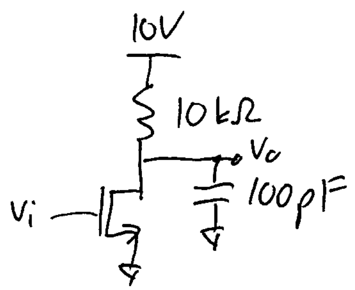
EE140 HW3 Solutions

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

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

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

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

$V_{ov} = 32mV$

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

$V_{ov} = 95\, mV$

$\Delta V_{ov} = 63mV$

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

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

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

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

e)

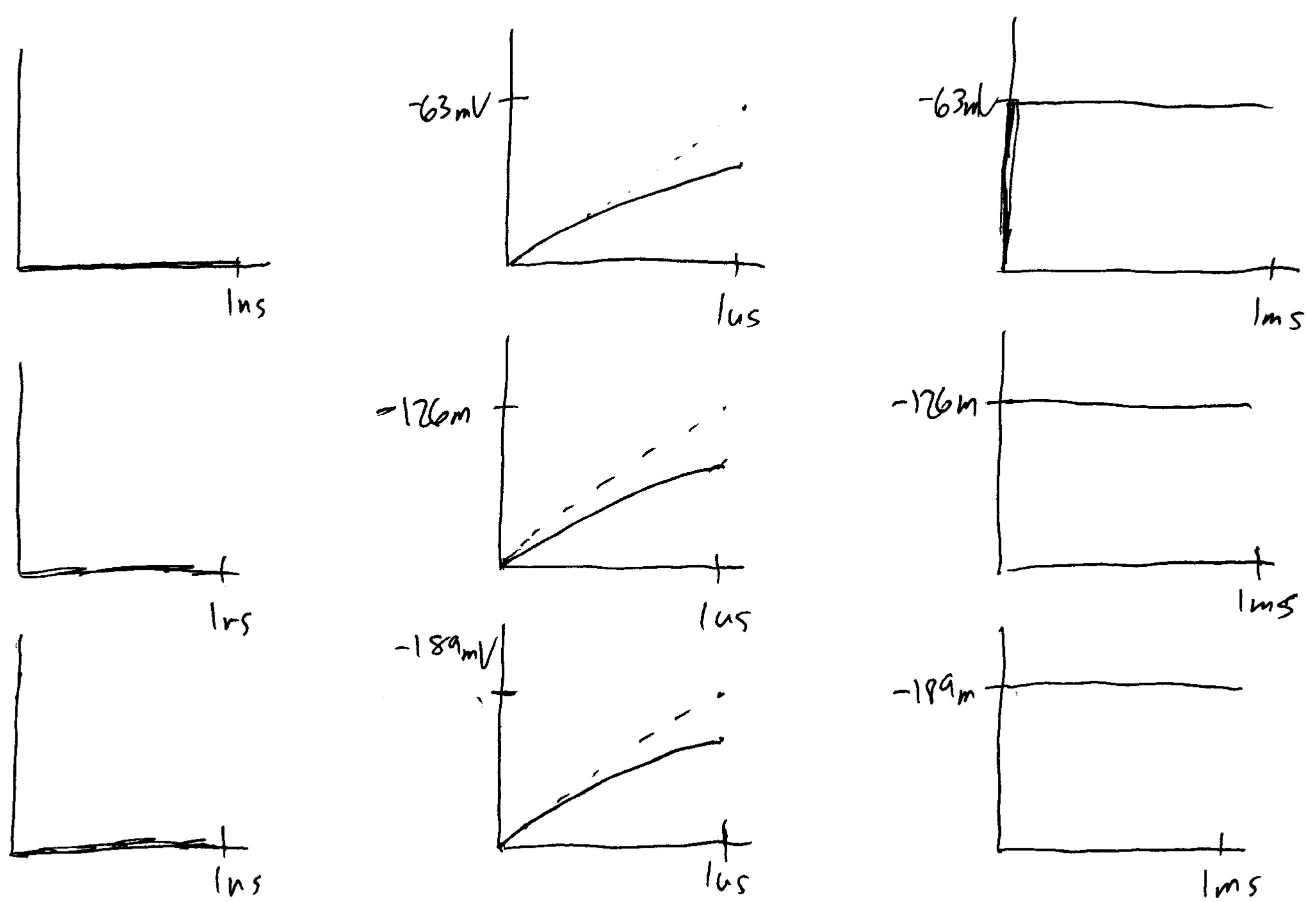
	I_D	g_m	r_o	A_{vo}	ω_p	ω_u
$V_o = 9V$	100uA	6.3mS	1MΩ	63 V/V	1Mrad/s	63 Mrad/s
$V_o = 6V$	400uA	12.6mS	250kΩ	126 V/V	1Mrad/s	126 Mrad/s
$V_o = 1V$	900uA	18.9mS	111kΩ	189 V/V	1Mrad/s	189 Mrad/s

f) $\tau = 1us$,

$V_o = 9V$

$V_o = 6V$

$V_o = 1V$



(2)

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

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

$\frac{10}{V_{DD} - 1} = 1$ $\boxed{V_{DD} = 11V}$

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

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

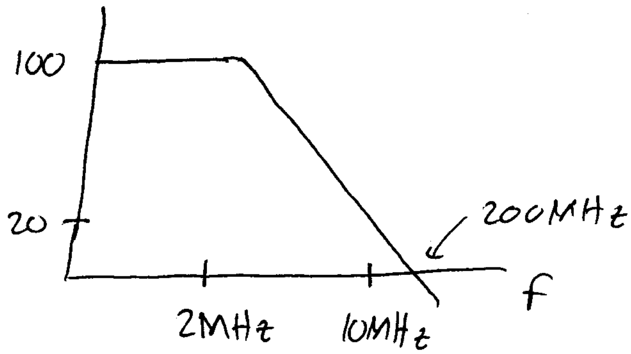
So we should approximate that $R_O = R_L$.

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

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

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

(3) $A_{vo} = 100$



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

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

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

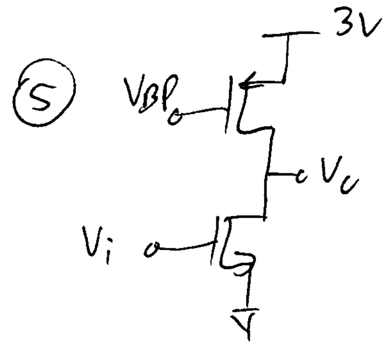
$f_p = 2MHz$

$f_u = 200MHz$

(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

5



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

a) $V_{BP} = 1.8V \qquad V_{dsat_p} = V_{GSP} - V_t = 3 - 1.8 - 1 = 200 mV$

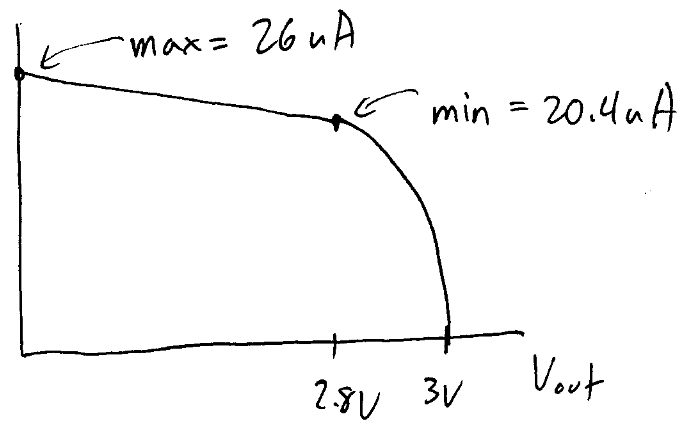
$V_{D_p} = 2.8V$

$I_{D_p} = \frac{\mu C_{ox}}{2} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS})$

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

$I_{D_p} = 20.4 \ \mu A$

b)

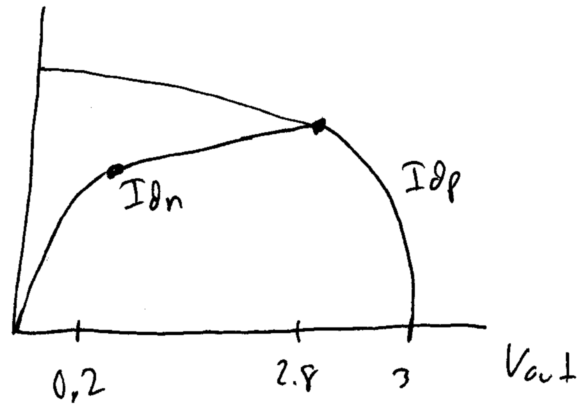


$I_{D_{p,max}} = \frac{1}{2} mA/V^2 (0.2)^2 \left(1 + \frac{0.1}{V} \times 3\right) = 26 \mu A$

c) $I_D = 20.4 \ \mu A \qquad V_o = 2.8V$

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

c cont)



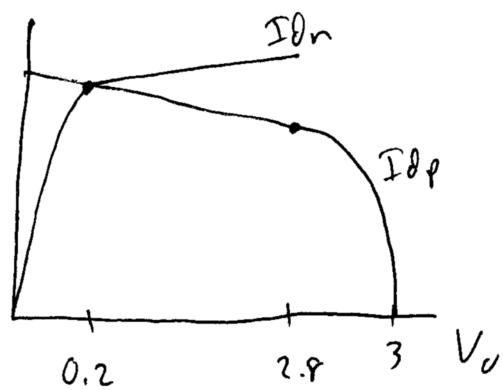
d) NMOS leaves saturation at 0.2 V V_{out}

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

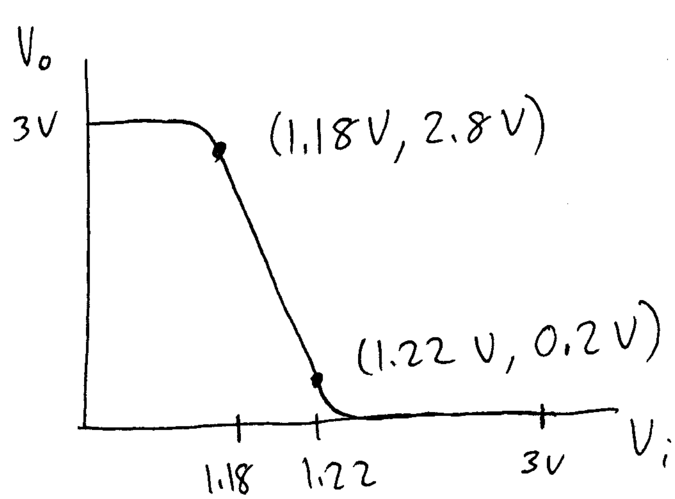
$$\frac{1}{2} \frac{mA}{V^2} (0.2V)^2 \left(1 + 0.1\,(2.8)\right) = 25.6\,uA$$

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

$\underline{V_i = 1.22\ V}$



e)



f) $A_v = \frac{\Delta V_o}{\Delta V_{in}} = \frac{2.6V}{}$ $\boxed{A_v = -65 \text{ V/V}}$

output range is 0.2V to 2.8V (2.6V swing)

input range is 1.18 V to 1.22 V (40 mV)

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

$$g_m = \frac{2I_D}{V_{ov}} = \frac{2(20.4\mu A)}{1.18-1} = 230\ \mu S$$

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

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

At $V_{o,DC} = 0.2V$, $I_D = 25.6\mu A$

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

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

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