**Problem 1** (35 points)

Use: $V_T = 1V$

$k_n (W/L) = 2A/V^2$

$q = 0$ for all transistors

The 0.25A current source is not ideal and may have a voltage drop across it.

All caps are large.

Solve the circuit for the DC values of:
(a) $V_{D2}$
(b) $V_{GS1}$, transistor M1's Q-pt.
(c) Is

\[ V_{G1} = 10V \]

**Assume Sat:**

\[ I_{D1} = \frac{1}{2} k_n (W/L) (V_{GS1} - V_T)^2 \]

\[ 0.25A = \frac{1}{2} (2) (10 - V_{S1} - 1)^2 \]

\[ \sqrt{0.25} = 0.5 \]

\[ V_{S1} = 9.5 \]

If $V_{S1} = 8.5$ then $V_{GS1} = \frac{10 - 8.5}{1} = 1.5$

If $V_{S1} = 9.5$ then $V_{GS1} = 10 - 9.5 = 0.5 < V_T$ (off)

\[ V_{D2} = 10 - I_S (2) \]

\[ V_{D2} = 10 - 1(2) = 8V \]

\[ V_{DS2} = 8 - 1 = 7V \geq 1 \] \hspace{1cm} (off)

**Saturation**

\[ V_{G2} = 0.25 (12) = 3V \]

\[ V_{S2} = I_S (12) \]

\[ I_{D2} = \frac{1}{2} k_n (W/L) (3 - I_S - V_T)^2 \]

\[ I_{D2} = I_S = \frac{1}{2} (2) (2 - I_S)^2 \]

\[ I_S = (4 - 4I_S + I_S^2) \]

\[ I_S^2 - 5I_S + 4 = 0 \Rightarrow I_S = \frac{5 \pm \sqrt{25 - 4(4)}}{2} = \frac{5 \pm 3}{2} = 4A, 1A \]

If $I_S = 4A$: $V_{S2} = 4V \Rightarrow V_{GS2} = 3 - 4 = -1 < V_T$ (off)

If $I_S = 1A$: $V_{S2} = 1V \Rightarrow V_{GS2} = 3 - 1 = 2 > V_T$ (on)
Problem 2 (10 points)

\( v_{\text{sig}} = 0.01 \sin(\omega t) \). Does this circuit operate as an AC amplifier? If so, what is the gain, \( \frac{V_o}{V_{\text{sig}}} \), of the following circuit in terms of VDD?

No, the gate is floating in the DC operation. The transistor is therefore not on or saturated and cannot amplify \( v_{\text{sig}} \).
Problem 3 (35 points)

Use: \( V_i = 1 \text{V} \)
\( k_0 = 1 \text{mA/V}^2 \)
\( V_{\text{sig}} \) is an AC source
Transistor 1 has DC values: \( V_{\text{G}} = 5 \text{V}, I_D = 8 \text{mA} \)
Transistor 2 has DC values: \( V_{\text{G}} = 5 \text{V}, I_D = 8 \text{mA} \)
Transistor 3 has DC values: \( V_{\text{G}} = 3 \text{V}, I_D = 2 \text{mA} \)
\( \lambda = 0 \) (for all transistors)

For the following hybrid-\( \pi \) equivalent circuit, find the following values:

(a) \( R_i \) (input resistance - ignore the 50ohm and \( V_{\text{sig}} \))

(b) \( R_{out} \) (output resistance)

(c) gain, \( \frac{V_o}{V_{\text{sig}}} \)

\( g_{m1} = \frac{kL}{W/L} \left(V_{GS1} - V_T\right) = \sqrt{\frac{2kT}{Li_d}} = 4 \text{m} \)
\( g_{m2} = \frac{kL}{W/L} \left(V_{GS2} - V_T\right) = \sqrt{\frac{2kT}{Li_d}} = 4 \text{m} \)
\( g_{m3} = 1 m (3 - 1) \approx \sqrt{2(1m)(2m)} = 2 m \)
\( r_o = \infty \)

\[ R_i = \frac{2}{g_{m2}} = 250 \Omega \]

\[ R_{out} = 20K || 20K = 10K \]

\[ R_i = \frac{4v}{g_{m2}} = \frac{4v}{2m} = 2K \]

\[ R_{gs2} = 0 - g_{m2} V_{gs2} (10k - 1v) \]

\[ V_{gsa} = \frac{1}{1 + g_{m2}(150)} = -V_{gsig} \]

\[ V_{gsa} = -g_{m2} V_{gsa} \cdot 1K = 4m(1k) \cdot V_{gsa} \]

\[ V_{gsa} = \frac{-V_{gsig}}{1 + 4m(150)} = -V_{gsig} \]

\[ 1K = \frac{1}{1.6} \]

\[ V_{gs3} = 4m(1k)(-V_{gsig}) = -2.5V_{gsig} \]

\[ \frac{V_o}{V_{gsig}} = -2.5 (-2m)(10k) = 50 \text{V/V} \]
**Problem 4** (20 points)

For the circuit shown below, draw the AC small-signal equivalent circuit (use hybrid-π or model T). Make sure that everything is labeled in terms of the transistor number (e.g., $g_{m1}$, $v_{m2}$, etc.). $\lambda = 0$ for all transistors. $v_{sig}$ is an AC source.