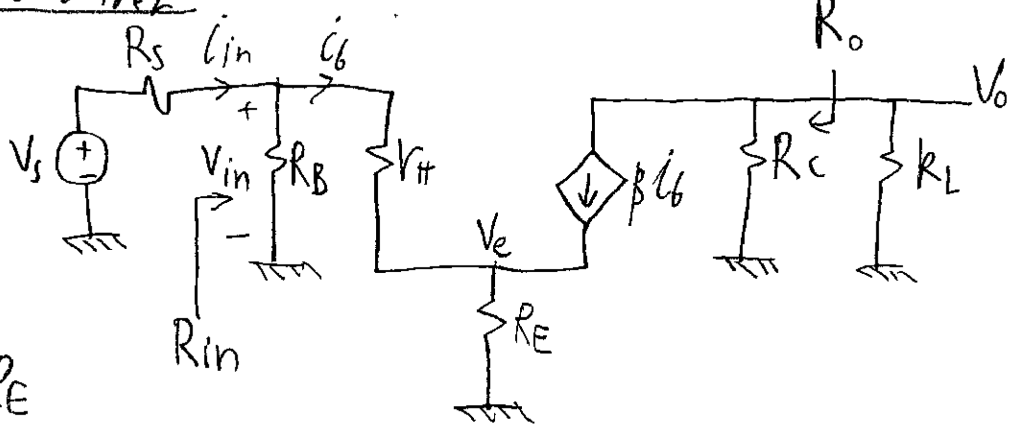
# EECE 2412 HW 8 Solution

## Problem 1

Part (a), (b), (c).

Small signal analysis "midband Freq".




**$\dfrac{V_o}{V_{in}}$**

$$V_o = -\beta i_b (R_L // R_C)$$

$$V_{in} = i_b r_\pi + i_b (\beta+1) R_E$$

$$i_b (r_\pi + (\beta+1) R_E) = V_{in}$$

$$i_b = \frac{V_{in}}{r_\pi + (\beta+1) R_E}$$

$$V_o = \frac{-\beta (R_L // R_C) V_{in}}{r_\pi + (\beta+1) R_E}$$

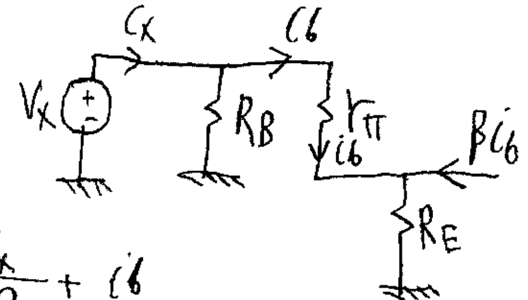
$$\therefore \boxed{\frac{V_o}{V_{in}} = \frac{-\beta (R_L // R_C)}{r_\pi + (\beta+1) R_E}}$$

$$\frac{V_o}{V_s} = \frac{V_o}{V_{in}} \times \frac{V_{in}}{V_s}$$

$$\frac{V_{in}}{V_s} = \frac{R_{in}}{R_{in} + R_s}$$

$$\boxed{\frac{V_o}{V_s} = \frac{-\beta (R_L // R_C)}{r_\pi + (\beta+1) R_E} \times \frac{R_{in}}{R_{in} + R_S}}$$

**$R_{in}$**




$$i_x = \frac{V_x}{R_B} + i_b$$

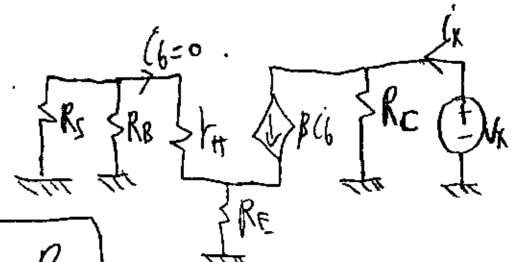
$$V_x = i_b r_\pi + i_b (\beta+1) R_E$$

$$i_b = \frac{V_x}{r_\pi + (\beta+1) R_E}$$

$$\therefore i_x = \frac{V_x}{R_B} + \frac{V_x}{r_\pi + (\beta+1) R_E}$$

$$\therefore \frac{V_x}{i_x} = \boxed{R_{in} = \frac{R_B (r_\pi + (\beta+1) R_E)}{r_\pi + R_B + (\beta+1) R_E}}$$

**$R_{out}$**




$$i_x = \frac{V_x}{R_C} + \beta \cancel{i_b} \to 0$$

$$\therefore \frac{V_x}{i_x} = \boxed{R_{out} = R_C}$$

## Problem 1 Cont.

DC Analysis:

$$15 - I_B R_B - 0.7 - (\beta+1) I_B R_E = 0$$

$$14.3 = \frac{I_C}{\beta}\left(R_B + (\beta+1) R_E\right)$$

$$I_C = \frac{14.3\beta}{R_B + (\beta+1) R_E} \leq 8\times10^{-3}$$

$$\therefore \boxed{R_B + 201 R_E \geq 357.5K\Omega} \quad (1)$$

$$|A_{VS}| = \left|\frac{V_o}{V_s}\right| = |-20|$$

$$\frac{V_o}{V_i} \times \frac{V_i}{V_s} = 20$$

$$\frac{\beta(R_C // R_L)}{r_\pi + (\beta+1) R_E} \times \frac{5000}{5000+500} = 20$$

$$\therefore \boxed{\frac{\beta(R_C // R_L)}{r_\pi + (\beta+1) R_E} \geq 22} \quad (2)$$

$$r_\pi = \frac{\beta V_T}{I_C} \rightarrow I_C = \frac{\beta V_T}{r_\pi} \leq 8\times10^{-3}$$

$$\therefore \boxed{r_\pi \geq 650\Omega} \quad (3)$$

$$R_{in} = \boxed{\frac{((\beta+1)R_E + r_\pi)R_B}{r_\pi + R_B + (\beta+1) R_E} \geq 5000} \quad (4)$$

Let $\boxed{R_C = 1000\Omega}$

$\therefore R_C // R_L = 937.5\Omega$

$\therefore$ From (2)

$$r_\pi + 201 R_E \leq 8.5227K\Omega$$

let $r_\pi = 700\Omega \rightarrow$ From (3)

$\therefore R_E \leq 39\Omega \rightarrow$ let $\boxed{R_E = 37.5\Omega}$

From (1)

$$R_B + 201 R_E \geq 357.5K\Omega$$

$\therefore R_B \geq 349K\Omega \rightarrow$ let $\boxed{R_B = 350K\Omega}$

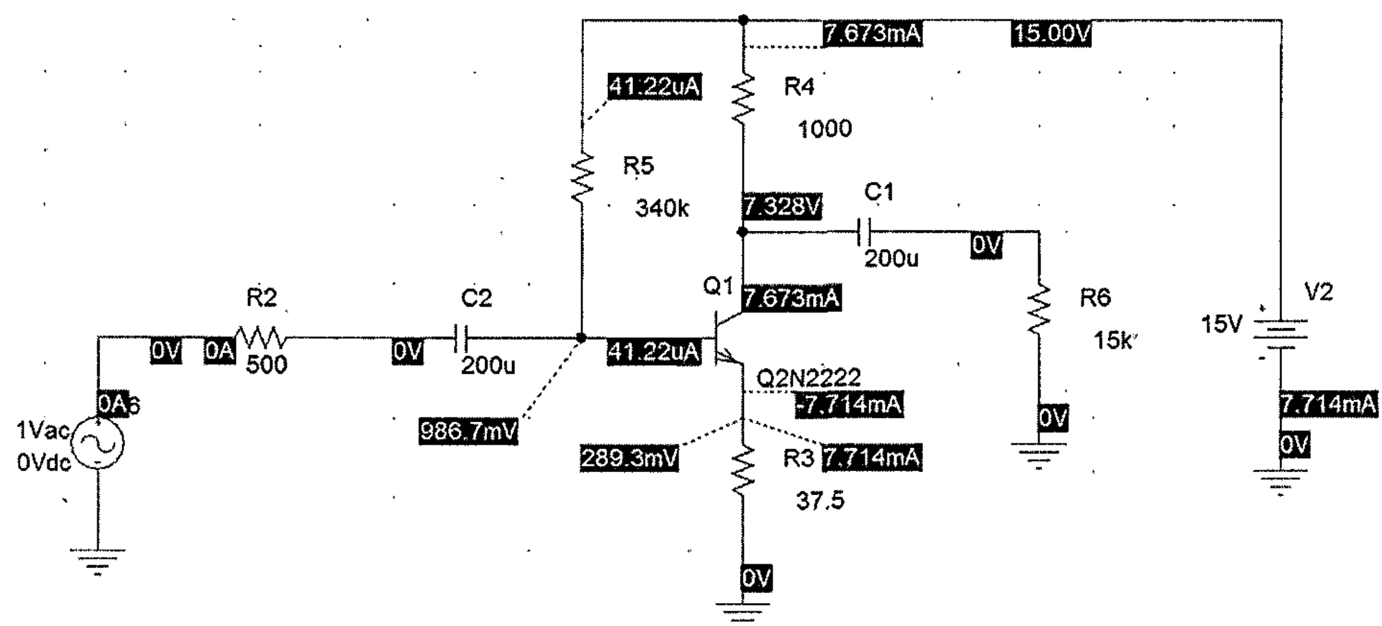
check $R_i$ from (4)

$R_i = 8.04K\Omega$ (satisfied).

P.3

Problem 1

Part d

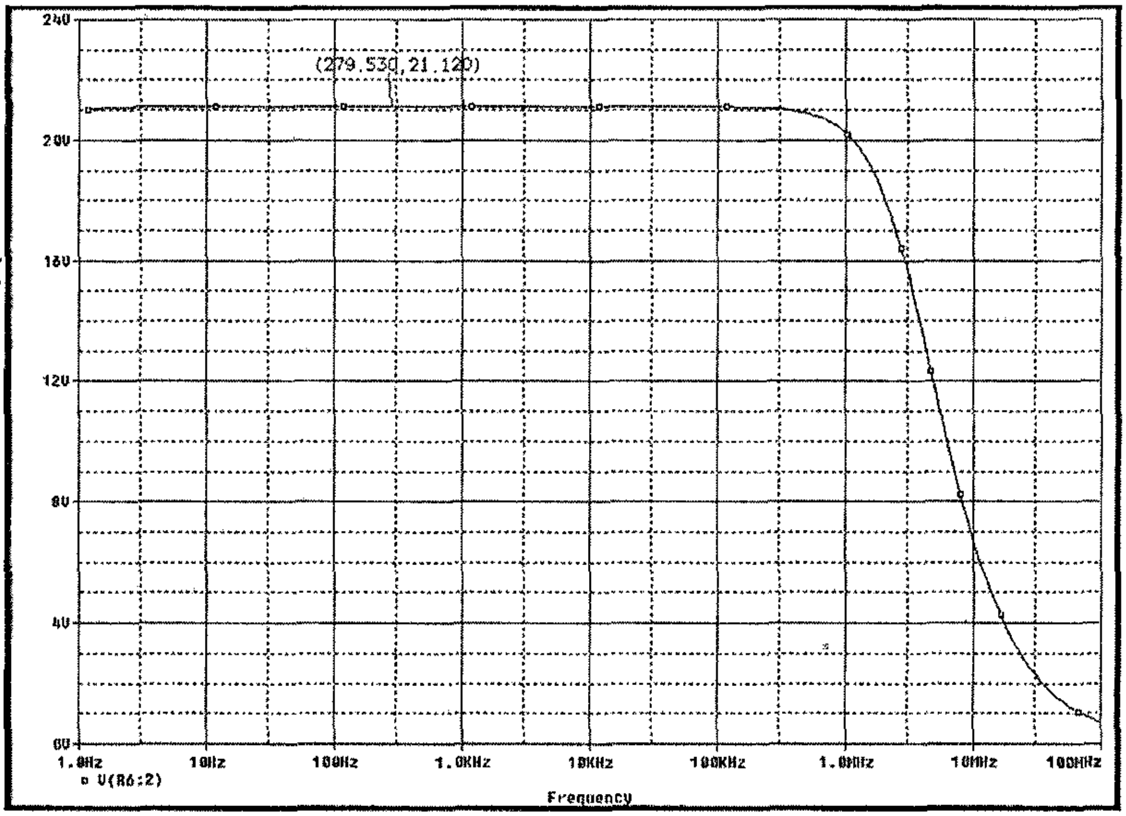



| | |
|---|---|
| NAME | Q_Q1 |
| MODEL | Q2N2222 |
| IB | 4.12E-05 |
| IC | 7.67E-03 |
| VBE | 6.97E-01 |
| VBC | -6.34E+00 |
| VCE | 7.04E+00 |
| BETADC | 1.86E+02 |
| GM | 2.90E-01 |
| RPI | 6.77E+02 |
| RX | 1.00E+01 |
| RO | 1.05E+04 |
| CBE | 1.57E-10 |
| CBC | 3.39E-12 |
| CJS | 0.00E+00 |
| BETAAC | 1.96E+02 |
| CBX/CBX2 | 0.00E+00 |
| FT/FT2 | 2.87E+08 |

(P.4)

Part e

the Avs From AC simulation is 21.12 ≃ 20 V/V

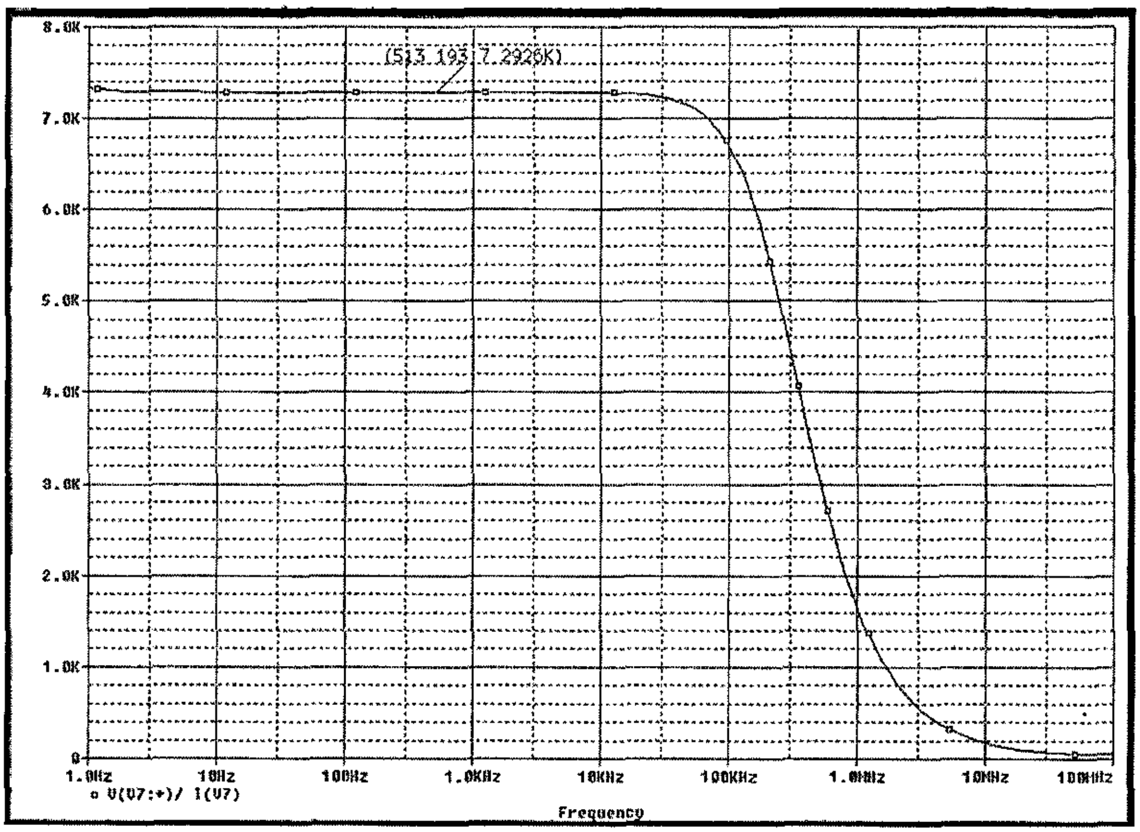



Part f

Rin (Simulated) = 7.2926 KΩ

Rin (calculated) = 8.04 KΩ

$Rin_{Sim} < Rin_{calc}$



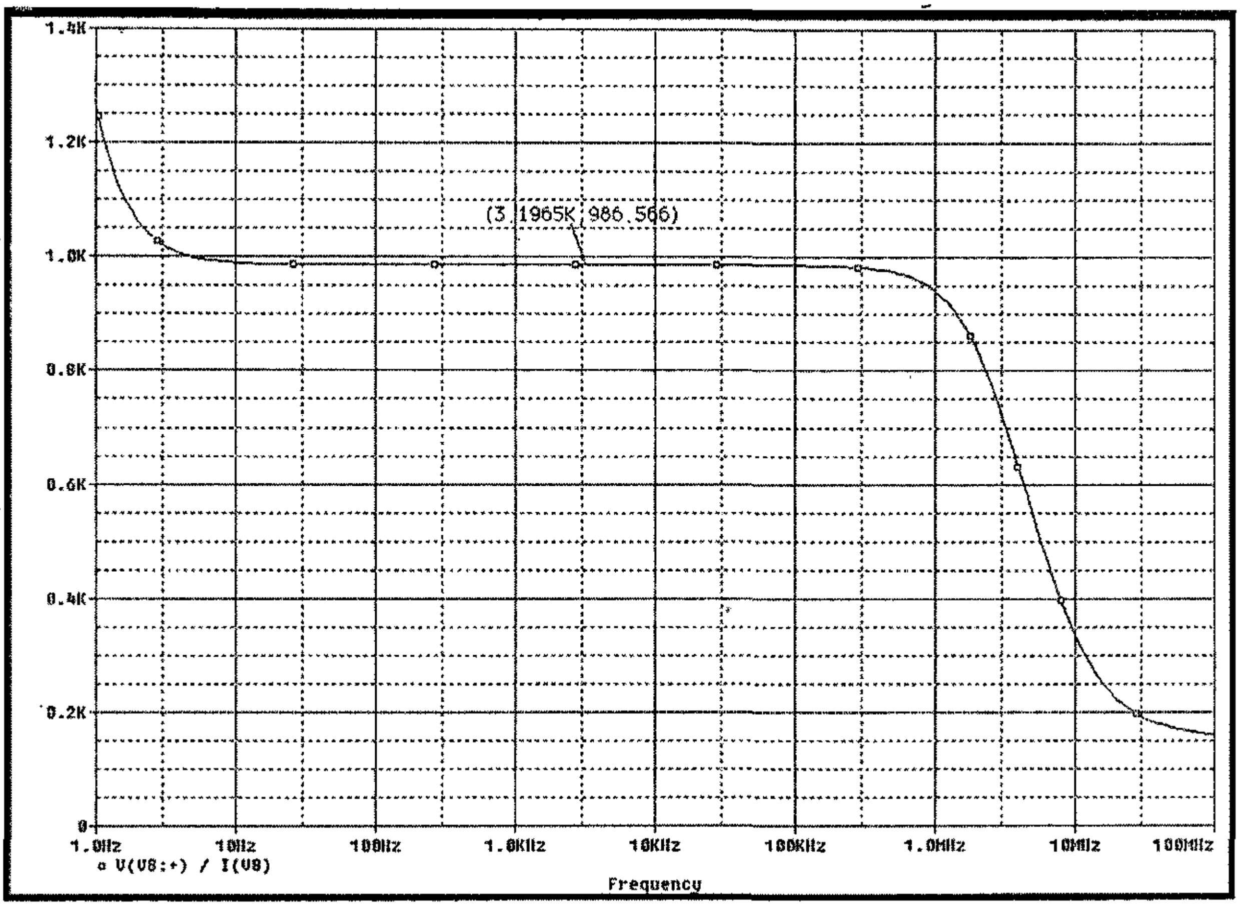
(P.5)

Part g

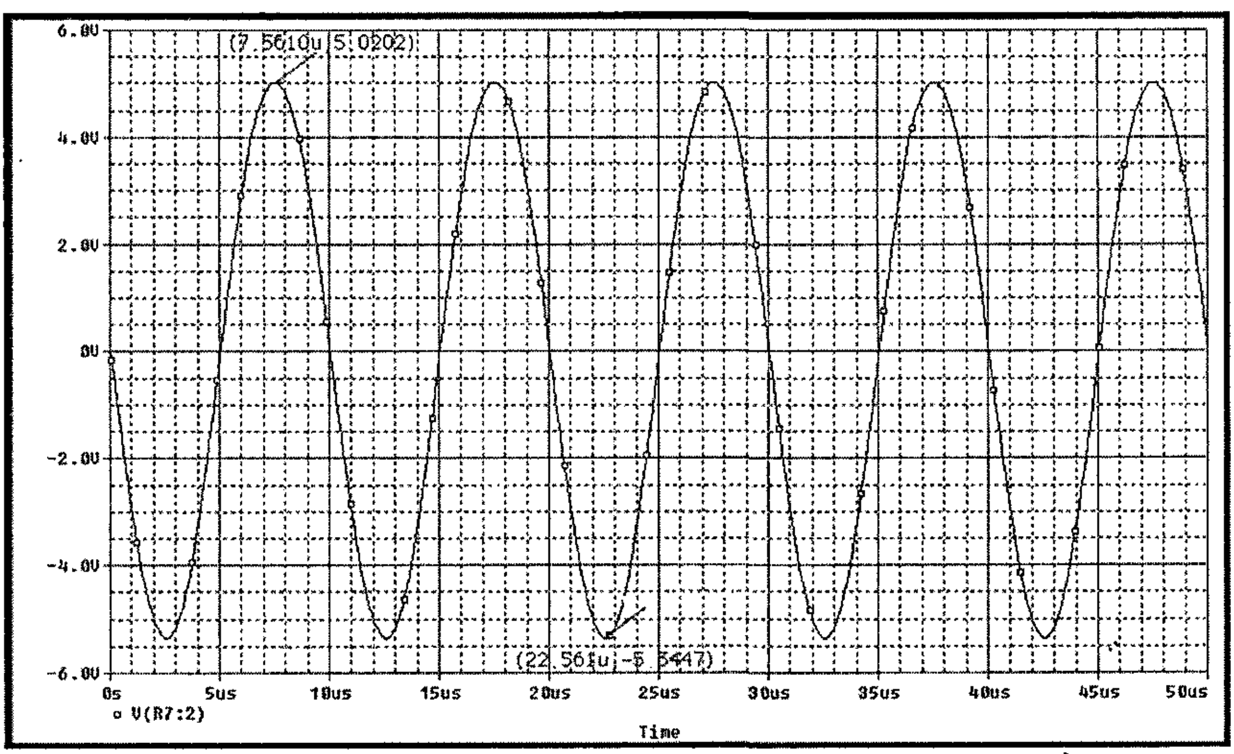
$R_{out}$ (simulated) $= 986.566\,\Omega$

$R_{out}$ (calculated) $= 937.5\,\Omega$

$\therefore R_{oSim} > R_{oCalc.}$




Part h




from simulation: $\text{gain} = \dfrac{5.0202 - (-5.3447)}{250\text{mV} \times 2} = 20.7298\,\text{V/V}$

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**Problem 2** $V_{to} = 1V$, $KP = 50\mu A/V^2$, $W = 50\mu m$, $L = 5\mu m$ $(\lambda = 0)$

a) $V_{GS} = 4V$, $V_{DS} = 10V$:

$$\left.\begin{array}{l} V_{GS} = 4V \geq 1V = V_{to} \\ V_{GS} - V_{to} = 4V - 1V = 3V \leq V_{DS} = 10V \end{array}\right\}$$ The NMOS is in $\boxed{\text{saturation}}$

$$K = \left(\frac{W}{L}\right)\cdot\left(\frac{KP}{2}\right) = \left(\frac{50\mu m}{5\mu m}\right)\cdot\left(\frac{50\mu A/V^2}{2}\right) = 250\ \frac{\mu A}{V^2}$$

in saturation: (with $\lambda = 0$) $I_D = K(V_{GS} - V_{to})^2 = \left(250\times10^{-6}\frac{A}{V^2}\right)(4V - 1V)^2$

$$\boxed{I_D = 2.25\,mA}$$

b) $V_{GS} = 4V$, $V_{DS} = 2V$:

$$\left.\begin{array}{l} V_{GS} = 4V \geq 1V = V_{to} \\ V_{GS} - V_{to} = 4V - 1V = 3V > 2V = V_{DS} \end{array}\right\}$$ The NMOS is in the $\boxed{\text{triode region}}$

in triode: (with $\lambda = 0$) $I_D = K\cdot\left[2\cdot(V_{GS} - V_{to})\cdot V_{DS} - V_{DS}^2\right]$

$$I_D = \left(250\times10^{-6}\frac{A}{V^2}\right)\cdot\left[2\cdot(4V - 1V)\cdot 2V - (2V)^2\right]$$

$$\boxed{I_D = 2\,mA}$$

c) $V_{GS} = 0V$, $V_{DS} = 10V$:

$V_{GS} = 0V < 1V = V_{to}$ $\rightarrow$ The NMOS is in $\boxed{\text{cutoff.}}$

$\hookrightarrow$ $\boxed{I_D = 0}$

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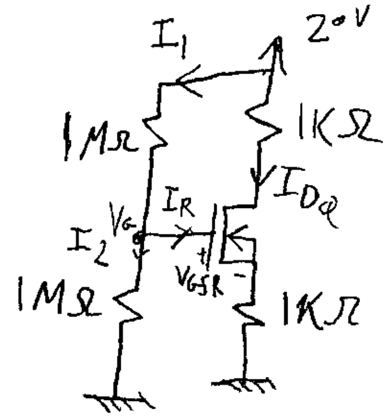
Problem 3




a) KVL: (Assume Saturation)

$20 - I_1 \times 1M\Omega - I_2 \times 1M\Omega = 0$

$I_2 + I_R = I_1$, $I_R = 0$

$\therefore I_1 = I_2$

$\therefore I_1 = \frac{20}{2M} = 10\mu A$

$\therefore V_G = 20 - 10\mu A \times 1M\Omega = 10^V$

$V_G - V_{GSR} - I_{DQ} \times 1K\Omega = 0$

$V_G - V_{GSR} - K(V_{GSR} - V_{t0})^2(1 + \lambda V_{DS}) \times 1K\Omega = 0$ ①

$\therefore V_{GSR} = 6V \rightarrow \boxed{I_{DQ} = K(V_{GSR} - V_{t0})^2(1 + \lambda V_{DS}) = 4mA}$

$V_{DS} = 20 - I_{DQ} \times 2K\Omega = 12V > V_{GSR} - V_{t0} = 2V \rightarrow \therefore$ Saturation

b) Resolving ① $\rightarrow V_{GSR} = 3.76556V$

$\therefore \boxed{I_{DQ} = K(V_{GSR} - V_{t0})^2(1 + \lambda V_{DS}) = 6.23444\ mA}$

$V_{DS} = 20 - I_{DQ} \times 2K\Omega = 7.5313\ V > V_{GSR} - V_{t0} = 1.76556V$

$\rightarrow \therefore$ Saturation