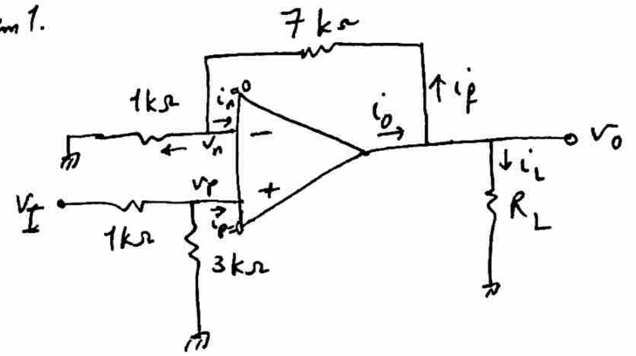
ECE 65 - Winter 2019 Final exam solutions

Problem 1.



a) ideal op-amp : $i_n = i_p = 0$, negative feedback is present $\Rightarrow v_n = v_p$

KCL at the inverting node:

$$\frac{v_n}{1k} + \frac{v_n - v_o}{7k} = 0 \rightarrow \frac{v_o}{7k\Omega} = \left(\frac{1}{1k} + \frac{1}{7k}\right) v_n$$

$$\rightarrow V_o = \left(1 + \frac{7k\Omega}{1k\Omega}\right) v_n \quad \xRightarrow[v_n = v_p]{} \quad v_o = \frac{3}{4}(1+7) v_I = 6\, v_I$$

$$v_p = \frac{3k\Omega}{3k\Omega + 1k\Omega} \times v_I$$

$$\rightarrow \boxed{V_o = 6\, V_I}$$

b) checking the positive peak of $v_I = 2V$:

@ $V_I = 2V$: $V_o = 6 \times 2 = 12V < V_{sat}$ $\Rightarrow$ we are not limited by the saturation voltage for the max positive v_I.

@ $V_I = 2$ V : $i_o = i_L + i_f$

$$i_L = \frac{V_o}{R_L} = \frac{12V}{1k\Omega} = 12\,mA \quad , \quad i_f = \frac{V_o}{8k\Omega} = \frac{12V}{8k\Omega} = 1.5\,mA$$

$$i_o = 12\,mA + 1.5\,mA = 13.5\,mA < 25\,mA$$ → we are not limited by the max output current for the max positive v_I.

checking the negative peak of $v_I = -3$ V:

@

@ $V_I = -3$ V → $V_o = 6 \times (-3) = -18V$ and $|-18V| > |V_{sat}|$

→ we are limitted by the saturation voltage for the max negative v_I.

Cannot go below $V_{sat} = -16V$

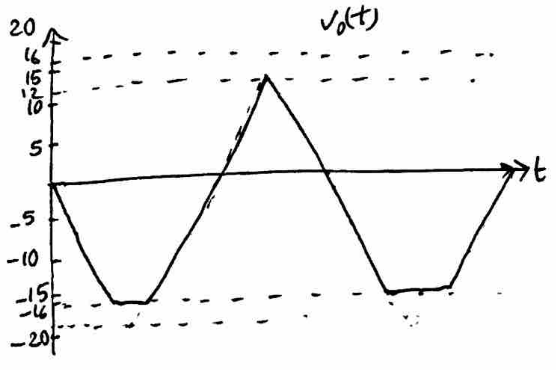
Ch → v_{out}

checking for the max output current at $V_{out} = -16$ V :

$$i_o = i_L + i_f \quad , \quad i_L = \frac{V_o}{R_L} = \frac{-16V}{1k} = -16\,mA$$

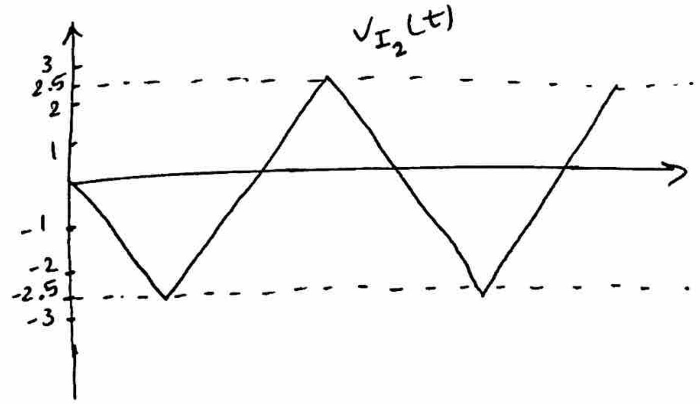
$$i_f = \frac{-16V}{8k\Omega} = -2\,mA \quad \rightarrow \quad i_o = -16\,mA - 2\,mA = -18\,mA$$

$$|i_o| < |i_{omax}|$$



c)

i)



ii)

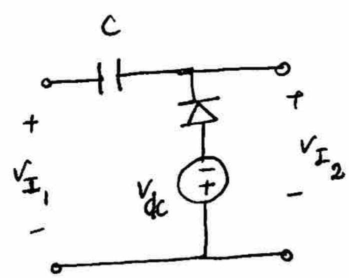
The max positive and negative values of v_I are $2.5V$ and $-2.5V$

For $|v_I| = 2.5V \longrightarrow |v_o| = 2.5 \times 6 = 15V$

$$|i_{o\,max}| = \frac{|V_{o\,max}|}{R_{L\,min}} + \frac{|V_{o\,max}|}{8k\Omega} = \frac{15V}{R_{L\,min}} + \frac{15V}{8k\Omega} = \frac{15V}{R_{L\,min}} + \underset{(mA)}{1.875} = 25mA$$

$$\frac{15V}{R_{L\,min}} = 23.125mA \longrightarrow R_{L\,min} \simeq 649\,\Omega$$

iii)



Assume using a diode with $V_{D_o} = 0.7V$

$$V_{I_2} = V_{I_1} + (V_p - V_{DC} - V_{D_o})$$

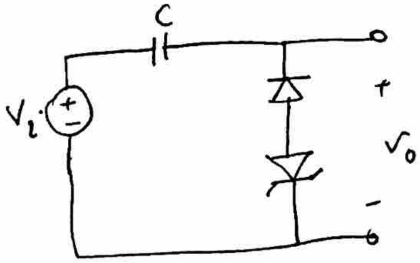
$$V_{I_2} = V_{I_1} + 0.5V$$

$$\rightarrow V_p - V_{DC} - V_{D_o} = 0.5V$$

$$3V - V_{DC} - 0.7V = 0.5V$$

$$\boxed{V_{DC} = 1.8V}$$

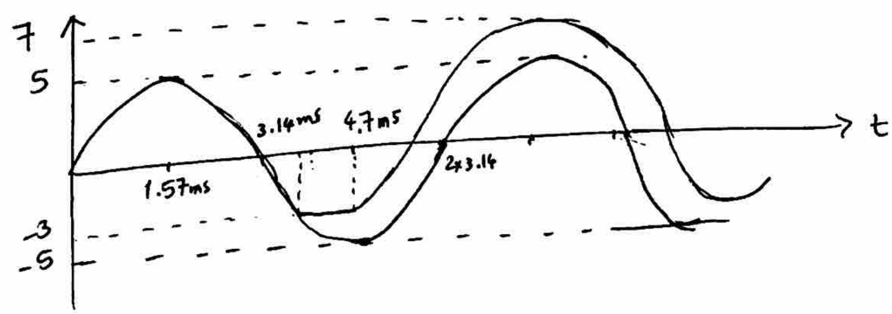
Problem 2.



The diodes will conduct when $|V_I| > |-(2.3V + 0.7)|$ until V_I reaches its max negative peak.

The period of the input signal $T = \frac{2\pi}{\omega} = 2 \times 3.14\ ms$

at $t = T/2$, V_I will



a) at $t = 2ms \rightarrow V_i > -3V \rightarrow$ diodes are off $\rightarrow V_o = V_i$

$V_o(t = 2ms) = V_i(t = 2ms) = 5 \times \sin(2) \approx 4.55(V)$

$\boxed{V_o(t = 2ms) = 4.55V}$

b and c) The diodes conduct when $V_i = -3V \rightarrow 5\sin(\omega t) = -3V$

$\rightarrow t \approx 3.78\ ms$

The negative peak happens at $t = 3/2 \times 3.14\ ms \simeq 4.71 ms$

$t = 6ms > 4.71\ ms \longrightarrow$ peak has passed $\rightarrow V_o = V_i + (V_p - V_{DZ} - V_{D_o})$

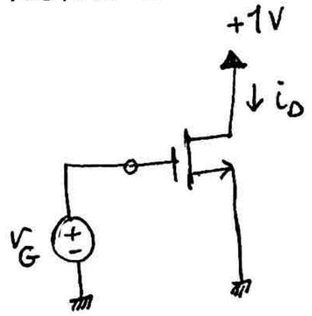
$V_o = V_i + 2V$

$V_o(t = 6ms) = V_i(t = 6ms) + 2V = 0.6V \rightarrow \boxed{V_o(t = 6ms) = 0.6V}$

at $t = 4\ ms \longrightarrow$ diodes conduct $\rightarrow V_o = -V_{D_o} - V_Z = -3V$

$\boxed{V_o(t = 4m) = -3V}$

Problem 3.



a & b) when $v_G < V_t$ → MOS is off $i_D = 0$

$V_G = V_{GS}$, $V_D = V_{DS} = 1V$

when

$V_{GS} - V_t \leq V_{DS}$ → MOS is in saturation

$0.5V \leq V_G \leq 1V + 0.5V \rightarrow 0.5V \leq V_G \leq 1.5V$ MOS is in saturation

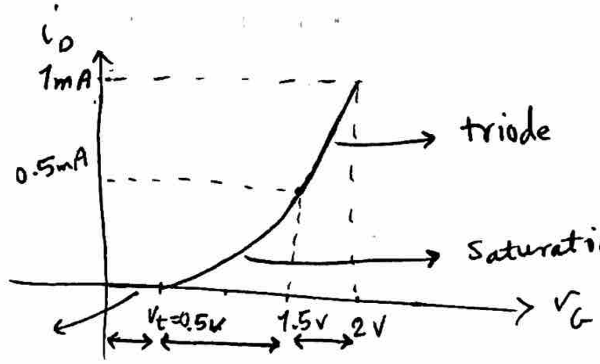
$$i_D = \frac{1}{2} k_n (V_{GS} - V_t)^2 = \frac{1}{2} \times 1 (mA/V^2) \times (V_G - 0.5)^2$$

when

$V_G > 1.5V$ → MOS is in triode:

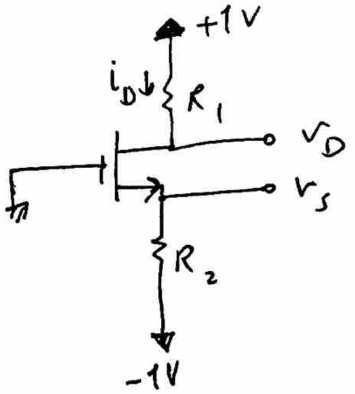
$$i_D = \frac{1}{2} k_n (2V_{ov} V_{DS} - V_{DS}^2) = \frac{1}{2} \times 1\, mA/V^2 \,(2 \times (V_G - 0.5) - 1)$$

$$i_D = V_G - 1$$



Cut-off $i_D = 0$

Problem 4.



$V_D = 0.3\,V$ and $i_D = 0.1\,mA$

$\rightarrow R_1 = \dfrac{1V - V_D}{i_D} = \dfrac{1V - 0.3V}{0.1\,mA} = 7\,k\Omega$

$\rightarrow \boxed{R_1 = 7\,k\Omega}$

$V_{DG} = V_{DS} - V_{GS} = 0.3\,V \rightarrow V_{DS} = V_{GS} + 0.3\,V$

$V_{OV} = V_{GS} - 0.5\,V$

$\Rightarrow V_{DS} > V_{OV}$

$\Rightarrow$ MOS is in Saturation

$i_D = \frac{1}{2} k_n V_{OV}^2 = 0.1\,mA$

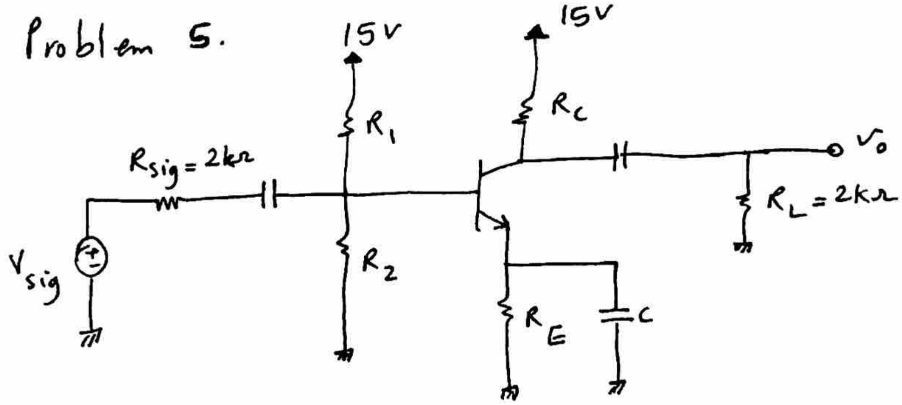
$\frac{1}{2} \times 5\,(mA/V^2) \times V_{OV}^2 = 0.1\,mA \longrightarrow \boxed{V_{OV} = 0.2\,V}$

$V_{GS} = V_{OV} + V_t = 0.7\,V \longrightarrow \boxed{V_S = -0.7\,V}$

$\rightarrow R_2 = \dfrac{V_S - (-1)}{i_D} = \dfrac{-0.7 + 1}{0.1} = 3\,k\Omega$ $\boxed{R_2 = 3\,k\Omega}$

$R_D = R_1 = 7\,k\Omega$, $R_S = R_2 = 3\,k\Omega$

Problem 5.



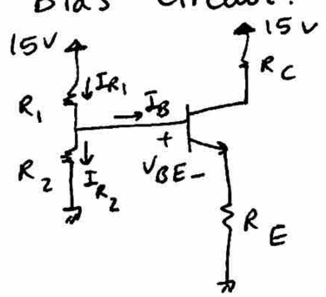
Common-emitter configuration $\rightarrow \left.\frac{v_o}{v_i}\right|_{R_L=\infty} = -g_m R_C$

$R_o = R_C$

$R_i = R_B \parallel r_\pi$

$$\frac{v_o}{v_{sig}} = \left(\frac{R_i}{R_i + R_{sig}}\right)\left(\frac{R_L}{R_L + R_o}\right) A_{v_o}$$

Bias circuit:



$V_B = \frac{1}{3} \times 15V = 5V$

$V_{BE} = 0.7V \rightarrow V_E = V_B - 0.7V = 4.3V$

$I_E = 2mA \rightarrow R_E = \frac{V_E}{I_E} \rightarrow \boxed{R_E = 2.15 k\Omega}$

$I_{R_2} = \frac{1}{10} \times I_E = 0.2 mA$

$R_2 = \frac{V_B}{I_{R_2}} = \frac{5V}{0.2mA} = 25 k\Omega \Rightarrow \boxed{R_2 = 25 k\Omega}$

$I_B = \frac{I_E}{1+\beta} = 19.8 \mu A$, KCL: $I_{R_1} = I_B + I_{R_2} = 0.2mA + 19.8\mu A = 0.2198 mA$

$R_1 = \frac{15V - 5V}{0.2198mA} \Rightarrow \boxed{R_1 = 45.49 k\Omega}$

$R_i = R_B \parallel r_\pi$, $R_B = R_1 \parallel R_2 = 45.44k \parallel 25\,k = 16.13\,k\Omega$

$$r_\pi = \frac{V_T}{I_B} = \frac{25\,mV}{I_E/1+\beta} = \frac{25\,mV \times 101}{2\,mA} = 1.26\,k\Omega$$

$R_i = 16.13k \parallel 1.26\,k\Omega \simeq 1.17\,k\Omega$, $g_m = \frac{\beta}{r_\pi} = \frac{100}{1.26\,k\Omega} = 79.36\,mA/V$

$$-\frac{v_o}{v_{sig}} = \frac{R_i}{R_i + R_{sig}} \times \frac{R_L}{R_L + R_o} \times A_{v_o} = \left(\frac{1.17k}{1.17k+2k}\right) \times \left(\frac{2k}{2k + R_C}\right) \times 79.36\,mA/V \times R_C$$

$$\rightarrow \frac{58.58\,R_C}{2k + R_C} = 40 \rightarrow 58.58 R_C = 80k + 40R_C$$

$$\rightarrow \boxed{R_C \simeq 4.3\,k\Omega}$$

Signal parameters:

$r_\pi = 1.26\,k\Omega$, $g_m = 79.36\,mA/V$, $r_o = \infty$

Signal circuit: