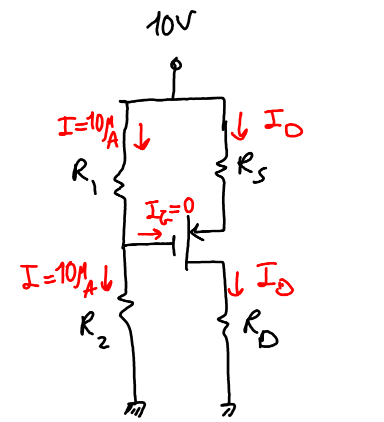
ECE 65 - HW #3 solutions



Problem 1:

$V_{SD} = V_{OV} + 1V$

$I_D = 1mA \longrightarrow \frac{1}{2} k_p V_{OV}^2 = 1mA \longrightarrow V_{OV} = 2V$

$V_{SD} = 3V \longrightarrow V_S - V_D = 3V$

$V_D = 3V \longrightarrow V_S - 3V = 3V \longrightarrow \boxed{V_S = 6V}$

$R_S = \frac{10V - V_S}{I_D} = \frac{10-6}{1mA} = 4k\Omega \quad \boxed{R_S = 4k\Omega}$

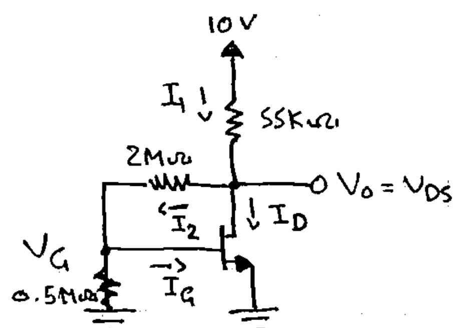
$R_D = \frac{V_D}{I_D} = \frac{3V}{1mA} = 3k\Omega \quad \boxed{R_D = 3k\Omega}$

$V_{OV} = 2V \longrightarrow V_S - V_G - |V_t| = 2V \longrightarrow \boxed{V_G = 3V}$

$R_1 = \frac{10-3}{10\mu A} = 700k\Omega, \quad R_2 = \frac{3V}{10\mu A} = 300k\Omega$

Problem 2:

Bias circuit:



$V_S = 0 \Rightarrow V_{GS} = V_G$

$I_G = 0$, so we have a voltage divider on the 0.5 and 2MΩ resistors

$\Rightarrow V_{DS} = 5V_G = 5V_{GS}$. KCL at D node: $I_1 = I_D + I_2$

$I_2 = \frac{V_G}{0.5M\Omega}$

KVL from D to S $\Rightarrow 10 = (55k\Omega) I_1 + V_{DS}$

$\Rightarrow 10 = (55k\Omega)\left(I_D + \frac{V_G}{0.5M\Omega}\right) + 5V_G \quad (I)$

MOSFET in saturation (since amplifier) $\Rightarrow I_D = \frac{1}{2} k_n V_{OV}^2$

$\Rightarrow I_D = (2.5\ mA/V^2)(V_G - 0.6)^2 \quad (II)$

Problem 2 continuation

Combine equations (I) and (II)

$$10 = (55\,k\Omega)\left((2.5\,mA/V^2)\left(V_G^2 - 1.2V_G + 0.36\ V^2\right) + \frac{V_G}{500\,k\Omega}\right) + 5V_G$$

$$\Rightarrow 10 = 137.5\,V_G^2 - 165\,V_G + 49.5 + \frac{11}{100}V_G + 5V_G$$

$$\Rightarrow 137.5\,V_G^2 - 159.89\,V_G + 39.5 = 0 \Rightarrow V_G = 0.36\,V \quad \text{or} \quad 0.81V$$

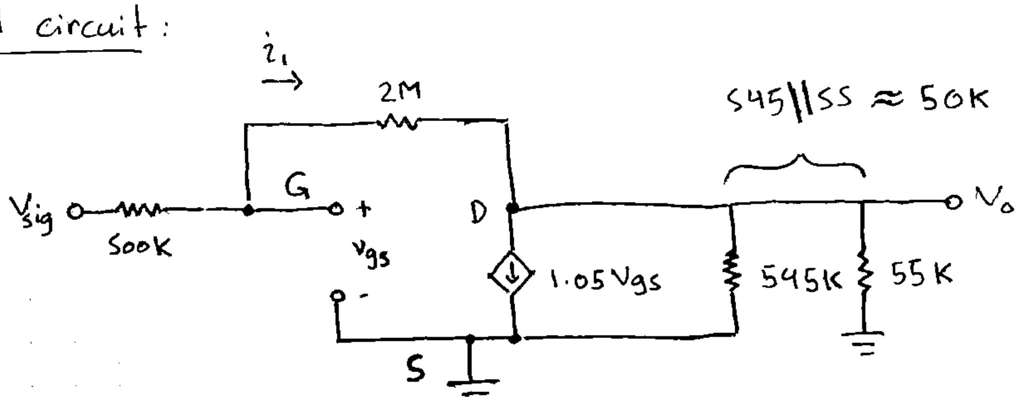
MOSFET on $\Rightarrow V_{ov} \geq 0 \Rightarrow V_{GS} = V_G \geq V_t = 0.6 \Rightarrow \boxed{V_{GS} = 0.81\,V}$

$$\Rightarrow \boxed{V_{ov} = 0.21\,V} \quad \Rightarrow \boxed{I_D} = (2.5\,mA/V^2)(0.21\,V)^2 = \boxed{0.11\,mA}$$

$$V_{DS} = 5V_G = \boxed{4.05V}$$

$$g_m = \frac{2I_D}{V_{ov}} = \frac{2(0.11\,mA)}{(0.21\,V)} = \boxed{1.05\,mA/V} \qquad \boxed{r_o} \approx \frac{V_A}{I_D} = \frac{60V}{0.11mA} \approx \boxed{545\,k\Omega}$$

Signal circuit:



$$i_1 = \frac{V_{sig} - V_o}{2.5M}$$

$$v_{gs} = V_g = V_{sig} - 500k\,i_1 = V_{sig} - \frac{1}{5}(V_{sig} - V_o) = \frac{4}{5}V_{sig} + \frac{1}{5}V_o$$

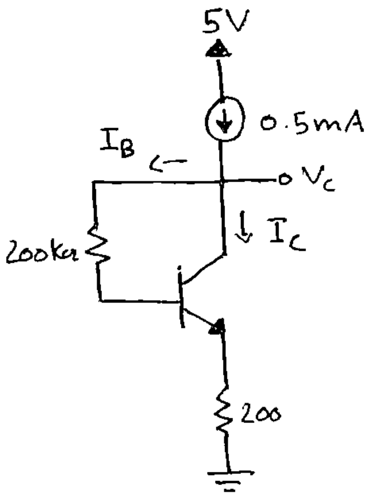
KCL at D: $$\underbrace{\frac{V_{sig} - V_o}{2.5M}}_{i_1} = \underset{\substack{mA/V \\ '' \\ 1/k\Omega}}{1.05}\Big(\underbrace{\tfrac{4}{5}V_{sig} + \tfrac{1}{5}V_o}_{v_{gs}}\Big) + \frac{V_o}{50K}$$

$$\Rightarrow V_{sig} - V_o = 2625\left(\tfrac{4}{5}V_{sig} + \tfrac{1}{5}V_o\right) + 50V_o$$

$$\Rightarrow V_o(-1 - 50 - 525) = 2100\,V_{sig} \Rightarrow \boxed{\frac{V_o}{V_{sig}} = -3.65\ V/V}$$

Problem 3:

Bias circuit:



KCL at C node $\Rightarrow$ $0.5\,mA = I_B + I_c$

Since amplifier, then BJT must be in saturation

$\Rightarrow I_B = \frac{I_c}{\beta} = 0.01\, I_c$

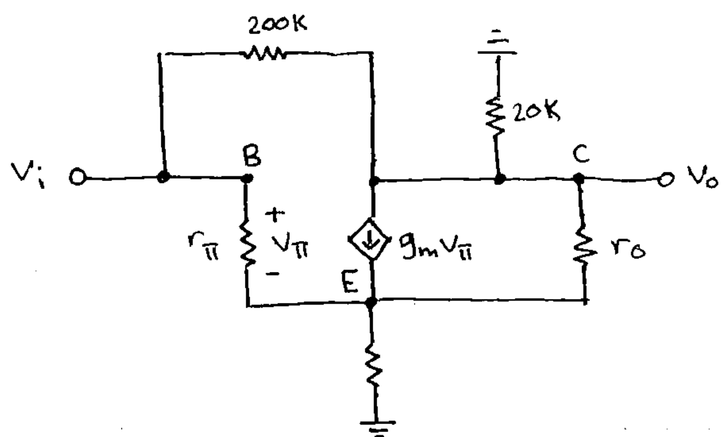
$\Rightarrow 0.5\,mA = 0.01 I_c + I_c \Rightarrow \boxed{I_c} = \frac{0.5\,mA}{1.01} = \boxed{0.495\,mA}$

KVL from V_c to E $\Rightarrow V_c = (200k\Omega) I_B + V_{BE} + 200\, I_E$

$\Rightarrow V_c = (200\,k\Omega)\left(\frac{0.495mA}{100}\right) + 0.7V + 200\,(0.5\,mA)$

$\Rightarrow V_c = 0.99V + 0.7V + 0.1V = \boxed{1.79\,V = V_c}$

Signal circuit:



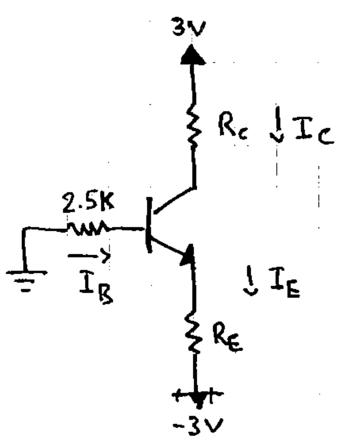
Current Source $\rightarrow$ Open

Voltage Source $\rightarrow$ ground

Capacitor $\rightarrow$ Short

Problem 4:

Bias Circuit:



a) B to E KVL $\Rightarrow (2.5k\Omega) I_B + V_{BE} + I_E R_E = 3$

Since in Active (amplifier) $V_{BE} = 0.7V$

and $I_B = \frac{I_E}{1+\beta} = \frac{I_E}{101}$

$\frac{2.5k\Omega}{101}(0.5\,mA) + 0.7V + (0.5\,mA) R_E = 3$

$\Rightarrow R_E = \frac{3 - 0.7 - 0.012}{0.5mA} \Rightarrow \boxed{R_E = 4.58\,k\Omega}$

Problem 4 continuation:

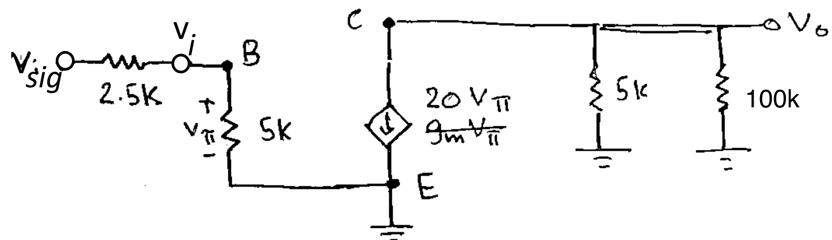
(b) $V_C = 0.5 \Rightarrow I_C R_C = 3V - 0.5V = 2.5V$

$$I_C = \frac{\beta}{\beta+1} I_E \approx I_E = 0.5mA \Rightarrow \boxed{R_C} = \frac{2.5V}{0.5mA} = \boxed{5k\Omega}$$

(c) $$g_m = \frac{I_C}{V_T} \approx \frac{0.5mA}{25mV} = \boxed{20\ mA/V}, \quad r_\pi = \frac{\beta}{g_m} = \frac{100}{20mA/V} = \boxed{5k\Omega}$$

$$V_A = \infty \Rightarrow \boxed{r_o = \infty}$$

Signal circuit:



Two resistor can be replaced with (5k || 100k)

(d) $R_o = R_C = \boxed{5K}$, $R_i = r_\pi = \boxed{5k\Omega}$

$$A_{v_o} = -g_m R_C = -(20mA/V)(5k\Omega) = \boxed{-100\ V/V}$$

(e) $$\frac{v_o}{v_{sig}} = \frac{R_L}{R_L+R_o} \cdot A_{v_o} \cdot \frac{R_i}{R_i + R_{sig}} = \frac{100k}{100k+5K}(-100\ V/V)\frac{5K}{5K+2.5K}$$

$$\Rightarrow \boxed{\frac{v_o}{v_{sig}} \approx -63.5\ V/V}$$