ The System is Underdamped Response. This is shown by the Magnitude Bode Plot above.

Q5	**Perform parametric sweep: $C_L = 2pF, 4pF, 8pF$.**



Point	Test	Output	Nominal	Spec
Parameters: CL=2p				
1	IEEE_Workshop:LAB_4_PART_2:1	peak	4.288	
1	IEEE_Workshop:LAB_4_PART_2:1	Vout dB		
Parameters: CL=4p				
2	IEEE_Workshop:LAB_4_PART_2:1	peak	3.238	
2	IEEE_Workshop:LAB_4_PART_2:1	Vout dB		
Parameters: CL=8p				
3	IEEE_Workshop:LAB_4_PART_2:1	peak	1.755	
3	IEEE_Workshop:LAB_4_PART_2:1	Vout dB		

Report the peaking vs C_L.

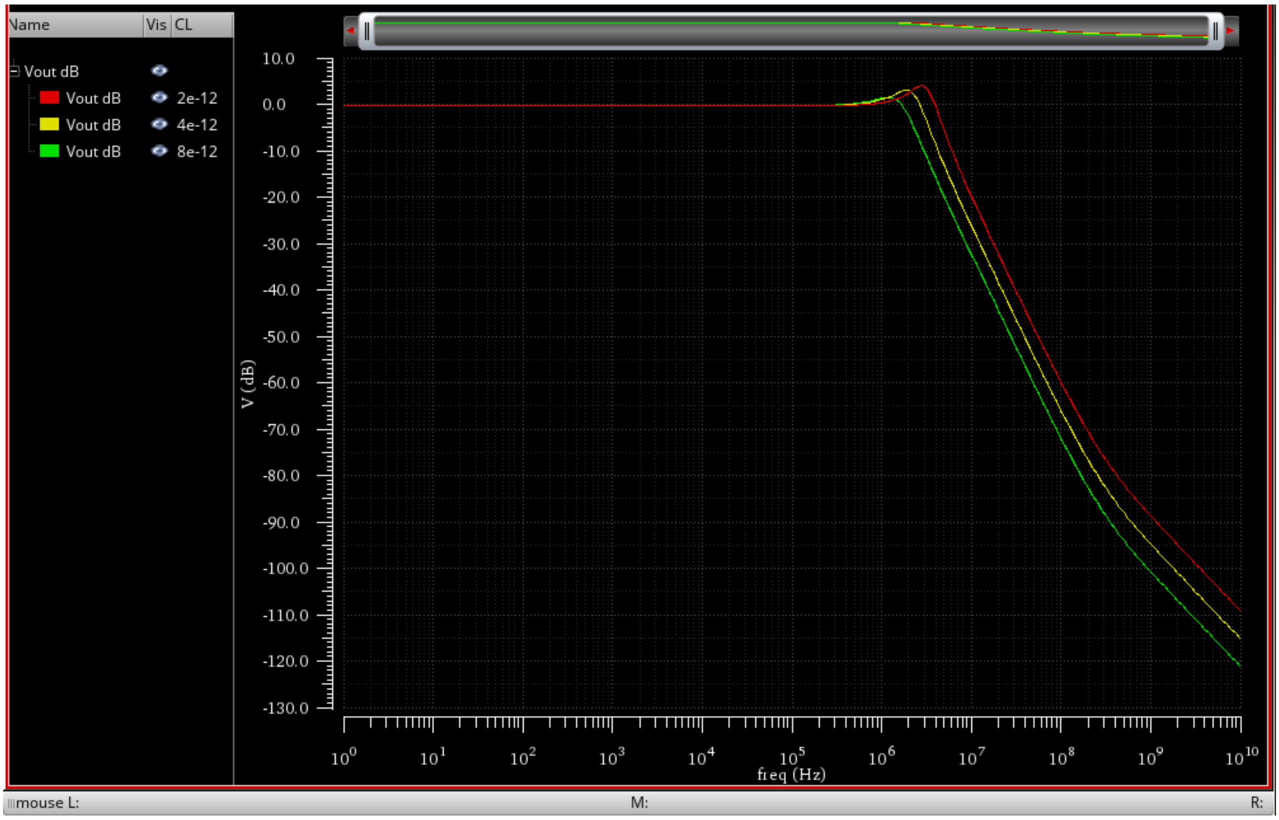


Comment.

- Increase C_L Eventually Decrease Q And Decrease the Peak. the bandwidth is inverse proportional to the shunt capacitance, so when increasing the capacitance, the band width tends to be much narrow.

Q5

Report Bode plot magnitude overlaid on same plot.

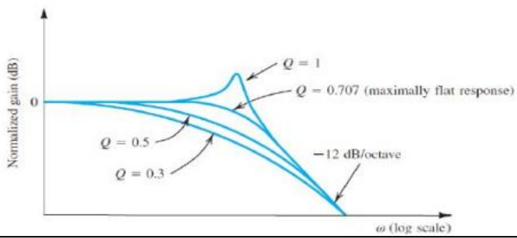


Comment.

- Increase C_L Eventually Decrease Q And Decrease the Peak. the bandwidth is inverse proportional to the shunt capacitance, so when increasing the capacitance, the band width tends to be much narrow.

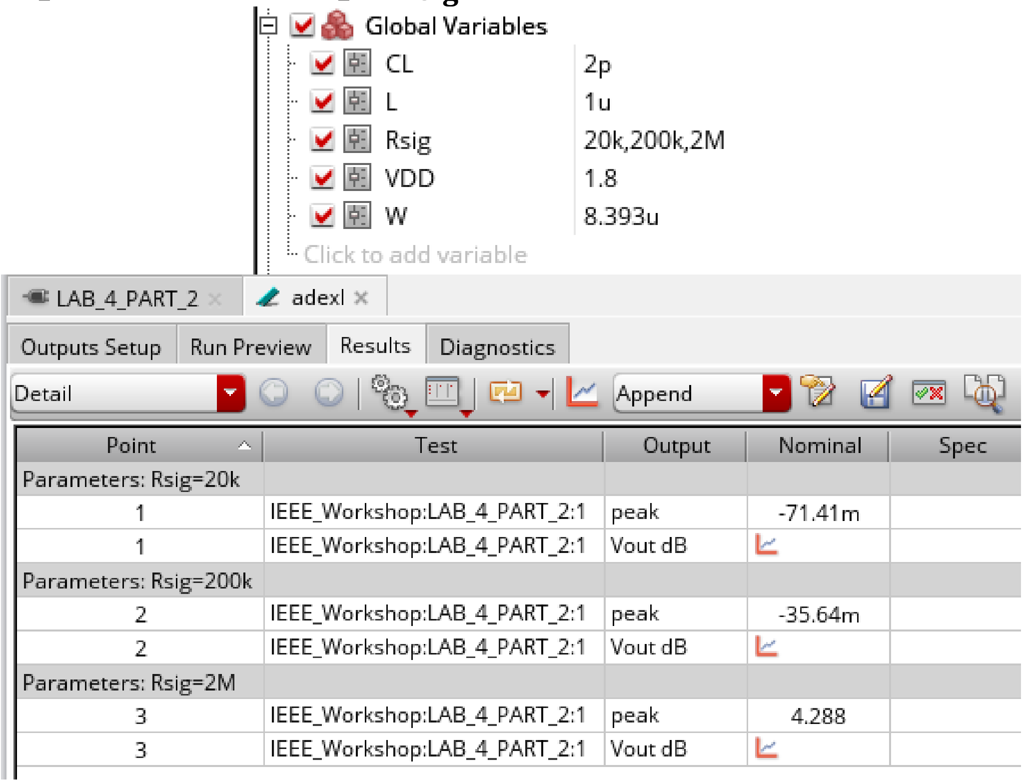
Peaking and Ringing

- For $Q > 0.5$ ($\zeta < 1$) → underdamped response
  - There's damping oscillation in time domain (Ringing) .
  - $\% \, overshoot = 100 \, e^{-\frac{\pi}{\sqrt{4Q^2-1}}}$
- For $Q = 0.707$ → maximally flat response.
- For $Q > 0.707$ → peaking in frequency.



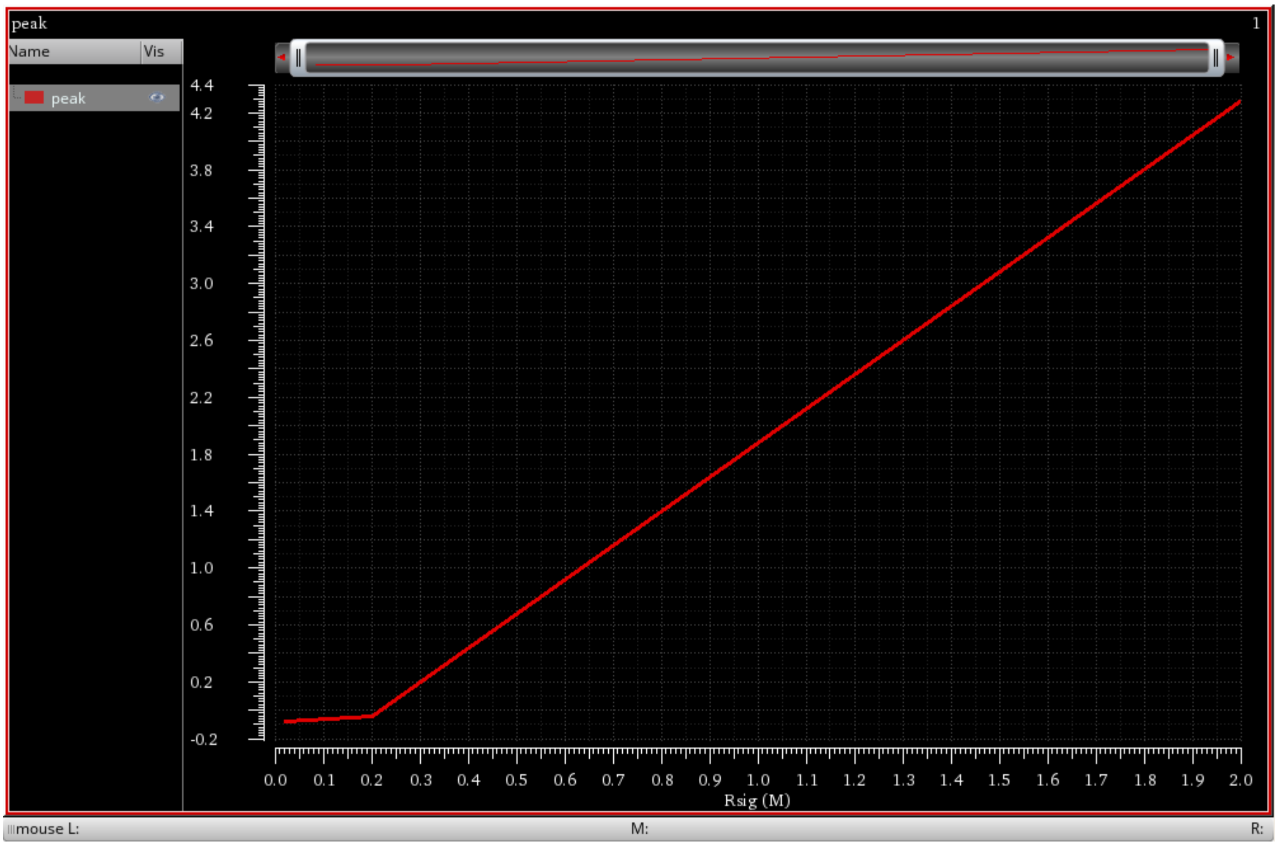
Q6

Perform parametric sweep: $R_{sig} = 20k, 200k, 2M$.



Q6

Report the peaking vs R_{sig}.



Report Bode plot magnitude overlaid on same plot.

Comment.

- **Increase R_{sig} Eventually Increase Q And Increase the Peak. For small R_{sig}, no peaks in frequency for the output, the output spectrum is just like a low-pass filter with attenuation after certain cut-off frequency. For small R_{sig}, system is overdamped, and for large R_{sig}, the system is underdamped.**

Peaking and Ringing

- For $Q > 0.5$ $(\zeta < 1)$ → underdamped response
  - There's damping oscillation in time domain (Ringing) .
  - $\%\,overshoot = 100\,e^{-\frac{\pi}{\sqrt{4Q^2-1}}}$
- For $Q = 0.707$ → maximally flat response.
- For $Q > 0.707$ → peaking in frequency.