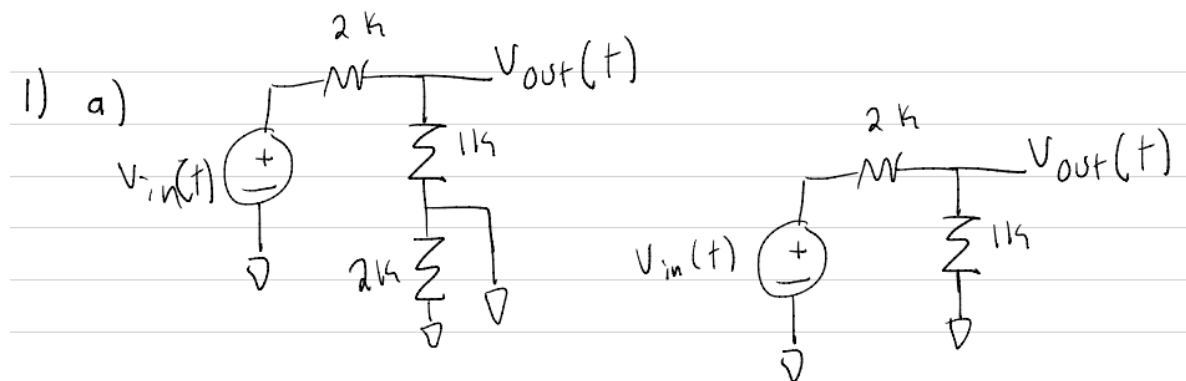


# Homework 9 Solutions

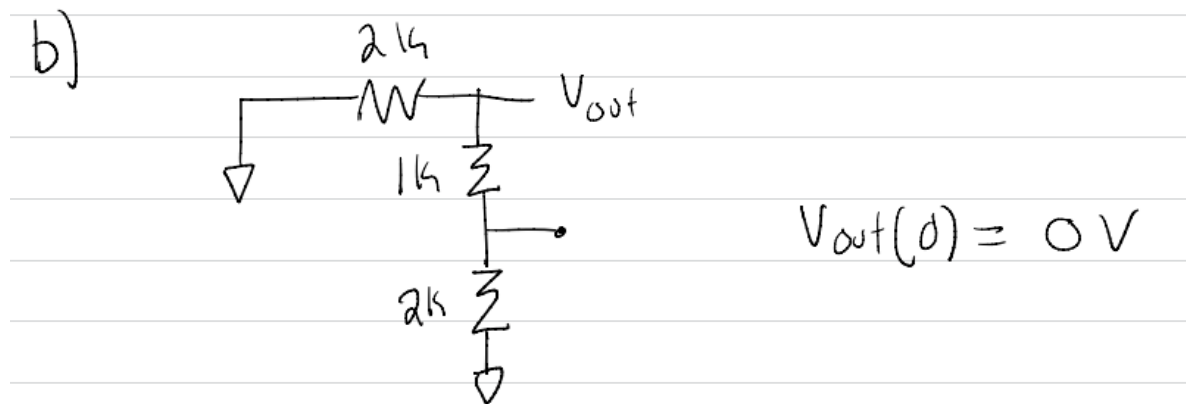
EE 330: FALL 2025

## Problem 1

a)



b)



c)

For small signal voltage gain:

$$A_v = \frac{1k}{1k + 2k} = \frac{1}{3}$$

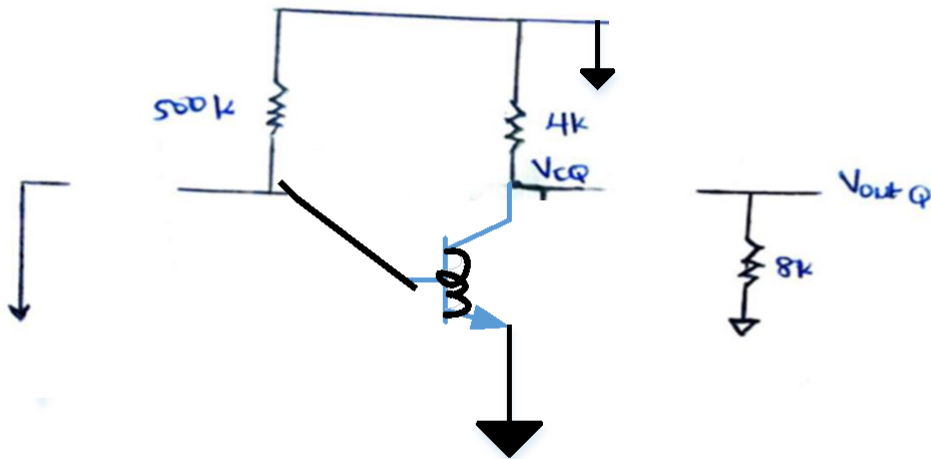
d)

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

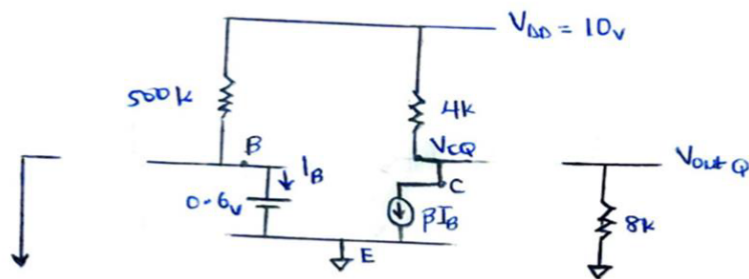
$$V_{out}(t) = \frac{2}{3} \sin(500t)$$

## Problem 2

(a)



(b)



- Assuming forward Active Region

$$\beta = 100$$

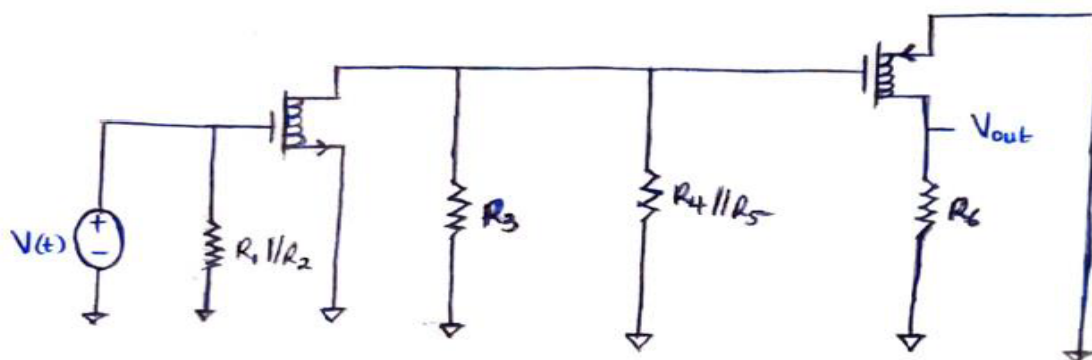
$$\rightarrow I_B = \frac{10 - 0.6}{500000} = 1.88 \times 10^{-5} \text{ A}$$

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

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

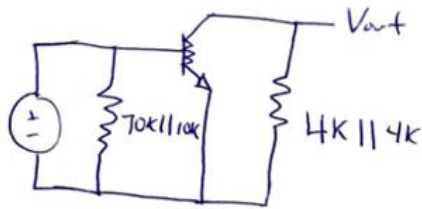
$$\rightarrow \text{Since } I_{RL} = 0, V_{outQ} = I_{RL} \cdot 8k = 0$$

### Problem 3



## Problem 4

(a) Draw the small signal equivalent circuit



(b) Determine  $V_C$  and  $V_{out}$

$$V_{out} = 0V$$

$$V_B = 3.859V$$

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

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

$$I_C = \beta I_B$$

$$\Rightarrow I_C = 100(16.114\mu A) = 1.611mA$$

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

$$I_B = 16.114\mu A$$

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

$$V_C = 25.55V$$

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  $\beta$  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

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

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

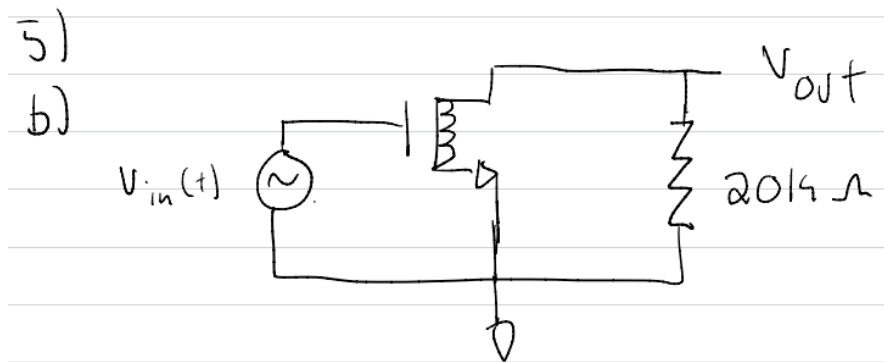
$$I_D = \mu_n C_{ox} \frac{W}{2 \cdot L} (V_{gs} - V_T)^2$$

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

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

$$W = 11.1 \mu m$$

b)



c)

Determine the small-signal voltage gain

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

$$A_v = -3.33 V/V$$

d)

Determine the THD

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

$$THD = 0.0833 = 8.33 \%$$

## Problem 6

a)

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

$V_N = V_{DS}$  of the mosfet

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

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

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

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

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

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

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

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

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

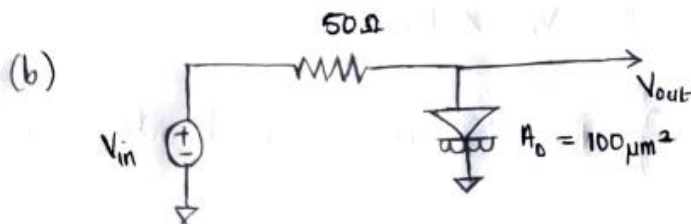
## Problem 7

### Problem 7

(a) No DC current goes through the capacitor

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

$$\rightarrow V_D = V_t \ln \left( \frac{I_B}{J_S A} + 1 \right) = 0.026 \ln \left( \frac{1 \times 10^{-3}}{10^{-14} \times 10^8} + 1 \right) = 0.539 \text{ V}$$



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

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

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

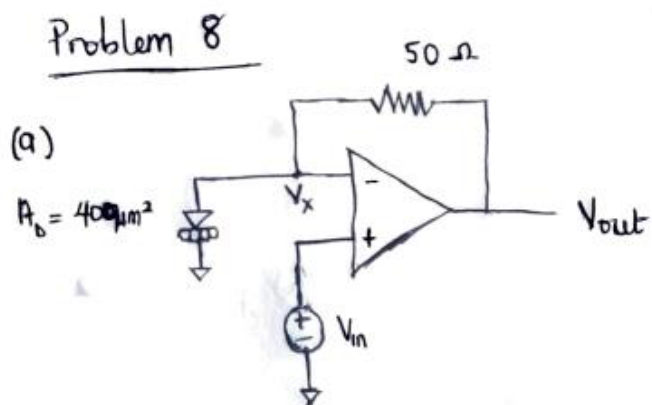
$$\text{But } R_o = \frac{V_t}{I_{\text{diode}}} = \frac{0.026}{0.001} = 26 \Omega$$

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

$$(d) \quad R_o = \frac{0.026}{0.005} = 5.2 \Omega$$

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

### Problem 8



(b) From the small signal equivalent circuit,

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

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

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

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

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

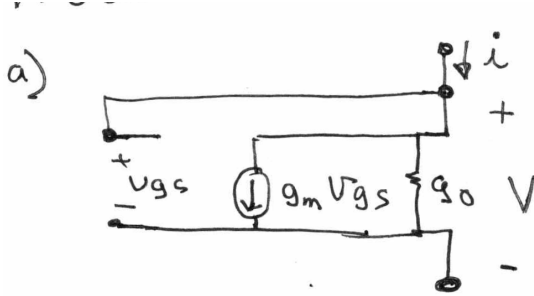
$$\rightarrow \frac{V_{out}}{V_{in}} = 1 + \frac{50}{26} = 2.923$$

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

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

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

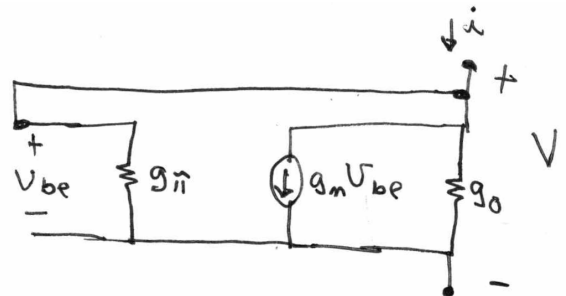
## Problem 9



$$\left. \begin{aligned} i &= g_m V_{gs} + g_o V \\ V_{gs} &= V \end{aligned} \right\}$$

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

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



$$\left. \begin{aligned} i &= g_m V_{be} + V g_o + g_{\pi} V_{be} \\ V &= V_{be} \end{aligned} \right\}$$

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

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

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

c)

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

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

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

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

## Problem 10

a)

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

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

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

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

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

$$R_1 < 3.46 \text{ k}\Omega$$

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)

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

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

$$V_{outQ} = 1.533 V$$

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

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

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