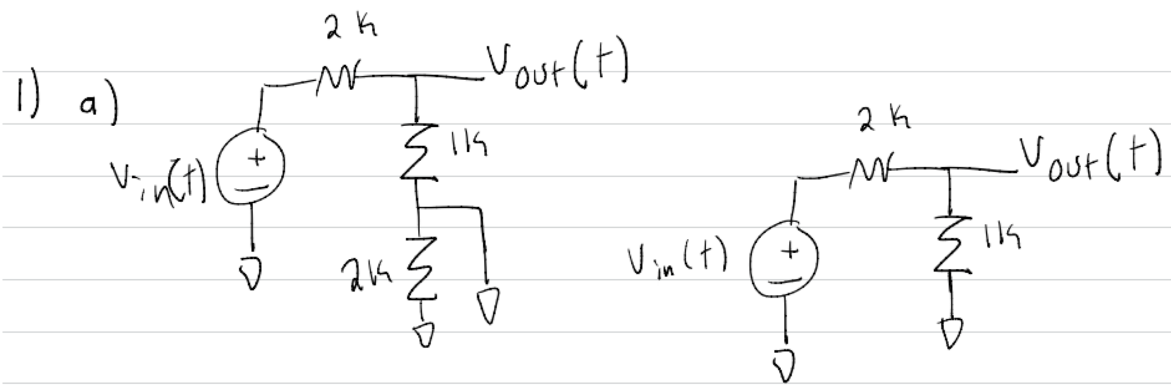
Homework 9 Solutions

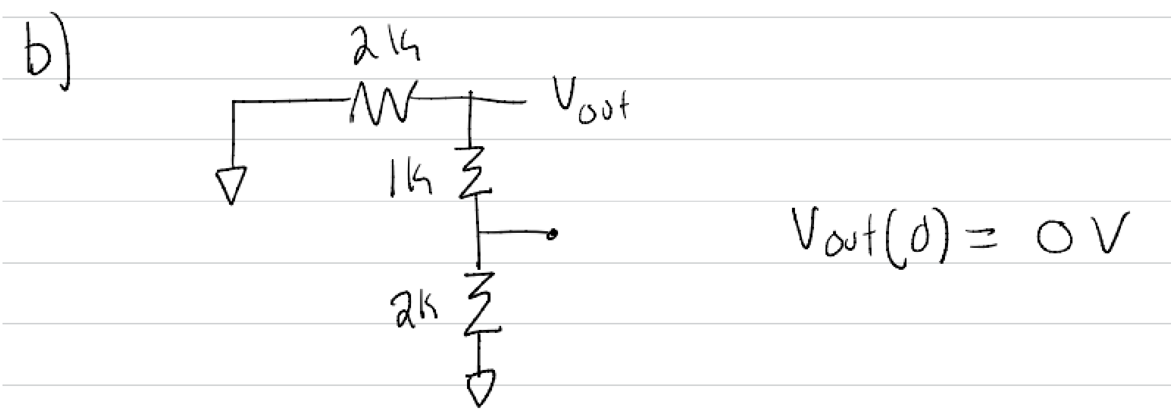
EE 330: FALL 2024

Problem 1

a)



b)



c)

For small signal voltage gain:

$$Av = \frac{1k}{1k + 2k} = \mathbf{\frac{1}{3}}$$

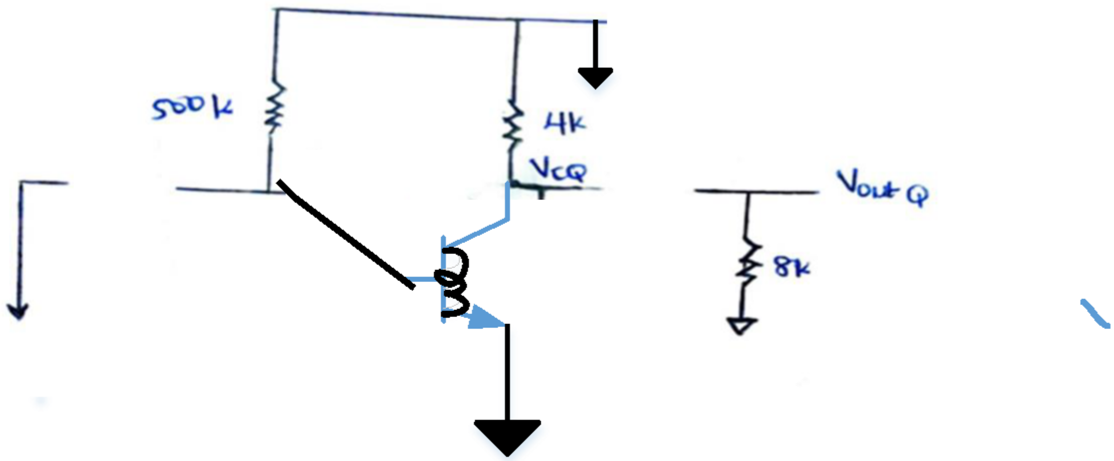
d)

$$Vout(t) = A_v \cdot V_{in}(t) = \frac{1}{3} \cdot (2sin(500t))$$

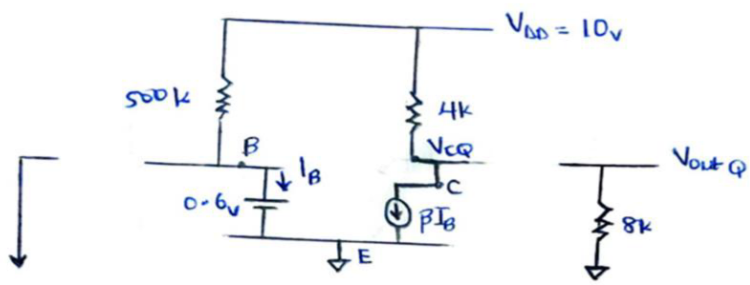
$$\mathbf{Vout(t) = \frac{2}{3}\,sin(500t)}$$

Problem 2

(a)



(b)



- Assuming Forward Active Region

$\beta = 100$

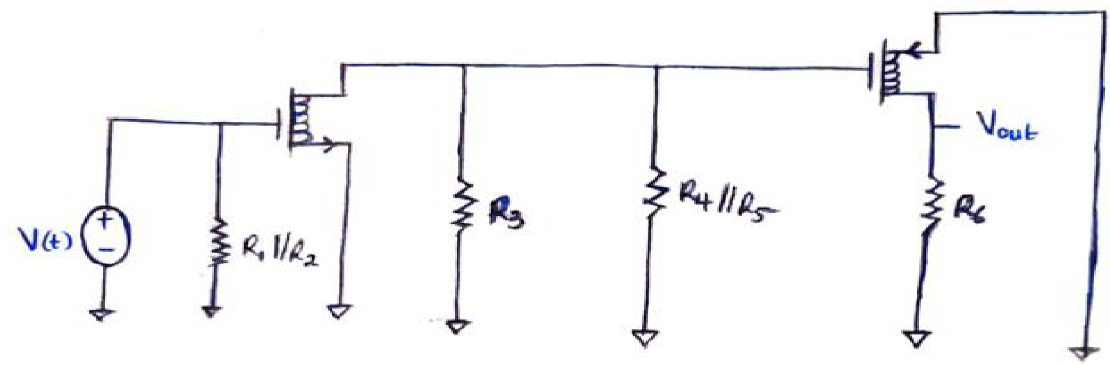
→ $I_B = \frac{10 - 0.6}{500000} = 1.88 \times 10^{-5} A$

→ $I_C = \beta I_B = 100 \times 1.88 \times 10^{-5} = 1.88 \times 10^{-3} A$

→ $V_{CQ} = V_{DD} - (I_C \times 4k) = 10 - (1.88 \times 10^{-3} \times 4000) = 2.48_v$

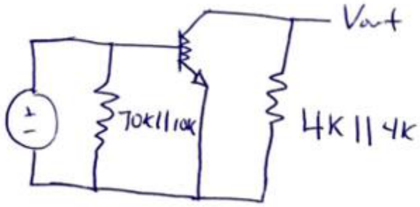
→ Since $I_{RL} = 0$, $V_{outQ} = I_{RL} \cdot 8k = 0$

Problem 3



Problem 4

(a) Draw the small signal equivalent circuit



(b) determine V_c and V_{out}

$$\boxed{V_{out} = 0V}$$

$$\frac{32 - V_B}{70k\Omega} - \frac{V_B}{10k} + \beta\left(\frac{32 - V_B}{70k\Omega} - \frac{V_B}{10k}\right) = \frac{V_B - 0.6V}{2k}$$

$$V_B = 3.859V$$

$$I_C = \frac{32V - V_C}{4k\Omega}$$

$$I_C = B\, I_B \quad \Rightarrow \quad I_C = 100(16.114\mu A) = 1.611mA$$

$$I_B + \frac{3.859}{10k} = \frac{32 - 3.859}{70k}$$

$$I_B = 16.114\mu A$$

$$I_C = 1.611mA = \frac{32V - V_C}{4k\Omega}$$

$$\boxed{V_C = 25.55V}$$

Alternately, if we assume I_B is negligible compared to the current through the $70K$ resistor, the voltage at the base is, by a voltage divider, $(1/8) * 32V = 4V$. Thus, the emitter voltage is $4V - 0.6V = 3.4V$. So the current in the emitter, $I_E = 3.4V/2K = 1.7mA$. But since β is large, $I_C = I_E$. Thus $V_C = 32V - I_C * 4K = 25.6V$.

Note this solution is somewhat simpler and the results are about the same as that obtained by including the base current.

Problem 5

a)

Assuming Saturation

$$V_{gs} = 0 - (-1)\,V = 1\,V$$

$$V_{ds} = (2 - I_D \cdot 10k) - (-1) = 3 - I_D \cdot 10k$$

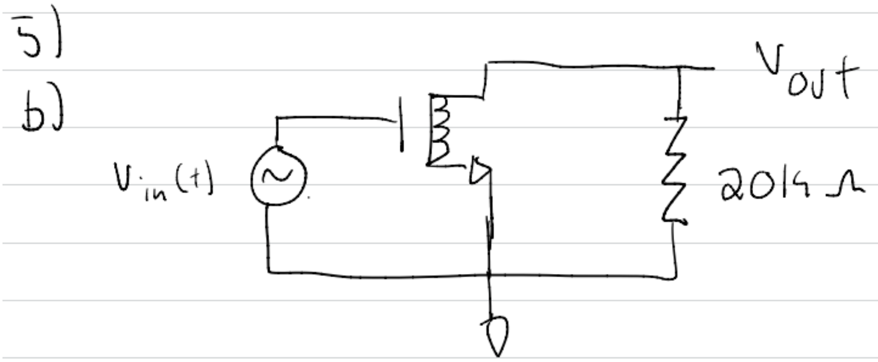
$$I_D = \mu_n C_{ox} \frac{W}{2 \cdot L}(V_{gs} - V_T)^2$$

$$100\,\mu A = 250\mu \frac{W}{2 \cdot 5\mu}(1 - 0.4)^2$$

$$W = \frac{100\mu \cdot 10\mu}{250\mu \cdot 0.6^2}$$

$$\mathbf{W = 11.1\,\mu m}$$

b)



c)

Determine the small-signal voltage gain

$$Av = \frac{2I_{DQ}R}{V_{SS} + V_T} = \frac{2(100\mu)(10k)}{(-1) + 0.4}$$

$$Av = -3.33\,V/V$$

d)

Determine the THD

$$THD = \frac{Vm}{4(V_{GS} - V_T)} = \frac{200\,mV}{4(1 - 0.4)}$$

$$THD = 0.0833 = 8.33\,\%$$

Problem 6

a)

Assuming the amplifier is ideal, $V_{IN} = V_N$

$V_N = V_{DS}$ of the mosfet

VGS of Mosfet: $V_{GS} = V_G - V_S = 1 - 0 = 1\,V$

For the Mosfet to be in saturation, $V_{DS} \geq V_{GS} - V_T$

Since $V_{DS} = V_C = V_{IN}$, thus $V_{DS} \leq 10\,mV$

The transistor is in the triode region; $V_{DS} < V_{GS} - V_T$

If $V_{xx} = 1\,V$, the transistor can be represented as a resistor by the channel resistance.

$$R_{ch} = \frac{1}{\mu C_{ox}\frac{W}{L}(V_{gs} - V_T)} = \frac{1}{250\mu\frac{12\mu}{1\mu}(1 - 0.4)}$$

$$R_{ch} = 555\,\Omega$$

$$Av = 1 + \frac{R_F}{R_{ch}} = \mathbf{1} + \frac{\mathbf{R_F}}{\mathbf{555\,\Omega}}\,\mathbf{V/V}$$

b)

From the R_{ch} equation, we notice that as V_{gs} increases, R_{ch} decreases; therefore, the gain of the non-inverting amplifier increases

Problem 7

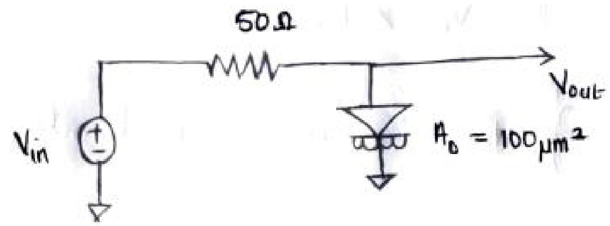
Problem 7

(a) No DC current goes through the capacitor

$\rightarrow I_D = I_B = J_S A\left(e^{\frac{V_D}{V_t}} - 1\right)$

$\rightarrow V_D = V_t \ln\left(\frac{I_B}{J_S A} + 1\right) = 0.026 \ln\left(\frac{1\times10^{-3}}{10^{-14}\times 100} + 1\right) = 0.539\,\text{V}$

(b)



(c) $\frac{(V_{out} - V_{in})}{50} + \frac{V_{out}}{R_D} = 0$

$\rightarrow V_{out}\left(\frac{1}{50} + \frac{1}{R_D}\right) = \frac{V_{in}}{50}$

$\rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{50\left(\frac{1}{50} + \frac{1}{R_D}\right)} = \frac{1}{1 + \frac{50}{R_D}}$

But $R_D = \frac{V_t}{I_{diode}} = \frac{0.026}{0.001} = 26\,\Omega$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{1+\frac{50}{26}} = 0.342$$

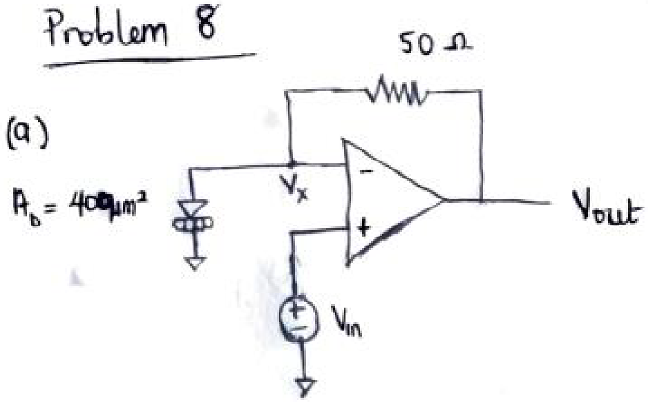
(d) $R_D = \frac{0.026}{0.005} = 5.2\,\Omega$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1+\frac{50}{5.2}} = 0.0942$$

Problem 8

Problem 8

(a)



(b) From the small signal equivalent circuit,

$$\frac{(V_x - V_{out})}{50} + \frac{V_x}{R_D} = 0$$

Assuming the amplifier is ideal, $V_x = V_{in}$

$$\rightarrow \quad V_{in}\left(\frac{1}{50} + \frac{1}{R_D}\right) = \frac{V_{out}}{50}$$

$$\rightarrow \quad \frac{V_{out}}{V_{in}} = 1 + \frac{50}{R_D}$$

$$R_D = \frac{V_t}{1mA} = \frac{0.026}{0.001} = 26\,\Omega$$

$$\rightarrow \quad \frac{V_{out}}{V_{in}} = 1 + \frac{50}{26} = 2.923$$

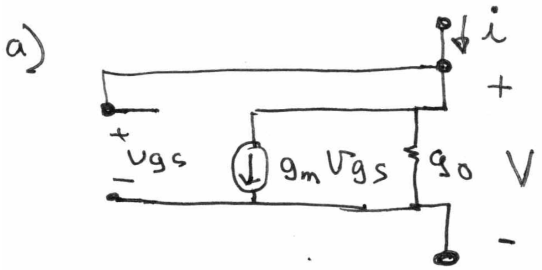
(c) $$\frac{V_{out}}{V_{in}} = 1 + \frac{50}{R_D}$$

$$R_D = \frac{0.026}{10 \times 10^{-3}} = 2.6$$

$$\Rightarrow \quad \frac{V_{out}}{V_{in}} = 1 + \frac{50}{2.6} = 20.23$$

Problem 9

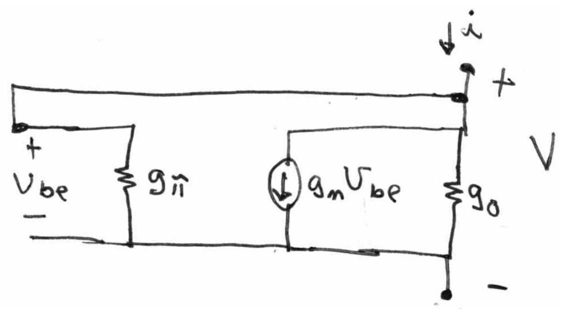
a)



$$i = g_m v_{gs} + g_o V$$
$$v_{gs} = V$$

$$\therefore \frac{V}{i} = \frac{1}{g_m + g_o} \simeq \frac{1}{g_m}$$

$$\text{Impedance} = \frac{1}{g_m}$$



$$i = g_m v_{be} + V g_o + g_\pi v_{be}$$
$$V = v_{be}$$

$$\therefore \frac{V}{i} = \frac{1}{g_m + g_\pi + g_o} \simeq \frac{1}{g_m}$$

$$\text{Impedance} = \frac{1}{g_m}$$

b) Small signal for both are resistors of value $\frac{1}{g_m}$

c)

$$R_{eq} = \frac{1}{\sqrt{\mu C_{ox} \frac{W}{L}} \sqrt{2 I_D}}$$

$$R_{eq} = \frac{1}{\sqrt{250\mu}\sqrt{2 \cdot 1m}} = 1.4\,k\Omega$$

$$R_{eq} = \frac{1}{\frac{I_{DQ}}{V_t}}$$

$$R_{eq} = \frac{25m}{1m} = 25\,\Omega$$

Problem 10

a)

Must have $V_{DS} \geq V_{GS} - V_T$

$$2\,V - I_D \cdot R_1 > (1 - 0.4)\,V$$

$$I_D = \mu_n C_{ox} \frac{W}{2 \cdot L} (V_{gs} - V_T)^2$$

$$I_D = 250\mu \frac{18\mu}{2 \cdot 2\mu} (1 - 0.4)^2 = 405\,\mu A$$

$$R_1 < \frac{2\,V - 0.6\,V}{I_D}$$

$$\mathbf{R_1 < 3.46\,k\Omega}$$

b)

$$Av = \mu_n C_{ox} \frac{W}{L} (V_{SS} + V_T) \cdot R$$

$$Av = 250\mu \frac{18\mu}{2\mu} (-1 + 0.4) \cdot 1.15k$$

$$Av = -1.556\, V/V$$

c)

$$V_{outQ} = V_{DD} - \mu_n C_{ox} \frac{W}{2L} (V_{SS} + V_T)^2 \cdot R$$

$$V_{outQ} = 2 - 250\mu \frac{18\mu}{2 \cdot 2\mu} (-1 + 0.4)^2 \cdot 1.15k$$

$$V_{outQ} = 1.533\, V$$

$$V_{out}(t) = V_{outQ} + Av \cdot V_m sin(\omega t)$$

$$V_{out}(t) = 1.533 + (-1.556) \cdot (1m \cdot sin(5000t + 75^\circ))$$

$$V_{out}(t) = 1.533 - 1.556m \cdot sin(5000t + 75^\circ))\, V$$