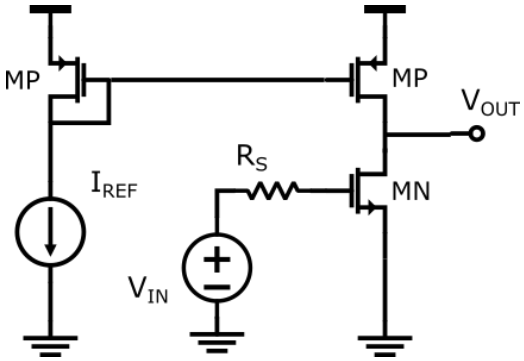
Carnegie Mellon University
ECE Department
Homework 4 – 18-421/623
Fall 2023

Instructions:	**Due Date(s):**
• 623 students: Exercises 1-3 are required. • 421 students: Exercises 1-2 are required.	• Friday, November 17, 2023 – 11:59PM EST **via Gradescope upload** • Extendible to Monday, November 20, 2023 – 11:59PM EST **via Gradescope upload***

If you use the gm_Id code to look up the values, specify the function and the arguments you used to get full credit. Discussing the homework with other students is <u>authorized</u> but submissions must be individual
***This means you may turn in the homework up to that date with no penalty. Homework will not be accepted beyond this date.**

Exercise 1 (30 pts): Common source amplifier analysis



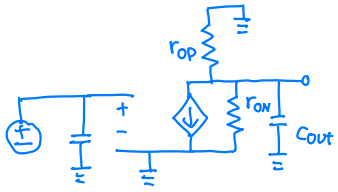
Set R_S=0.

1) Draw a small signal model including g_m, r_o, C_{GS}, C_{GD}, and C_{DD} (this is C_{db} in the gm/ID script).

2) What is the small-signal low-frequency gain? $g_{m,N}(r_{ON} \parallel r_{OP})$

3) Identify the Miller capacitor. C_{GDP}

4) Draw the small signal model using the Miller approximation.



5) What is the total input capacitance C_{IN} and the total output capacitance C_{OUT} in terms?

$C_{IN} = (1 + g_{m,N}(r_{OP} \parallel r_{ON}))\, C_{GDN} + C_{GSN}$

$C_{OUT} = C_{GDN} + C_{DDN} + C_{GDP} + C_{DDP}$

6) What is the transfer function $\frac{V_{out}}{V_{in}}(s)$ in terms of g_m, r_o, C_{GS}, C_{GD}, and C_{DD}?

$\frac{V_{out}}{V_{in}}(s) = g_{mN}(r_{OP} \parallel r_{ON}) \times \frac{1}{1 + s(r_{OP} \parallel r_{ON})\, C_{OUT}}$

7) For a transfer function $\frac{V_{out}}{V_{in}}(s) = A \times \frac{1}{1+s/p_1}$, show that its -3dB bandwidth $\omega_{3dB} = p_1$.

8) Write your transfer function $\frac{V_{out}}{V_{in}}(s)$ as $A \times \frac{\prod 1+(s/z_i)}{\prod 1+(s/p_i)}$. How many poles and zeros are in this design and where are they?

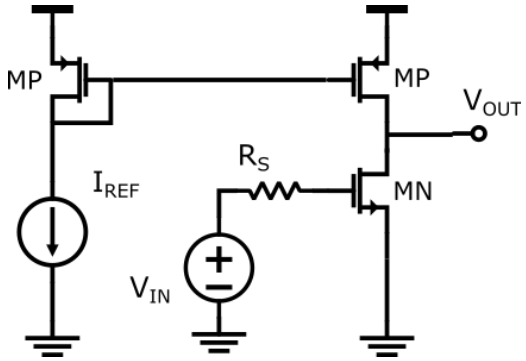
One pole at $1/(r_{OP} \parallel r_{ON})\, C_{OUT}$

9) If R_S>0, how does the number of poles and zeros change?

You have a second pole at $1/R_S C_{in}$

Exercise 2 (30 pts): Design a common source amplifier with g_m/I_D

Use L=400 nm for all transistors, with R_S=0, and I_{REF} = 40 uA. Design this amplifier for a g_m/I_D factor equal to 10. Assume $V_{DS,P} = V_{DS,N} = 0.5V_{DD}$ during your analysis.



1) Based on the information given, find the value of V_{IN} using the gm/ID code?

   look_up VGS (nch, GM_ID, 10, VDS, 0.5, L, 0.4) = 0.5698

2) What is the current density (I_D/W) of each transistor using the gm/ID code?

   look_up (nch, ID_W, GM_ID, 10, VDS, 0.5, L, 0.4) = 14.1 (uA/um)

   pch 10.1 (μA/μm)

3) Complete the first row of the table below based on V_{IN}.

4) What is the small-signal low-frequency gain?

   $A_V = g_{mN}(r_{op} \parallel r_{ON}) = \frac{400}{13.95+11.21} = 15.89$

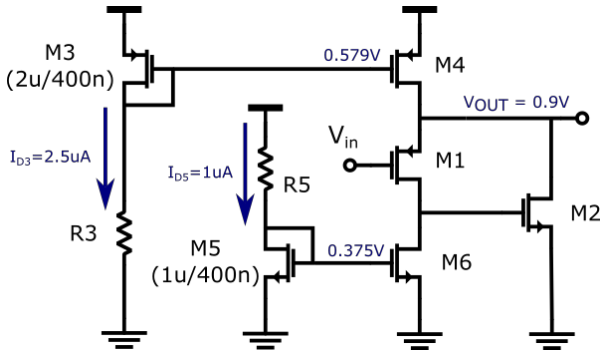
5) What is f_{3dB}?

   $f_{3dB} = \frac{\omega_{3dB}}{2\pi} = \frac{1}{2\pi} \times \frac{1}{r_{op} \parallel r_{ON}} \times \frac{1}{C_{OUT}} = \frac{1}{2\pi} \times (g_{dsN} + g_{dsp}) \times \frac{1}{C_{OUT}} = \frac{1}{2\pi} \times (13.95+11.21) \times \frac{1}{3.7f} = 1.08\ (GHz)$

6) Implement this amplifier in Cadence and simulate it. Attach screenshot of your schematic with g_m and I_D annotated, and for the ac response of the transfer function $\frac{V_{out}}{V_{in}}(s)$. Then complete the second row of the table with measurements from the simulation data.

	V_{IN}	W_N (μ)	W_P (μ)	I_D (μ)	g_m (μ)	$g_{ds,N}$	$g_{ds,P}$	Gain	f_{3dB}
Estimated	570m	2.88	4.0	40u	400u	13.95u	11.21u	15.8	1.07G
Measured	-	-	-	39.5u	393u	13.96u	10.98u	15.5	1.07G

Exercise 3 (40 pts): Design a super source follower with g_m/I_D



Design a low output-resistance super source follower using the gm/ID method. Use L=400 nm, V_{OUT}=0.9V, I_{D3}=2.5µA, I_{D5}=1µA (by setting R3 = 225k and R5 = 580k).

1) What are the drain currents for M_4, M_6, M_1, M_2?
   2.5 1 1 1.5
2) What is the total power dissipation in this circuit.
   (2.5+2.5+1)×1 = 6µW
3) Show that the small-signal output resistance r_{out} is $\frac{1}{I_{D2}(g_m/I_D)_2(g_m/g_{ds})_1}$, and which parameter is width-dependent?
   width dependent
4) Assume we pick $(g_m/I_D)_1=(g_m/I_D)_2=20$, find V_{G2}, $(I_D/W)_2$ given I_{D2} and $(g_m/I_D)_2$
   V_{G2} = 382.3 mV look_up(nch, ID_W, GM_ID, 20, L, 0.4, VDS, 0.9) = 1.02µ
5) Given I_{D4}, V_{OUT}, V_{G4}, and V_{DD}, what is $(I_D/W)_4$?
   look_up(pch, ID_W, VGS, 0.421, VDS, 0.1, L, 0.4) = 0.88µ
6) Given V_{G2} and V_{G6}, what is $(I_D/W)_6$?
   look_up(nch, ID_W, VGS, 0.375, VDS, 0.382, L, 0.4) = 0.68µ
7) Given I_{D1}, $(g_m/I_D)_1$, V_{OUT}, what is V_{IN}?
   look_upVGS(pch, GM_ID, 20, VDS, 0.9-0.382, L, 0.4) = 446 mV ⇒ V_{IN} = 444 mV
8) Given $(I_D/W)_{1,2,4,6}$, what are W_1, W_2, W_4, and W_6?
   581 1470 2840 1470
9) Build and simulate the circuit in Cadence based on your estimated parameters and complete the following table based on your measurements from the simulation?
10) Discuss the reason for any discrepancies between your estimated and measured values.
    The approximation is not precise

	g_m (µ)		I_D (µ)			g_m/I_D		g_m/g_{ds}	r_{out}
	M_1	M_2	M_1	M_2	M_4	M_1	M_2	M_1	
Estimated	20	30	1	1.5	2.5	20	20	50.06	666
Measured	29	31	1.3	1.57	2.89	22.3	19.7	52.24	1451