Carnegie Mellon University
ECE Department
Homework 3 – 18-421/623
Fall 2023

Instructions:	**Due Date(s):**
• 623 students: Exercise 1 is required. • 421 students: Exercise 1 is required.	• Friday, Octobor 6, 2023 – 11:59PM EST **via Gradescope upload** • Extendible to Monday, Octobor 9, 2023 –11:59PM EST **via Gradescope upload***

Discussing the homework with other students is authorized 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 (100 pts): g_m/I_D in the GPDK 45nm process

In this exercise, we will use a MATLAB script to estimate gm/ID in the GPDK 45 nm process in a precomputed table to help our analog circuit design. Before starting this exercise, following the steps.

Step 1. Copy the MATLAB files over from the course directory:
```
$ cp –r /afs/ece.cmu.edu/class/ece623/F22/gmId ./
```
Step 2. Move into the gmId folder
```
$ cd gmId
```
Step 3. Open MATLAB
```
$ matlab &
```
Step 4. Run techsweep_spectre_run.m. This script generates two lookup tables, nch.mat and pch.mat, in about 40min.
Step 5. Run plots_45.m for both the NMOS and PMOS. You will see 7 figures after running the script. Answer the following question based on these figures.

1) Fill the following table by using look_up function

g_m/C_{gs}

	L	$\lvert V_{GS}\rvert$	$\lvert V_{DS}\rvert$	g_m/I_D	g_m/g_{ds}	I_D/W	ω_T
NMOS	45	0.4	0.5	19.71	14.57	1.18μ	93.8G
		0.5	0.5	15.32	12.73	6.68μ	269G
		0.6	0.5	12.38	12.12	26.7μ	646G
		0.6	1	11.62	22.49	381μ	873G
	400	0.5	0.5	13.41	32.16	6.25μ	21.8G
		0.6	0.5	8.84	26.89	187μ	38.5G
		0.6	1	8.63	51.76	209μ	42.4G
PMOS	45	0.4	0.5	23.42	25.47	0.27μ	28.8G
		0.5	0.5	18.52	21.70	2.19μ	132G
		0.6	0.5	14.43	19.57	11.5μ	359G
		0.6	1	13.84	29.90	15.3μ	456G
	400	0.5	0.5	14.45	44.24	4.96μ	20.5G
		0.6	0.5	7.98	30.07	14.6μ	29.5G
		0.6	1	7.78	44.20	16.2μ	31.9G

2) Fill the following table by using look_upVGS function

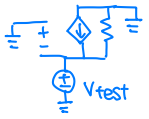
	L	$\|V_{GS}\|$	$\|V_{DS}\|$	g_m/I_D	g_m/g_{ds}	I_D/W	ω_T
NMOS	45	835m	0.5	5	7.06	189μ	88.4G
		821m	1	5	15.33	222μ	1732G
		648m		10	21.72	63.8μ	1150G
		389m		20	27.83	1.58μ	129.7G
	400	762m		5	37.29	60.3μ	66.2G
		563m		10	55.21	14.9μ	35.9G
		381m		20	61.75	10.4μ	7.42G
PMOS	45	846m	0.5	5	8.66	105μ	782G
		839m	1	5	16.89	125μ	928G
		682m		10	26.16	40.6μ	708G
		459m		20	33.63	1.45μ	108G
	400	708m		5	34.57	31.6μ	38.2G
		554m		10	49.79	10.8μ	28.4G
		438m		20	60.32	2.04μ	13.4G

3) Which term is width-dependent in the following? (a) I_D (b) g_m/g_{ds} (c) g_m/I_D (d) ω_T

4) Show a common-source amplifier has a small-signal voltage gain $A_v = \frac{g_m}{g_{ds}}$

Since $r_o = \frac{1}{g_{ds}}$, $A_v = g_m r_o = g_m/g_{ds}$

5) Show a source follower has a small-signal output resistance $r_{out} = \frac{1}{I_D} \times \frac{g_m/g_{ds}}{g_m/I_D(g_m/g_{ds}+1)}$



$i_{test} + g_m(0 - V_{test}) = V_{test}/r_o$

$\Rightarrow r_{out} = V_{test}/i_{test} = \frac{1}{g_m + 1/r_o} = \frac{1}{I_D} \times \frac{1}{g_m/I_D + 1/r_o I_D} = \frac{1}{I_D} \times \frac{g_m r_o}{(g_m/I_D)(g_m r_o + 1)} = \frac{1}{I_D} \times \frac{g_m/g_{ds}}{(g_m/I_D)(g_m/g_{ds}+1)}$

6) What change will you make if your source follower needs a higher gain?
(a) higher g_m/I_D (b) lower g_m/I_D (c) longer channel (d) shorter channel (e) higher $|V_{GS}|$ (f) lower $|V_{GS}|$

7) What change will you make if your source follower needs a higher bandwidth?
(a) higher g_m/I_D (b) lower g_m/I_D (c) longer channel (d) shorter channel (e) higher $|V_{GS}|$ (f) lower $|V_{GS}|$

8) When you select a NMOS with $g_m/I_D = 20$, $V_{DS} = 1V$ and $I_D = 1\mu A$, what is your expected gain for a CS amplifier?

$A_v = g_m/g_{ds} = 61.75$ if $L = 400$ nm

27.83 if $L = 45$ nm

9) When you select a NMOS with $g_m/I_D = 20$, $V_{DS} = 1V$ and $I_D = 1\mu A$, what is your expected r_{out} for a source follower?

$r_{out} = \frac{1}{I_D} \times \frac{g_m/g_{ds}}{(g_m/I_D)(g_m/g_{ds}+1)} = \frac{1}{1\mu A} \times \frac{61.75}{20 \times (61.75+1)} = 49.2k$