INTEGRATED CIRCUITS 1
LAB03

SUEZ CANAL UNIVERSITY

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Part 1: Sizing Chart

1) We can show that the intrinsic gain of a MOSFET is given by

$$|A_v| \approx g_m r_o = \frac{2I_D}{V_{ov}} \times \frac{V_A}{I_D} = \frac{2V_A}{V_{ov}}$$

Interestingly, the gain only depends on λ and V_{ov}. However, to derive this expression we used $g_m = \frac{2I_D}{V_{ov}}$ which is based on the square-law. For a real MOSFET, if we compute V_{ov} and $\frac{2I_D}{g_m}$ they will not be equal. Let's define a new parameter called V-star (V^*) which is calculated from actual simulation data using the formula

$$V^* = \frac{2I_D}{g_m} \leftrightarrow g_m = \frac{2I_D}{V^*}$$

For a square-law device, $V^* = V_{ov}$, however, for a real MOSFET they are not equal. The actual gain is now given by

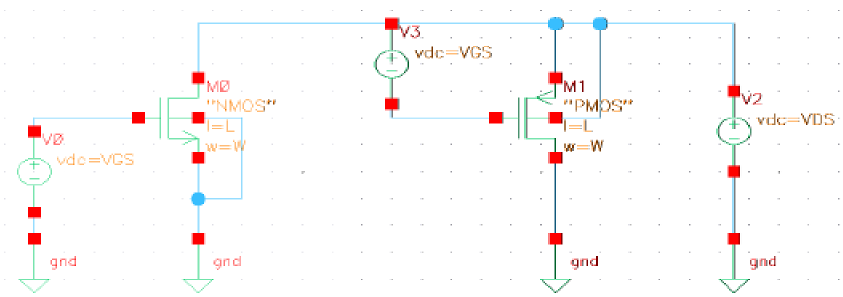
$$|A_v| \approx \frac{2V_A}{V^*}$$

The lower the V^* the higher the gain, but the larger the area and the lower the speed. An often used sweet-spot that provides good compromise between different trade-offs is $V^* = 200mV$.

2) We want to design CS and cascode amplifiers with the parameters below.

Parameter	0.13um CMOS	0.18um CMOS
L[1]	$0.5\mu m$	$0.5\mu m$
V^*	$200mV$	$200mV$
Supply	$1.2V$	$1.8V$
Current consumption	$20\mu A$	$20\mu A$

3) The remaining variable in the design is to calculate W. Since the square-law is not accurate, we cannot use it to determine the sizing. Instead, we will use a sizing chart generated from simulation. Create a testbench for NMOS transistor as shown below (we will use NMOS only in this lab). Use $W = 10\mu m$ (we will understand why shortly) and $L = 0.5\mu m$ (the same L selected before).



4) Sweep VGS from 0 to $\approx V_{TH} + 0.4V$ with 10mV step. Set $V_{DS} = V_{DD}/2$.

5) We want to compare $V^* = 2I_D/g_m$ and $V_{ov} = V_{GS} - V_{TH}$ by plotting them overlaid. Use the calculator to create expressions for V^* and V_{ov}. You can save the expressions to reuse them later.

6) Plot V^* and V_{ov} overlaid vs VGS. Make sure the y-axis of both curves has the same range. You 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.

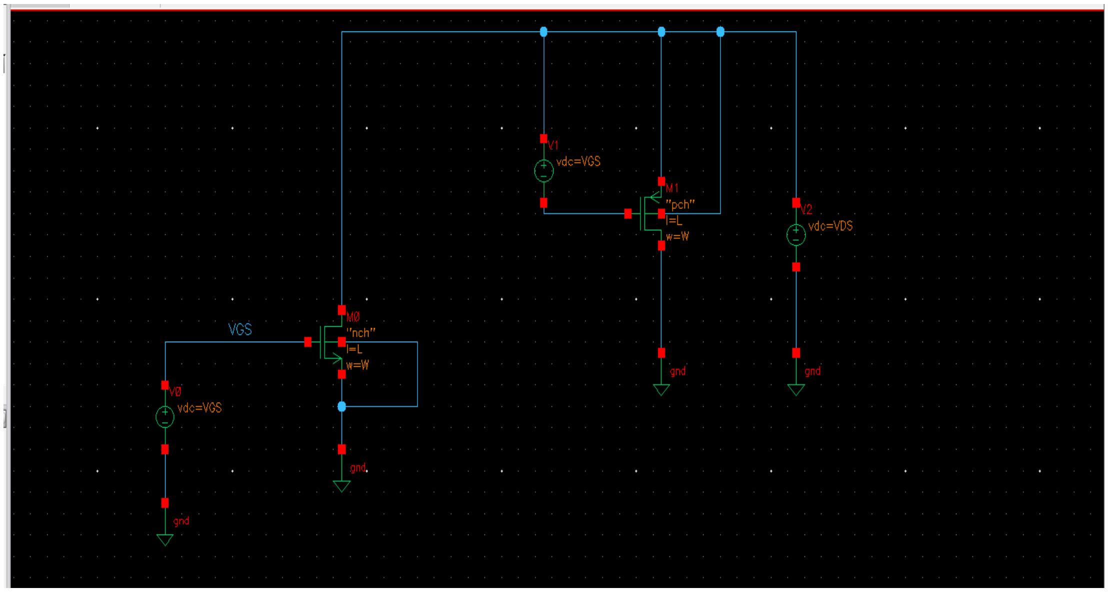
7) An often used sweet-spot that provides good compromise between different trade-offs is $V^* = 200mV$. On the V^* and V_{ov} chart locate the point at which $V^* = 200mV$. Find the corresponding V_{ovQ} and V_{GSQ}.

8) Plot I_D, g_m, and g_{ds} vs V_{GS}. Find their values at V_{GSQ}. Let's name these values I_{DX}, g_{mX}, and g_{dsX}.

9) 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 $I_{DQ} = 20\mu A$ as given in the specs. Calculate W as shown below.

W	I_D
$10\mu m$	I_{DX} @V_Q^* (from the chart)
?	$I_{DQ} = 20\mu A$ (from the specs)

10) 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, $r_o = 1/g_{ds}$ is **inversely** proportional to W (I_D) as long as L is constant. Before leaving this part, calculate g_{mQ} and g_{dsQ} using ratio and proportion (cross-multiplication).



$L = 0.5\ \mu m$

$V^* = 200\ mV$

Supply $= 1.8V$

Current Consump. $= 20\ \mu A$

$V_{th} = 441\ mV$

at $V^* = 200\ mV$ $\rightarrow$ $V_{ovQ} = 202.983\ mV$, $V_{GSQ} = 643.977\ mV$

$I_{D_x} = 96.0691\ uA$

$g_{m_x} = 959.32\ uS$

$g_{ds_x} = 9.7245\ uS$

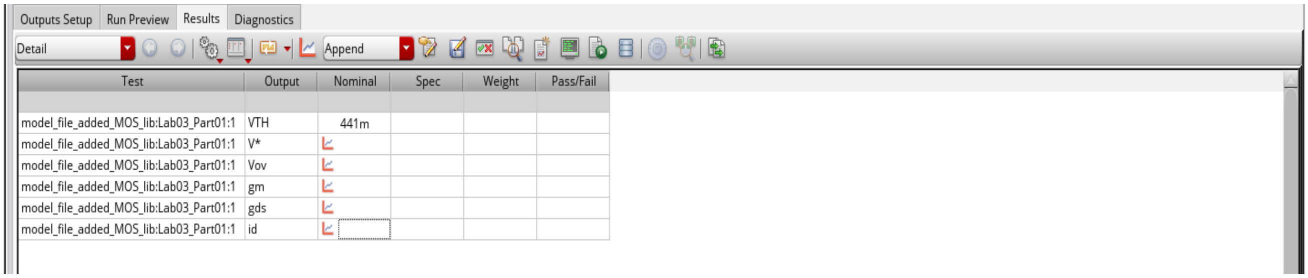
W	I_D
$10\ \mu m$	$96.0691\ \mu A$
?	$20\ \mu A$

$\therefore \boxed{W = 2.08183\ um}$

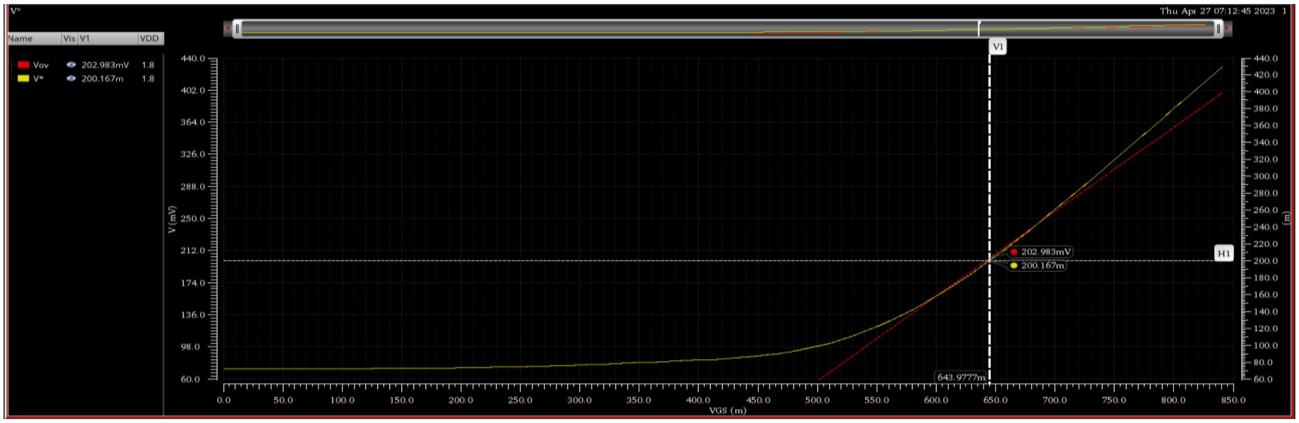
$g_m \propto W$ → at Const. V_{ov} → This is different from the square Law

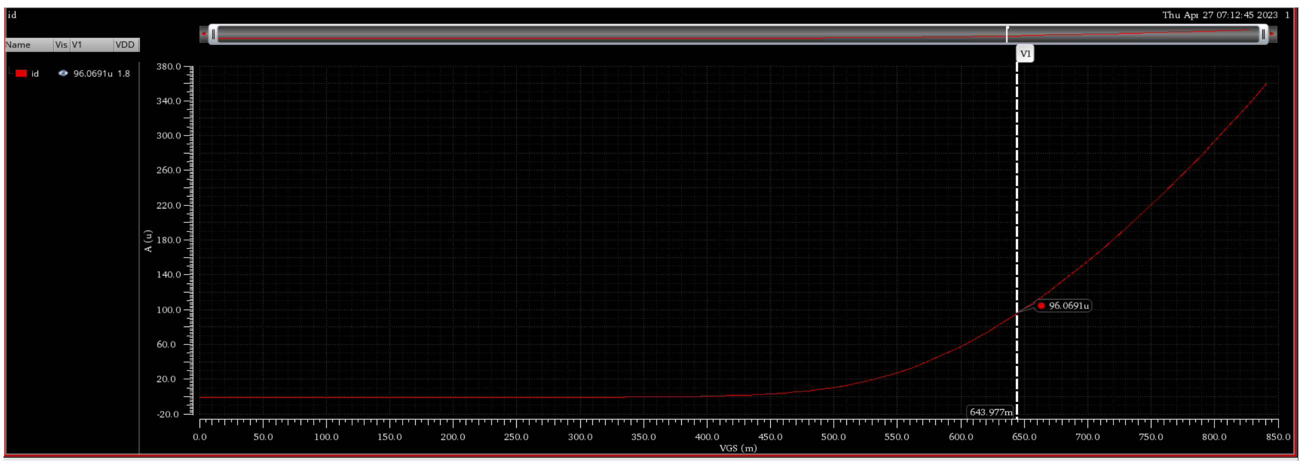
$$\frac{g_{m1}}{g_{m2}} = \frac{W_1}{W_2} \qquad \frac{959.32}{g_{m2}} = \frac{10}{2.0818} \qquad \therefore g_{m_2} = 201.16\ \mu s$$

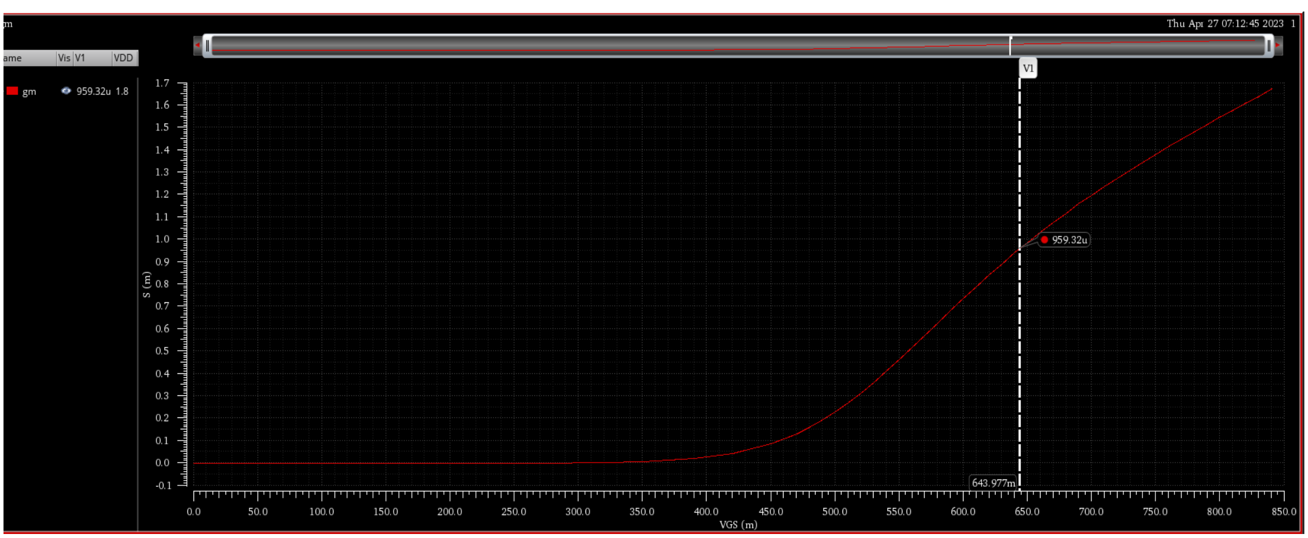
CS Scanned with CamScanner

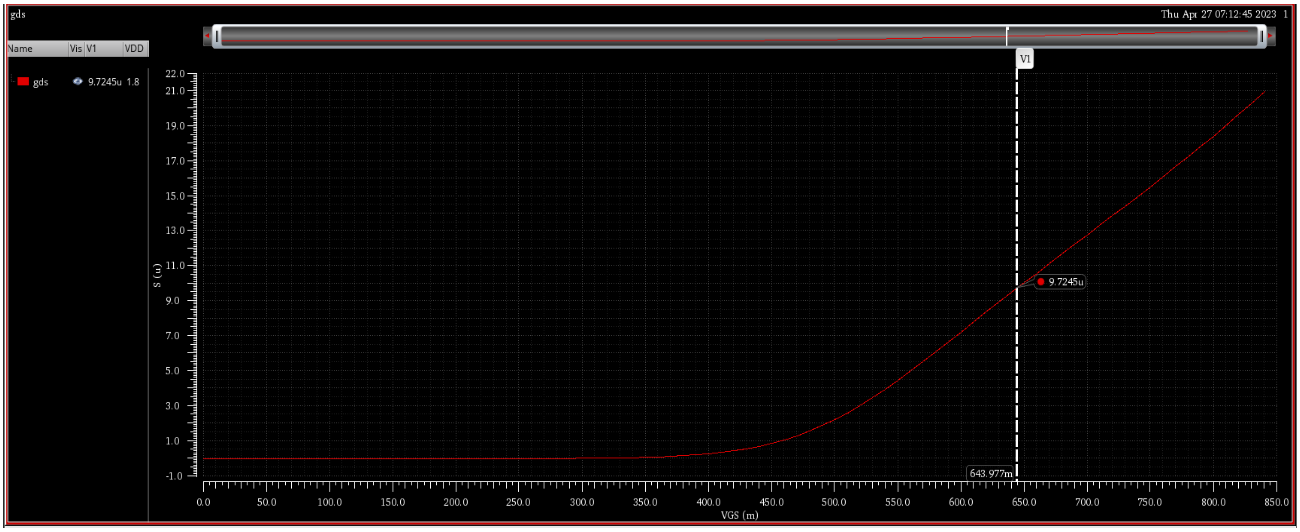


Test	Output	Nominal	Spec	Weight	Pass/Fail
model_file_added_MOS_lib:Lab03_Part01:1	VTH	441m			
model_file_added_MOS_lib:Lab03_Part01:1	V*				
model_file_added_MOS_lib:Lab03_Part01:1	Vov				
model_file_added_MOS_lib:Lab03_Part01:1	gm				
model_file_added_MOS_lib:Lab03_Part01:1	gds				
model_file_added_MOS_lib:Lab03_Part01:1	id				









$$g_{ds} = \frac{I_D}{V_A} = I_D \lambda$$

So at L Const.

$$g_{ds} \propto I_D$$
$$g_{ds} \propto W$$

$$\therefore \frac{g_{ds_1}}{g_{ds_2}} = \frac{W_1}{W_2}$$

$$\frac{9.7245}{g_{ds_2}} = \frac{10}{2.0818} \quad \therefore g_{ds_2} = 2.0244 \ \mu S$$

parameters

I_{DQ}	20 μA
g_{mQ}	199.7 μS
g_{dsQ}	2.0244 μS
r_o	493.97 $k\Omega$
W	2.0818 μm
L	0.5 μm
Supply Volt	1.8 V
V^*	200 mV
V_{ovQ}	202.983 mV
V_{GSQ}	643.977 mV

PART 2: Cascode for Gain

1. OP Analysis

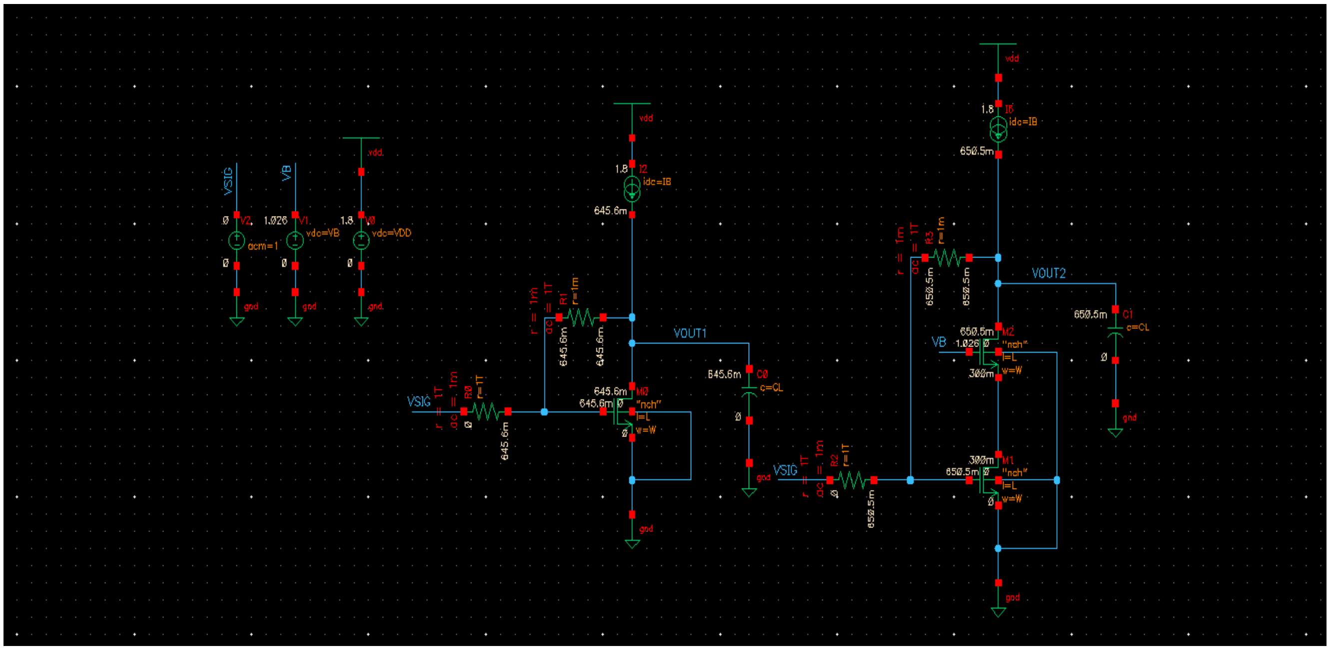
1) Create a new cell and schematic. Construct the circuit shown below. Use $I_B = 20\mu A$, $L = 0.5\mu m$, W as selected in Part 1, and $C_L = 1pF$.

2) Choose V_B (the cascode device bias voltage) such that M2 has $V_{DS} \approx V^* + 100mV$ (you may sweep VB and plot VDS vs VB to help you choose a good value for VB).
3) We need to bias transistors in saturation; however, the output node is a high impedance node; thus, it is difficult to control its DC voltage. As a workaround in simulation, we use a feedback loop and resistors with different resistances in DC/AC to change the circuit connections in DC/AC simulations (use the AC property in ideal_resistor). The input transistor is diode connected for DC simulation (always in saturation), while in AC simulation the feedback is disconnected, and the AC input source is connected. Set the feedback resistance $1m\Omega\ DC$ and $1T\Omega\ AC$ and set the source resistance oppositely. We will study how to do biasing practically later in this course inshaAllah.
4) Simulate the DC OP point of the above CS and cascode amplifiers. Report a snapshot showing the following parameters for M1, M2 and M3 in addition to DC node voltages clearly annotated.

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

"vdsat" is the minimum drain-source voltage required to bias the transistor in saturation. It is equal to V_{ov} for a square-law device. It is also referred to as "vdss" (drain-source saturation voltage).

5) Check that all transistors operate in saturation.
6) Do all transistors have the same vth? Why?
7) What is the relation $(\ll, <, =, >, \gg)$ between gm and gds?
8) What is the relation $(\ll, <, =, >, \gg)$ between gm and gmb?
9) What is the relation $(\ll, <, =, >, \gg)$ between cgs and cgd?
10) What is the relation $(\ll, <, =, >, \gg)$ between csb and cdb?

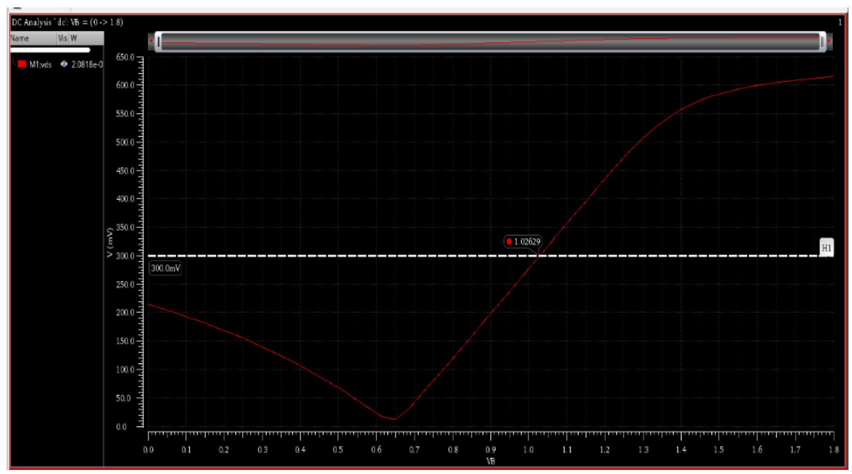


$V_{DS} \simeq V^* + 100\ mV \simeq 300\ mV$

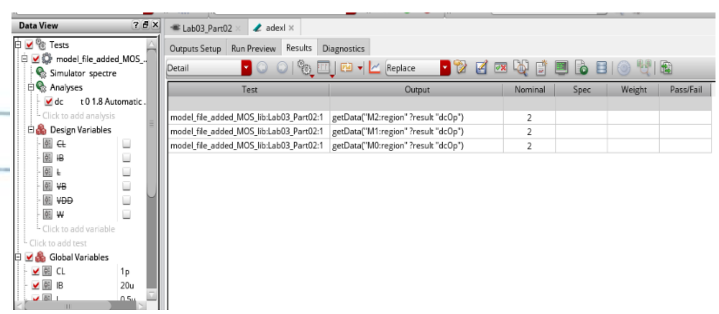
↓

M1

From The graph $VB \simeq 1.02629\ V$



5) all transistors operate in Sat as they all have the region 2



Snap shots required in Question 4:

	1
W	2.082E-6
M0:id	20.00E-6
M0:vgs (V)	645.6E-3
M0:vds (V)	645.6E-3
M0:vth (V)	442.1E-3
M0:vdsat (V)	155.1E-3
M0:vdss (V)	155.1E-3
M0:gm	199.7E-6
M0:gds	2.253E-6
M0:gmb	53.96E-6
M0:cdb	-1.748E-15
M0:cgd	-983.0E-18
M0:cgs	-7.497E-15
M0:csb	-3.743E-15
M0:region	2

	1
W	2.082E-6
M1:id	20.00E-6
M1:vgs (V)	650.5E-3
M1:vds (V)	300.0E-3
M1:vth (V)	444.7E-3
M1:vdsat (V)	156.7E-3
M1:vdss (V)	156.7E-3
M1:gm	196.3E-6
M1:gds	4.440E-6
M1:gmb	53.09E-6
M1:cdb	-1.910E-15
M1:cgd	-1.011E-15
M1:cgs	-7.508E-15
M1:csb	-3.735E-15
M1:region	2

	1
W	2.082E-6
M2:id	20.00E-6
M2:vgs (V)	726.3E-3
M2:vds (V)	350.5E-3
M2:vth (V)	530.5E-3
M2:vdsat (V)	160.2E-3
M2:vdss (V)	160.2E-3
M2:gm	199.8E-6
M2:gds	3.608E-6
M2:gmb	48.50E-6
M2:cdb	-1.759E-15
M2:cgd	-997.6E-18
M2:cgs	-7.444E-15
M2:csb	-3.327E-15
M2:region	2

6) $V_{th} = \underline{V_{GS}} - \underline{V_{dsat}}$

→ these values differ from one transistor to the other

as we can see the first two transistors are close to each other in V_{th} as their body effect can be neglected by the third one has body effect as the body is not connected to the source M2

7) $g_m \gg g_{ds}$ from 50 to 100 times

8) $g_m > g_{mb}$ 3-4 times

9) $C_{gs} > C_{gd}$ 3-5 times

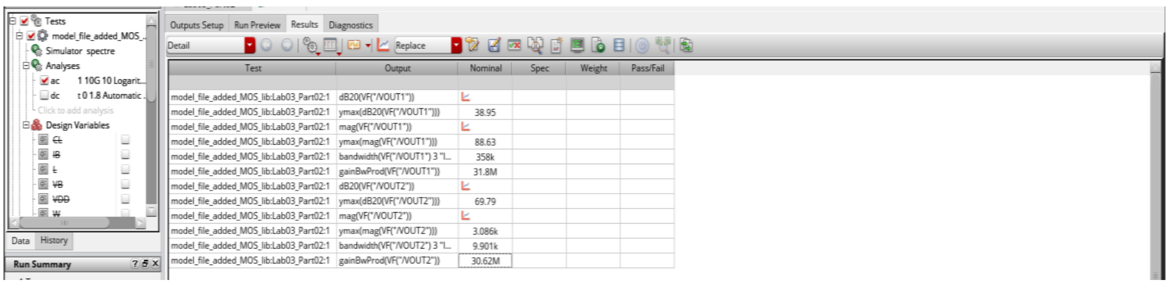
10) $C_{sb} > C_{db}$ 3-5 times

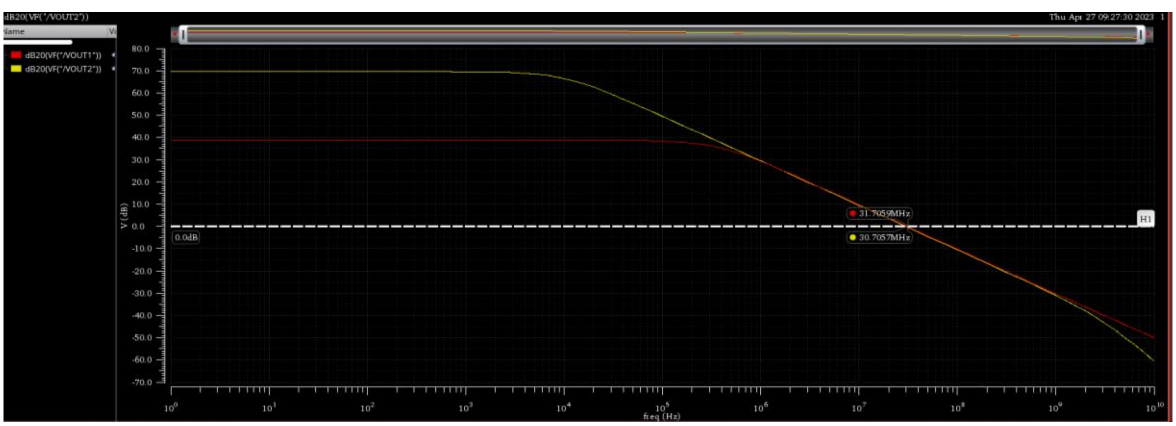
2. AC Analysis

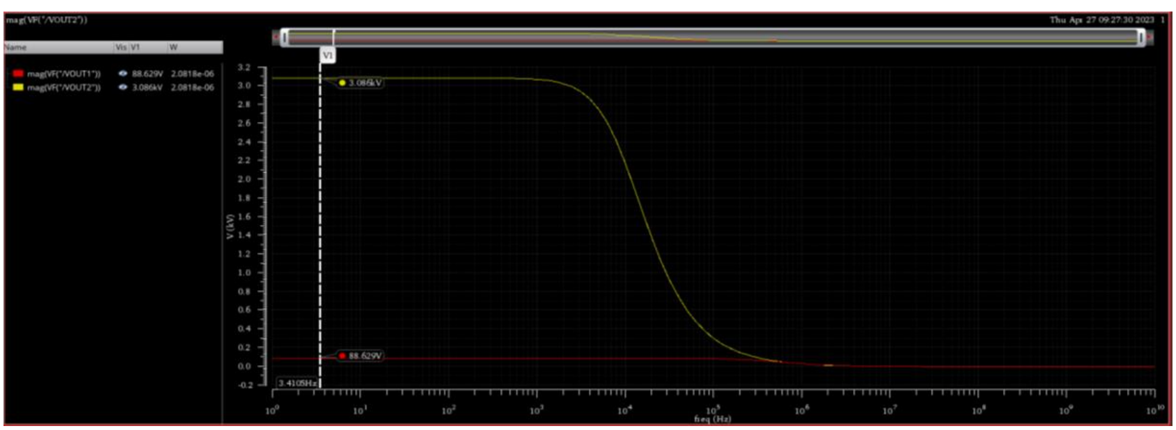
1) Create a new simulation configuration. Perform AC analysis (1Hz:10GHz, logarithmic, 10points/decade) to simulate gain and bandwidth.
2) Use calculator to create expressions for circuit parameters (DC gain, BW, GBW, and UGF) and export them to adexl.
   ➔ Cadence Hint: Use the following expressions in the calculator, and send them to adexl to quickly calculate circuit parameters.

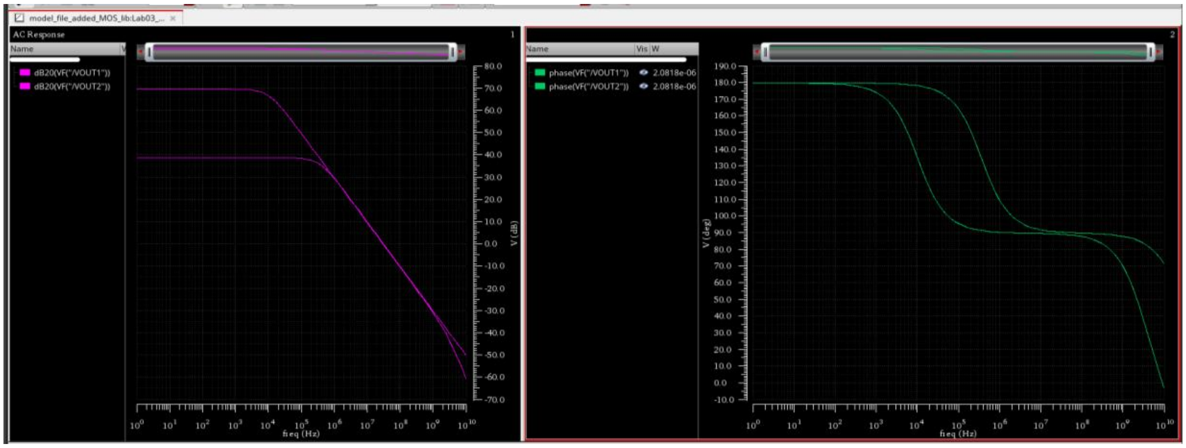
Type	Expression/Signal/File	EvalType	Plot
expr	dB20(VF("/vout1"))	point	✓
expr	ymax(dB20(VF("/vout1")))	point	✓
expr	ymax(mag(VF("/vout1")))	point	✓
expr	bandwidth(VF("/vout1") 3 "low")	point	✓
expr	gainBwProd(VF("/vout1"))	point	✓
expr	dB20(VF("/vout2"))	point	✓
expr	ymax(dB20(VF("/vout2")))	point	✓
expr	ymax(mag(VF("/vout2")))	point	✓
expr	bandwidth(VF("/vout2") 3 "low")	point	✓
expr	gainBwProd(VF("/vout2"))	point	✓

3) Report the Bode plot (magnitude) of CS and cascode **appended on the same plot**.
4) Using small signal parameters from OP simulation, perform hand analysis to calculate DC gain, BW, and GBW of both circuits.
5) Report a table comparing the DC gain, BW, UGF, and GBW of both circuits from simulation and hand analysis.
6) Comment on the results.









AC analysis.

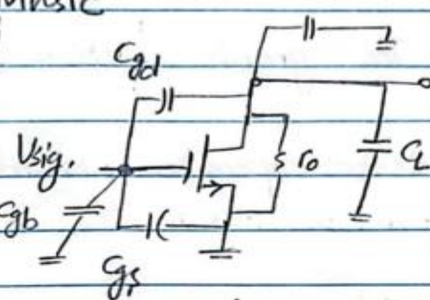
for The Common Source :

$$\text{gain} = |A_v| = g_m r_o \quad (\text{intrinsic})$$

$$= \frac{199.7\times10^{-6}}{2.253\times10^{-6}}$$

$$= 88.637 \text{ v/v}$$

$$= 38.952 \text{ dB}$$



$$\omega_{P_{out}} \simeq BW = \frac{1}{r_o\left(C_L + C_{db} + C_{gd}\left(1+\frac{1}{A_v}\right)\right)}$$

$$= 2.246 \times10^{6} \text{ rad/sec}$$

$$f_{BW} = \frac{\omega_{P_{out}}}{2\pi} = 357.77 \text{ KHZ}$$

$$GBW = \text{gain} \times \omega_{P_{out}} = 31.783 \times10^{6}$$

$$UGF \simeq GBW = 31.783\times10^{6} \text{ MHZ}$$

A Method to get f_u is that $|A_v| = 1$

$$A_v = G_m R_{out} \quad \therefore \quad R_{out\,unity} = \frac{1}{G_m}$$

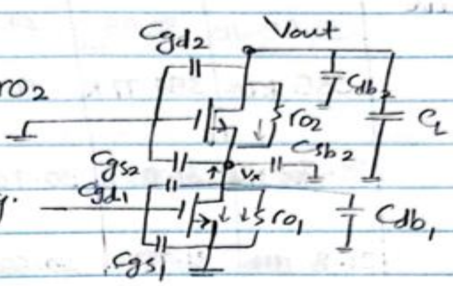
$$\therefore \omega_{P_{out}} = \frac{g_m}{C_L + C_{db} + C_{gd}(1+ 1/A_v)}$$

Don't forget the body effect

For The Cascode

$R_{out} = r_{o1} + r_{o2} + g_{m2}' r_{o1} r_{o2}$

$G_m = \frac{i_{osc}}{V_{sig}} \simeq -g_{m1}$



$R_{out} = 16.002\ M\Omega$

$\therefore$ Gain $= -g_{m1}(r_{o1} + r_{o2} + g_{m2}' r_{o1} r_{o2})$

$= -3086.7\ V/V$

dB $\Rightarrow$ 69.789 dB

$\because V_x$ is a Low input node

it will not be dominant

$\therefore BW \simeq \omega_{P_{out}} = \frac{1}{R_{out}[C_L + C_{db2} + C_{gd2}]}$

$= 62320.396$ rad/s

$f_{BW} = 9.923$ KHz

GBW = 30.629 M

$f_u \approx$ GBW = 30.629 MHz

$i_{sc} + \frac{V_x}{r_{o1}} + g_{m1} V_{sig} = 0$

$V_x = -i_{sc} r_o - g_{m1} r_{o1} V_{sig}$

$\therefore -g_{m2}' V_x - \frac{V_x}{r_{o2}} + i_{sc} = 0$

$i_{sc} = (g_{m2}' + \frac{1}{r_{o2}})(-i_{sc} r_{o1} - g_{m1} r_{o1} V_{sig})$

$i_{sc}(1 + g_{m2} r_{o1} + \frac{r_{o1}}{r_{o2}}) = -g_{m1} r_{o1} (g_{m2} + \frac{1}{r_{o2}}) V_{sig}$

neglected body effect

-0.011137

$\therefore G_m = \frac{-g_{m1} r_{o1} (g_{m2}' + 1/r_{o2})}{1 + g_{m2}' r_{o1} + \frac{r_{o1}}{r_{o2}}}$

$= -1.9289 \times 10^{-4}$ S

	CS		Cascode	
	Simu.	hand	Simu.	hand.
DC gain	38.95 dB	38.95 dB	69.79 dB	69.789 dB
BW	385 KHz	357.77 K	9.901 K	9.923 K
UGF	31.705 MHz	31.783 M	30.705 M	30.62 M
GBW	31.8 MHz	31.783 M	30.62 M	30.62 M

* We used (OCTC + Millers) approx. for hand analysis

My comment on the previous data:

→ The addition of The Cascode increased The output resistance to a high Value Thus it increased the gain but at the Same lowered The dominant pole Thus lowered The Bandwidth.

with Cascode gain ↑ BW ↓ swing ↓

to get f_u : $|A_v| = G_m R_{out} = 1$

$$\therefore R_{out_{unity}} = \frac{1}{G_m}$$

$$\therefore f_u = \frac{1}{2\pi} \times \frac{G_m}{C_L + C_{db_2} + C_{gd_2}}$$

In Common Source

$$\text{Gain} \times BW \simeq g_{m_1} R_{out} \times \frac{1}{R_{out} C_{out}} \simeq \frac{g_{m1}}{C_{out}}$$

In Cascode

$$GBW = g_m R_{out} \times \frac{1}{R_{out} C_{out}} \simeq \frac{g_m}{C_{out}}$$

Cascode doesn't change The GBW much because The output pole is dominant for both topologies and thus if The gain inc. by a factor K with The Cascode the gain will decrease by the same factor thus GBW would be constant

GBW is independent of The output impedance

~~cascod~~ Cascading might change the GBW if the dominant pole changed from the output to the input but this ~~diff~~ didnot happen here.

PART 3 [Optional]: Cascode for BW

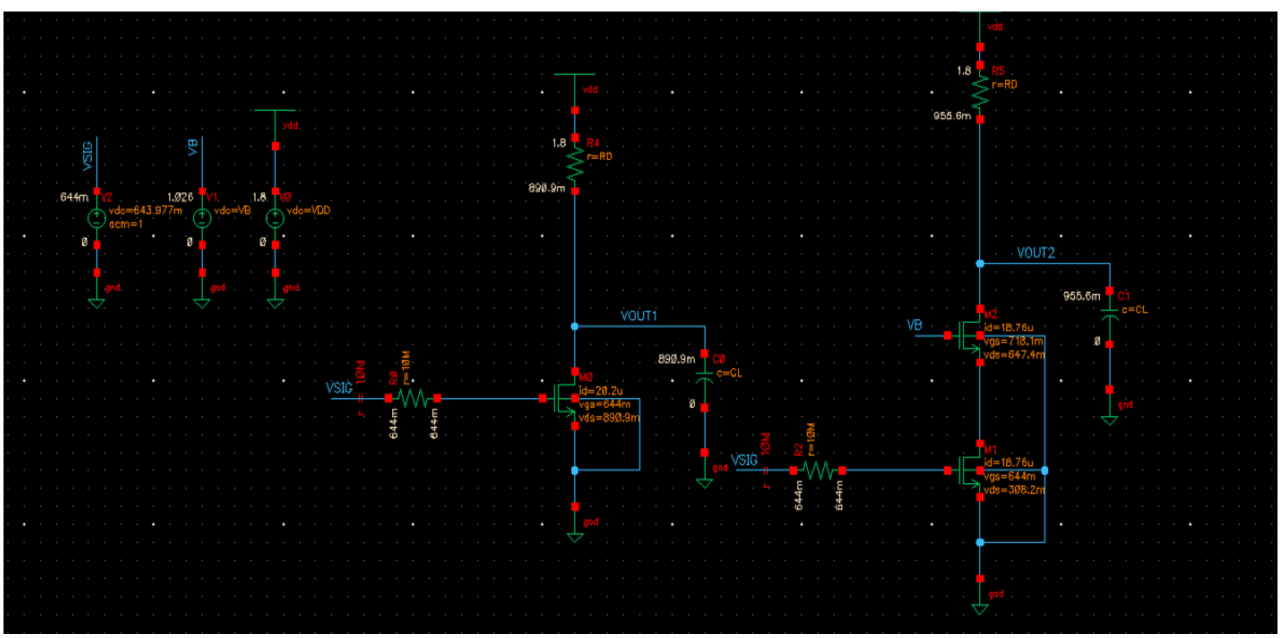
1. OP Analysis

1) Create a new cell and schematic. Copy the old schematic instances to the new one. Make the following modifications: remove the feedback resistance, set $C_L = 1fF$, replace the current source with a resistor RD, make the signal source resistance $= 10M\Omega$ (remove the AC value). Set VGS of the input device as calculated in Part 1.

2) Calculate R_D analytically such that the voltage drop on it is $\approx V_{DD}/2$ (the current remains roughly the same as in Part 2 because we are using the same VGS).
3) Note that the DC voltage of the output node is set by the resistance (R_D); thus, we don't need a feedback loop as in the previous case.
4) Simulate the DC OP point of the new CS and cascode amplifiers. Add monitors and report a snapshot showing the following parameters for M1, M2 and M3 in addition to DC node voltages clearly annotated.

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

5) Check that all transistors operate in saturation.



	1
W	2.082E-6
M0:id	20.20E-6
M0:vgs (V)	644.0E-3
M0:vds (V)	890.9E-3
M0:vth (V)	440.3E-3
M0:vdsat (V)	155.3E-3
M0:gm	201.3E-6
M0:gds	2.083E-6
M0:gmb	54.34E-6
M0:cdb	-1.672E-15
M0:cgd	-981.6E-18
M0:cgs	-7.494E-15
M0:csb	-3.744E-15
M0:region	2

	1
W	2.082E-6
M1:id	18.76E-6
M1:vgs (V)	644.0E-3
M1:vds (V)	308.2E-3
M1:vth (V)	444.6E-3
M1:vdsat (V)	152.4E-3
M1:gm	190.6E-6
M1:gds	3.942E-6
M1:gmb	51.61E-6
M1:cdb	-1.903E-15
M1:cgd	-1.007E-15
M1:cgs	-7.502E-15
M1:csb	-3.735E-15
M1:region	2

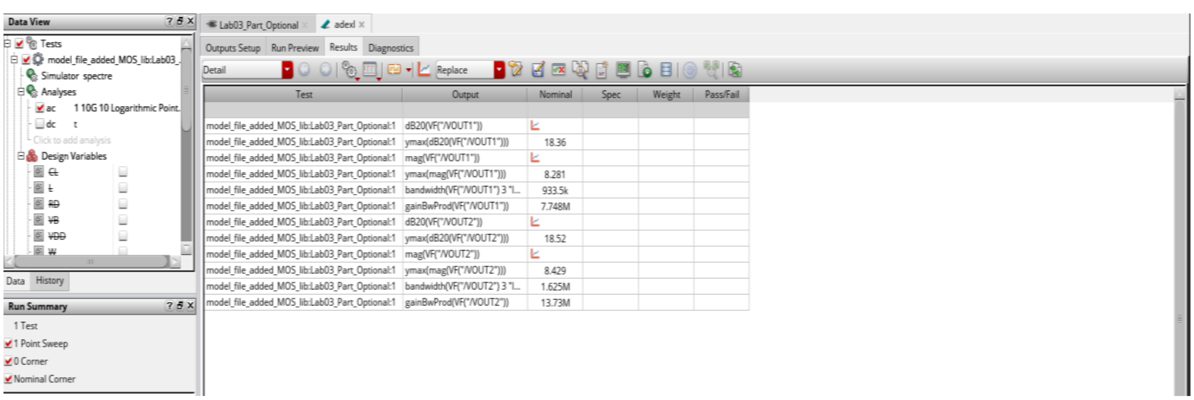
	1
W	2.082E-6
M2:id	18.76E-6
M2:vgs (V)	718.1E-3
M2:vds (V)	647.4E-3
M2:vth (V)	530.5E-3
M2:vdsat (V)	154.8E-3
M2:gm	195.9E-6
M2:gds	2.220E-6
M2:gmb	47.45E-6
M2:cdb	-1.657E-15
M2:cgd	-982.0E-18
M2:cgs	-7.427E-15
M2:csb	-3.321E-15
M2:region	2

$R_D = \frac{V_{RD}}{I_B} \quad \therefore \quad R_D = \frac{0.9}{20\ \mu A} = 45\ k\Omega$

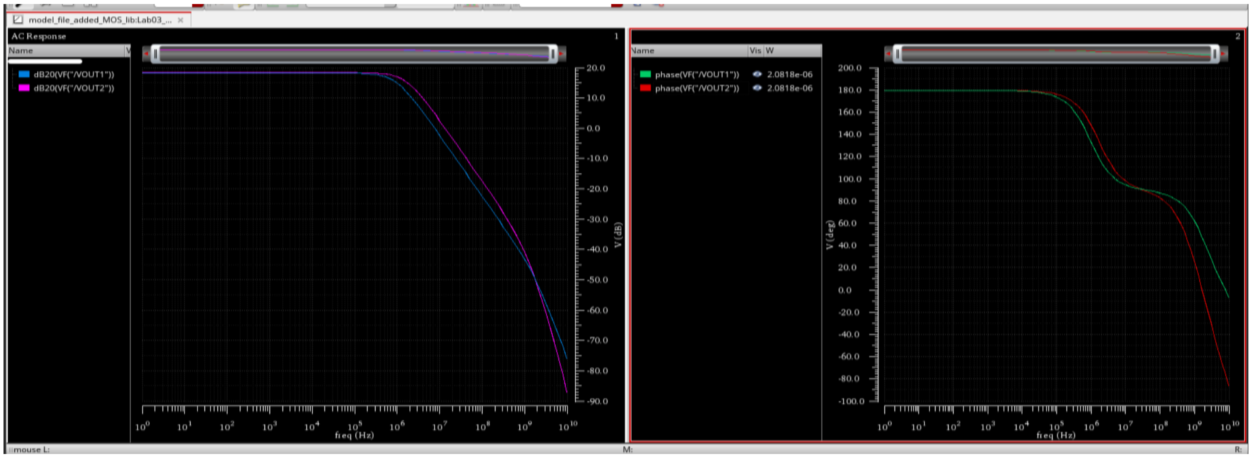
5) All transistors operate in saturation since they are all region 2

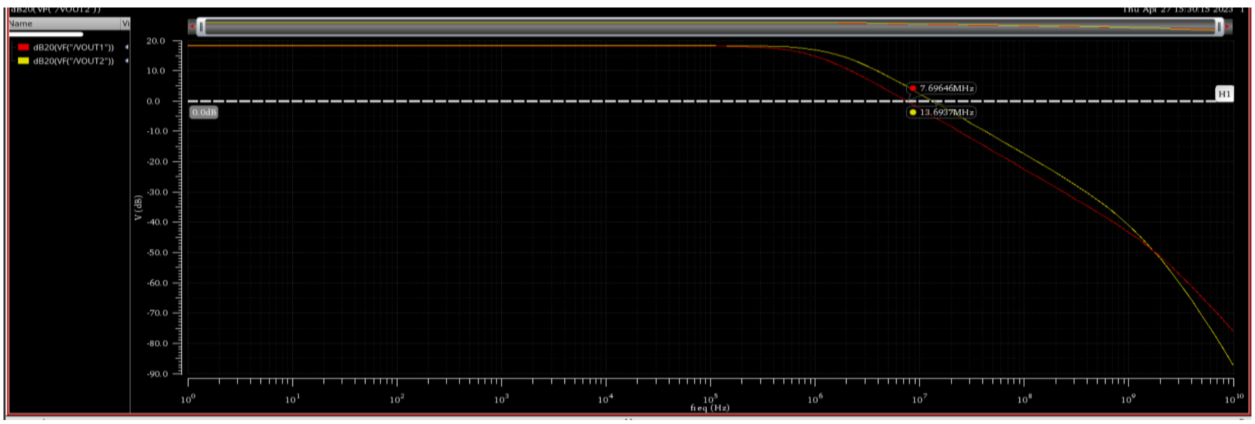
2. AC Analysis

1) Perform AC analysis (1Hz:10GHz, logarithmic, 10points/decade) to simulate gain and bandwidth.
2) Use calculator to create expressions for circuit parameters (DC gain, BW, GBW, and UGF) and export them to adexl.
3) Report the Bode plot (magnitude) of CS and cascode **<u>appended on the same plot</u>**.
4) Using small signal parameters from OP simulation, perform hand analysis to calculate DC gain, BW, and GBW of both circuits.
5) Report a table comparing the DC gain, BW, UGF, and GBW of both circuits from simulation and hand analysis. Comment on the results.



Test	Output	Nominal	Spec	Weight	Pass/Fail
model_file_added_MOS_lib:Lab03_Part_Optional:1	dB20(VF("/VOUT1"))				
model_file_added_MOS_lib:Lab03_Part_Optional:1	ymax(dB20(VF("/VOUT1")))	18.36			
model_file_added_MOS_lib:Lab03_Part_Optional:1	mag(VF("/VOUT1"))				
model_file_added_MOS_lib:Lab03_Part_Optional:1	ymax(mag(VF("/VOUT1")))	8.281			
model_file_added_MOS_lib:Lab03_Part_Optional:1	bandwidth(VF("/VOUT1") 3 "l...	933.5k			
model_file_added_MOS_lib:Lab03_Part_Optional:1	gainBwProd(VF("/VOUT1"))	7.748M			
model_file_added_MOS_lib:Lab03_Part_Optional:1	dB20(VF("/VOUT2"))				
model_file_added_MOS_lib:Lab03_Part_Optional:1	ymax(dB20(VF("/VOUT2")))	18.52			
model_file_added_MOS_lib:Lab03_Part_Optional:1	mag(VF("/VOUT2"))				
model_file_added_MOS_lib:Lab03_Part_Optional:1	ymax(mag(VF("/VOUT2")))	8.429			
model_file_added_MOS_lib:Lab03_Part_Optional:1	bandwidth(VF("/VOUT2") 3 "l...	1.625M			
model_file_added_MOS_lib:Lab03_Part_Optional:1	gainBwProd(VF("/VOUT2"))	13.73M			





For The Common Source: As Calculated in the Previous part

$$\text{gain} = -g_m(r_o \parallel R_D)$$

$$r_o = \frac{1}{2.083\times10^{-6}} = 480.076\ k\Omega$$

$$= 201.3\times10^{-6} \times 41.143\times10^{3} = -8.282\ V/V$$

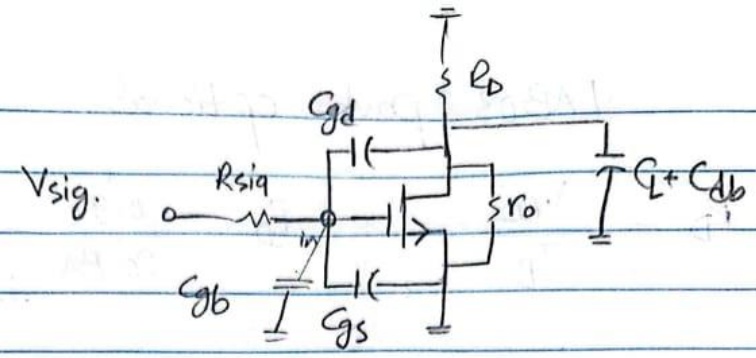
$$= 18.3628\ dB$$

$$\omega_{p_{out}} = \frac{1}{R_{out}\left(C_L + C_{db} + C_{gd}\left(1+\frac{1}{A_v}\right)\right)}$$

$$= \frac{1}{41143.42\left(10^{-15} + 1.67\times10^{-15} + 981.6\times10^{-18}\left(1+\frac{1}{8.28}\right)\right)}$$

$$= 6.4467\times10^{9}\ rad/sec$$

$$= 1.0265\ GHz$$



$$\omega p_{in} = \frac{1}{R_{sig}(C_{gs} + C_{gb} + C_{gd}(1+A))}$$

$$= \frac{1}{10\times10^{6}\left[\frac{7.494}{10^{15}} + \frac{981.6}{10^{18}}(1+8.282)\right]}$$

$$= 6.0222\times10^{6}\ \text{rad/sec}$$

$BW \simeq 958.9$ KHz

input pole will be the dominant pole

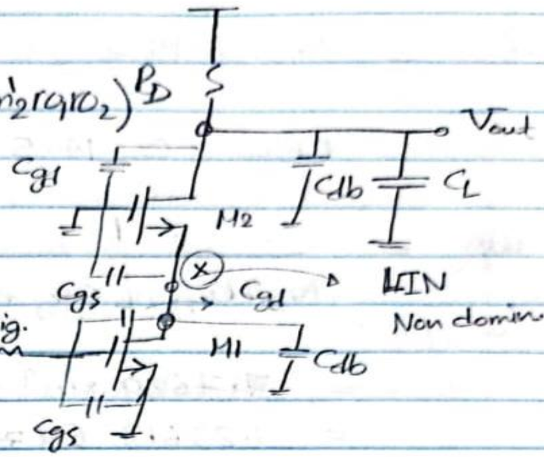
$$BW = \frac{1}{\frac{1}{\omega p_{in}} + \frac{1}{\omega p_{out}}} \approx \omega p_{in}$$

$GBW = 7.9416$ MHz

$f_u \simeq GBW = 7.941$ MHz

CS Scanned with CamScanner

Cascode circuit:



$$R_{out} = R_D \,//\, (r_{o1} + r_{o2} + g_{m2}' r_{o1} r_{o2})$$
$$= 44.929 \text{ K}\Omega$$

$$G_m \simeq -g_{m1}$$

$$Gain = G_m R_{out}$$
$$= -8.563 \text{ V/V}$$
$$= 18.6529 \text{ dB}$$

The BW will be determined by ωp_{in}, ωp_{out}

$$\omega p_{out} = \frac{1}{R_{out}\,(C_{db_2} + C_{L_2} + C_{gd_2})} = 6.11633 \times 10^9 \text{ rad/sec}$$
$$= 973.93 \text{ MHz}$$

$$\omega p_{in} = \frac{1}{R_{sig}\,(C_{gs} + C_{gd}(1 + A_o))}$$

$$A_o = -g_{m1}\,(r_{o1} \,//\, R_{LRS})$$

$$= 10682260.23 \text{ rad/sec} \qquad R_{LRS} = \frac{1}{g_{m2}'}\left(1 + \frac{R_D}{r_{o2}}\right)$$

$$= 1.7 \text{ MHz}$$

$$= 4519.827 \,\Omega$$

$$A_o = 0.84639 \text{ V/V}$$

$$BW = \frac{1}{\frac{1}{\omega p_{in}} + \frac{1}{\omega p_{out}} + \frac{1}{\omega p_x}} \simeq 1.697 \text{ MHz}$$

$$GBW = 14.531 \text{ MHz}$$

$$f_u \simeq GBW \simeq 14.5 \text{ MHz}$$

$$\omega p_x = \frac{1}{(r_{o1} \,//\, R_{LRS})\left[C_{gs_2} + C_{db_1} + C_{sb_2} + C_{gs_1}\left(1 + \frac{1}{A_o}\right)\right]}$$

4439.9

$$= 7.7629 \times 10^9 \text{ rad/sec}$$
$$= 1.23613 \text{ GHz}$$

Table and comment:

		CS Simu.	CS Hand	Cascode Simu.	Cascode Hand
CS	DC gain	18.36 dB	18.362 dB	18.52 dB	18.6529 dB
	BW	933.5 K	958.9 K	1.625 M	1.697 MHz
	UGF	7.696 M	7.941 M	13.693 M	14.5 MHz
	GBW	7.748 M	7.941 M	13.73 M	14.5 MHz

→ we used the OCIC + Millers technique

Comment

adding The Cascode didnot change the gain much because R_D was too small that it prevents the Cascode from increasing the output impedance since it's parallel to it thus the gain didnot change.

as for the Band width, the dominant pole is the input pole and adding the Cascode decreases the Miller's effect on the input pole thus Caused band width extension.

This Caused the gain bandwidth product to change.

THE END