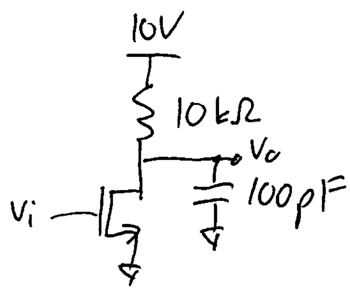
EE140 HW3 Solutions

In general, your answers don't need more than 1 sigfig

(1)



$\mu C_{ox} = \frac{20\mu A}{V^2}$ $\quad \frac{W}{L} = 10^4$ $\quad V_{th} = 1V$

$\lambda = 0.01\ V$

a) $I_D = \frac{V_{DD} - V_o}{R}$

+1 for Id=f(Vo) equation

as V_o goes from 9V to 1V:

$I_D = \frac{10-9}{10k} = 0.1mA$

$I_D = \frac{10-1}{10k} = 0.9mA$

0.1mA to 0.9mA

+1 for Id range

b) $I_D = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_t)^2$

@ $I_D = 0.1\ mA = \frac{20\mu A}{2V^2} 10^4 (V_{GS} - 1)^2$ $\quad V_{GS} = 1.032\ V$

$V_{ov} = 32mV$

@ $I_D = 0.9mA = \frac{20\mu A}{2V^2} 10^4 (V_{GS} - 1)^2$ $\quad V_{GS} = 1.095\ V$

$V_{ov} = 95\ mV$

+1 each for high and low Vov and Vgs

$\Delta V_{ov} = 63mV$

c) $g_m = \sqrt{2 \mu C_{ox} \frac{W}{L} \left(\frac{V_{DD} - V_o}{R}\right)}$

+1 for gm=f(Vo)

$r_o = \frac{1}{\lambda I_D} = \frac{R}{\lambda (V_{DD} - V_o)}$

+1 for ro=f(Vo)

d) $A_{vo} = -g_m r_o = \dfrac{2}{\lambda V_{ov}}$ $\qquad V_{ov} = \sqrt{\dfrac{2 I_D}{\mu C_{ox} \frac{W}{L}}}$

$$A_{vo} = \frac{2}{\lambda \sqrt{\dfrac{2 I_D}{\mu C_{ox} \frac{W}{L}}}} = \frac{2}{\lambda \sqrt{\dfrac{2 (V_{DD} - V_o)}{\mu C_{ox} \frac{W}{L} R}}}$$

+1 for an Av equation and
+1 if it is a function of Vo

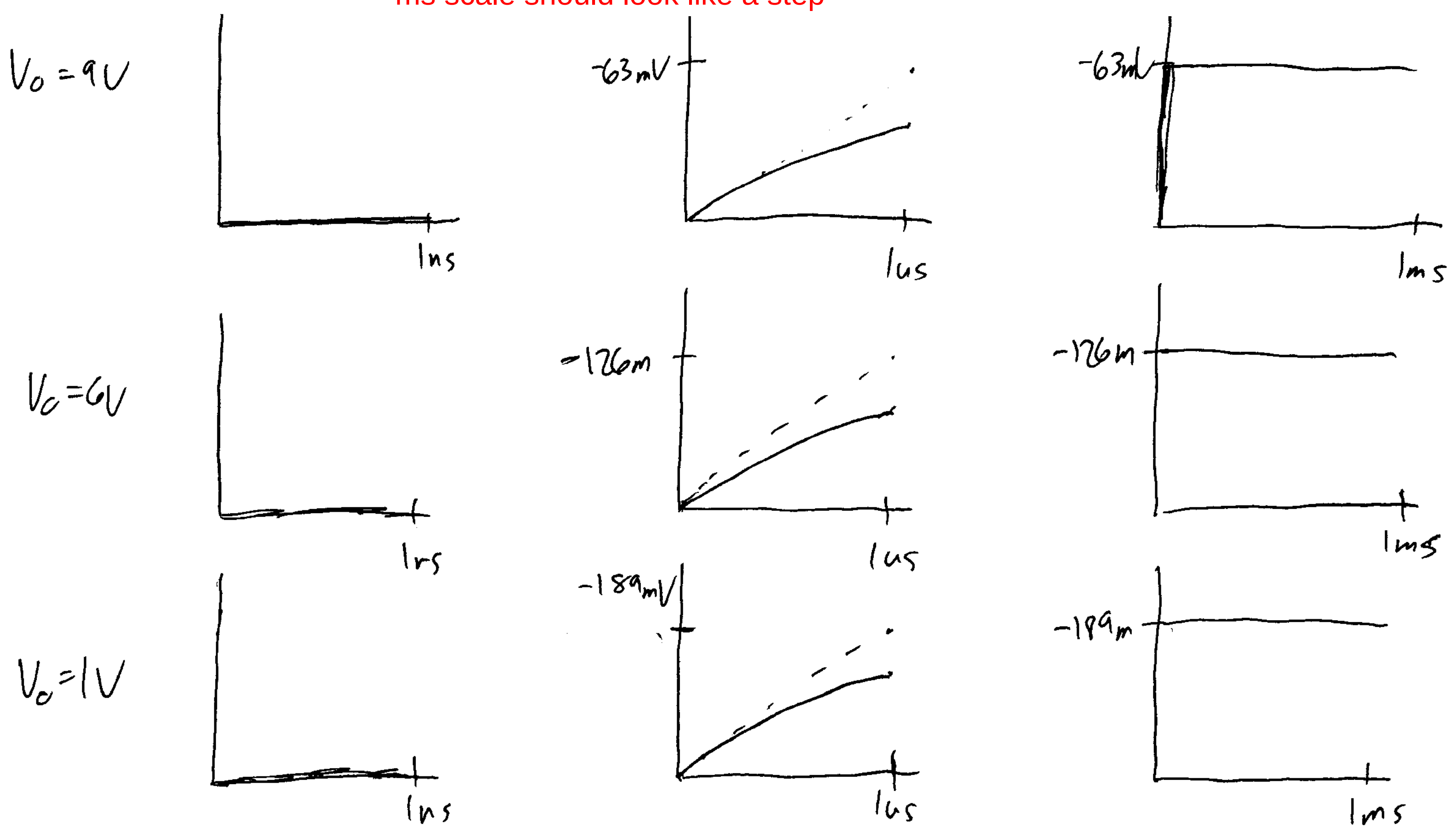
e)

	I_D	g_m	r_o	A_{vo}	ω_p	ω_u
$V_o = 9V$	100uA	6.3mS	1MΩ	63 V/V	1 Mrad/s	63 Mrad/s
$V_o = 6V$	400uA	12.6mS	250kΩ	126 V/V	1 Mrad/s	126 Mrad/s
$V_o = 1V$	900uA	18.9mS	111kΩ	189 V/V	1 Mrad/s	189 Mrad/s

+0.5 per entry, within ~10-20% is fine, 1 sig fig is sufficient

f) $\tau = 1\mu s$,

+1 per plot,
ns scale should be ~flat
us scale should look exponential and end at 0.63 of the final value
ms scale should look like a step



(2)

$\lambda = 0.1\,V^{-1}$

a) $R_L = r_o = \dfrac{1}{\lambda I_D} = \dfrac{1}{\lambda \dfrac{(V_{DD} - V_c)}{R_L}}$

+1 for equation
+1 for 11V as answer

$\dfrac{10}{V_{DD} - 1} = 1 \qquad \boxed{V_{DD} = 11\,V}$

b) If $V_{DD} = 2V$ and $V_{o,DC} = 1V$

+1 for approx as Ro=RL
+1 for some reasoning why
+2 for getting reasonably close to 10% error

$r_o = \dfrac{1}{\lambda I_D} = \dfrac{1}{0.1 \dfrac{(2-1)}{R_L}} = 10R_L$

So we should approximate that $R_o = R_L$.

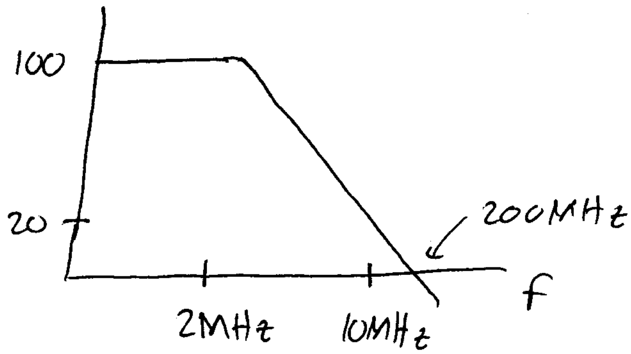
$10R_L // R_L = \dfrac{10R_L}{11} \approx 0.9R_L$ Approximation is off ~10%

c) $A_v = -g_m R_L \qquad g_m = \dfrac{2I_D}{V_{ov}} \qquad I_D = \dfrac{2-1}{R_L} = \dfrac{1}{R_L}$

$A_v = \dfrac{-2}{V_{ov} R_L} \cdot R_L \qquad \boxed{A_v = \dfrac{-2}{V_{ov}}}$

+1 for a gain equation
+1 for correct answer

(3) $A_{vo} = 100$



+2 for setting up equations for fp and fu
+1 for correct fp
+1 for correct fu

$GBW = 10MHz \cdot 20 = 200MHz$

f_p has gain of 100: $\frac{200MHz}{100} = 2MHz$

f_u has gain of 1: $\frac{200MHz}{1} = 200MHz$

$f_p = 2MHz$

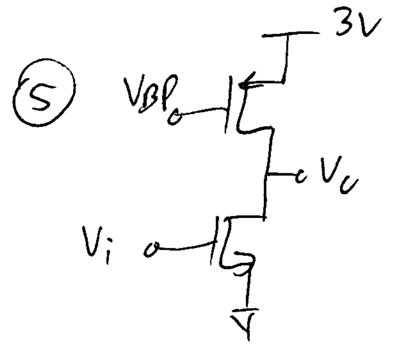
$f_u = 200MHz$

(4)

A_{vo} [V/V]	ω_p [rad/s]	ω_u	g_m [A/V]	r_o [Ω]	C_L [F]
100	1M	100M	10^{-4}	10^6	1p
200	10M	2G	$2 \cdot 10^{-3}$	100k	1p
100	10M	1G	10^{-4}	1M	100f
10^6	10	10M	10^{-4}	10^{10}	10p

+1 per blank (12 points total)
1 sig fig, but answers should be exact

(5)



$u C_{ox} \frac{W}{L} = 1 mA/V^2$ $|V_T| = 1V$ $\lambda = 0.1 V^{-1}$

a) $V_{BP} = 1.8V$

$V_{dsat_p} = V_{GSp} - V_T = 3 - 1.8 - 1 = 200mV$

$V_{dp} = 2.8V$

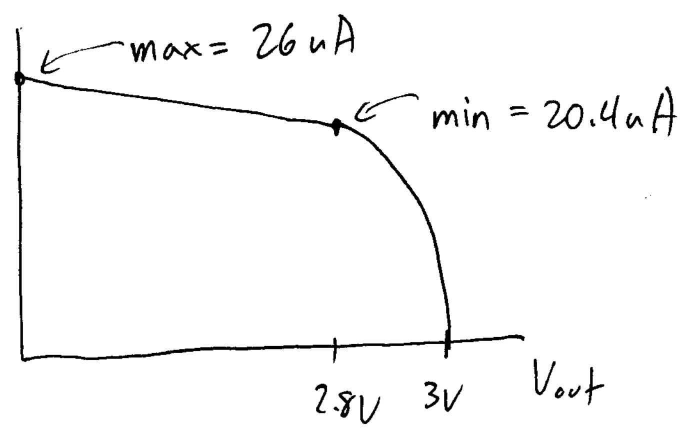
$I_{dp} = \frac{uC_{ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2(1 + \lambda V_{DS})$

+1 for Vdp equation
+1 for Idp equation setup
+1 for correct Vdp
+1 for correct Id (don't need 0.1uA accuracy)

$I_{dp} = \frac{1}{2} 1mA/V^2 (0.2V)^2 \left(1 + \frac{0.1}{V} 0.2V\right) = \frac{1}{2} 0.04m(1 + .02)$

$I_{dp} = 20.4 uA$

b)



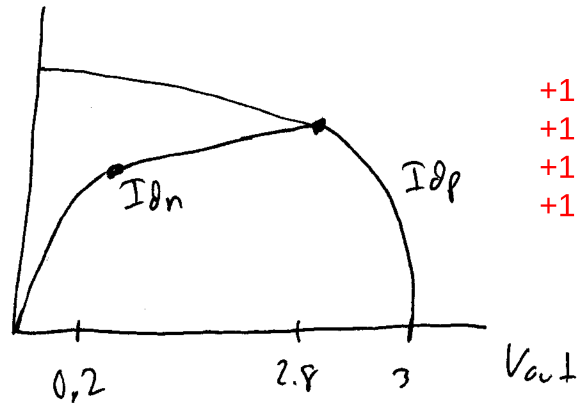
+2 for correct plot shape, axis
+2 for max current
+2 for min current

$I_{dp,max} = \frac{1}{2} mA/V^2 (0.2)^2 \left(1 + \frac{0.1}{V} \times 3\right) = 26uA$

c) $I_d = 20.4 uA$ $V_o = 2.8V$

$I_d = \frac{1}{2}\frac{mA}{V^2}(V_i - V_T)^2(1 + 0.1(2.8))$ $\underline{V_i = 1.18V}$

c cont)



+1 for equation to find Vi
+1 for Vi within 0.1 V
+1 for Idn curve
+1 for Idp curve

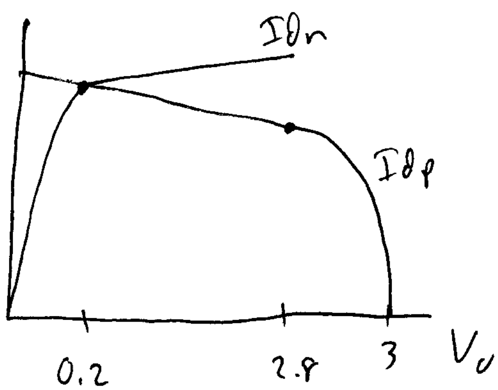
d) NMOS leaves saturation at 0.2 V Vout

I_{dp} @ $V_{out} = 0.2V$ is:

$$\frac{1}{2}\frac{mA}{V^2}(0.2v)^2(1 + 0.1(2.8)) = 25.6\,uA$$

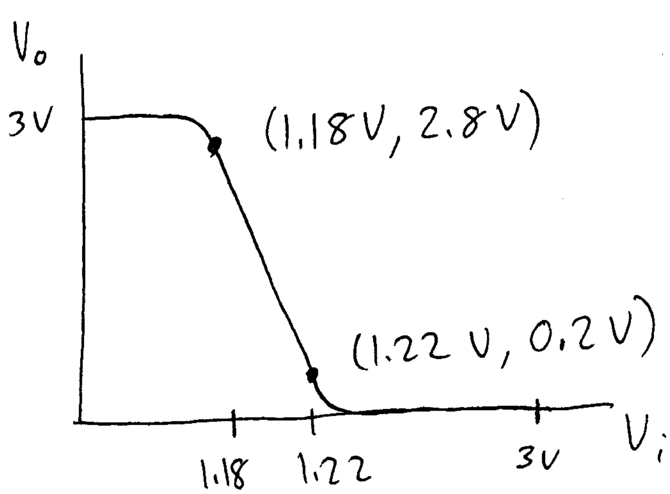
$$25.6uA = \frac{1}{2}\frac{mA}{V^2}(V_i - V_t)^2(1 + 0.1(0.2))$$

$V_i = 1.22\ V$



+1 for equation to find Vi
+1 for Vi within 0.1 V
+1 for Idn curve (including finding the current at Vout = 0.2V)
+1 for Idp curve

e)



7 pts total
+1 nmos off and pmos off regions
+1 nmos triode (roughly quadratic)
+1 pmos triode (roughly quadratic)
+2 for the high gain start (x,y) points
+2 for the high gain end (x,y) points

f) $A_v = \frac{\Delta V_o}{\Delta V_{in}} = \frac{2.6V}{}$

$$A_v = -65 \text{ V/V}$$

output range is 0.2V to 2.8V (2.6V swing)
input range is 1.18 V to 1.22 V (40 mV)

+1 for gain estimate within 20% of -65 V/V
+1 for range (to within 0.1 V is fine)

g) At $V_{o,DC} = 2.8V$

$$g_m = \frac{2I_D}{V_{oV}} = \frac{2(20.4uA)}{1.18-1} = 230\ uS$$

$$r_o = \frac{1}{2}\frac{1}{\lambda I_D} = \frac{1}{2}\frac{1}{0.1\ (20.4uA)} = 245k\Omega$$

Or $A_v = -g_m r_o = \frac{-1}{\lambda V_{oV}} = \frac{-1}{(0.1)(0.18)} = -55.6\ V/V$

At $V_{o,DC} = 0.2V$, $I_D = 25.6uA$

$$A_v = \frac{-1}{\lambda V_{oV}} = \frac{-1}{0.1\ (0.22)} = -45.5\ V/V$$

+1 for gm,ro at high Vo
+1 for gain at high Vo
+1 for gm,ro at mid Vo
+1 for gain at mid Vo
+1 for gm,ro at low Vo
+1 for gain at low Vo
Fewer sig figs OK

At $V_{o,DC} = 1.5V$, $I_D = \frac{1}{2} mA/V^2 (0.2V)^2 (1+0.1(1.5)) = 23uA$

$$A_v = \frac{-1}{\lambda V_{ov}} = \frac{-1}{(0.1)(0.2)} = -50\ V/V$$

(NMOS V_{ov} must be 0.2V)

In summary:

$V_{o,DC} = 2.8V$	$A_v = -55.6$ V/V
$V_{o,DC} = 1.5V$	$A_v = -50$ V/V
$V_{o,DC} = 0.2V$	$A_v = -45.5$ V/V

HW3 grading rubric

1) 28 pts total
1a) 2
1b) 4
1c) 2
1d) 2
1e) 9 (0.5 for each entry in the table)
1f) 9, 1 for each plot

2) 8 pts total
2a) 2 pts
2b) 4 pts; 1 for right answer, 1 for some reasoning, 2 for error calc
2c) 2 pts.

3) 4 pts, 2 for each frequency

4) 12 pts, 1 per blank

5) 33 pts total
5a) 4 pts
5b) 6 pts: 2 for plot, 2 each for min/max Idp
5c) 4 pts: 2 for Vi ; 2 for plot
5d) 4 pts: 2 for Vi ; 2 for plot
5e) 7 pts: 1 for "nmos off" region, 1 for pmos triode, 1 each for the X and Y location of the beginning of high gain, 1 each for the X and Y location of the end of high gain, 1 for nmos triode. The triode regions should be vaguely quadratic, and the high gain region should be a straight line.
5f) 2 pts
5g) 6 pts