

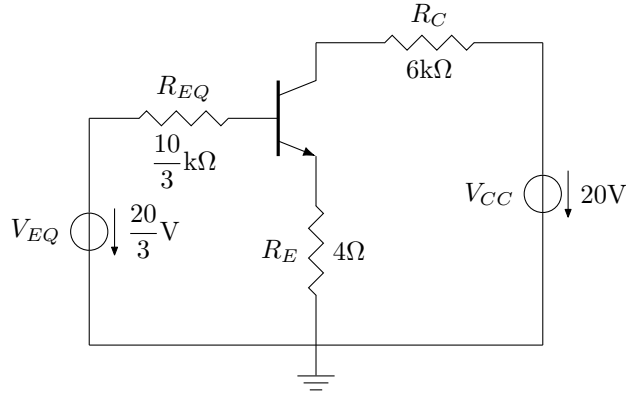
VE311 Homework 4

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Problem 1.

- (a) C_1 is a coupling capacitors which couples v_1 , C_2 is a by-pass capacitor, C_3 is a coupling capacitors which couples v_0 .
- (b) The signal voltage at the emitter of Q_1 is zero.
- (c) It is a PNP BJT transistor.

Problem 2.



Suppose $V_{BE} = 0.7V$,

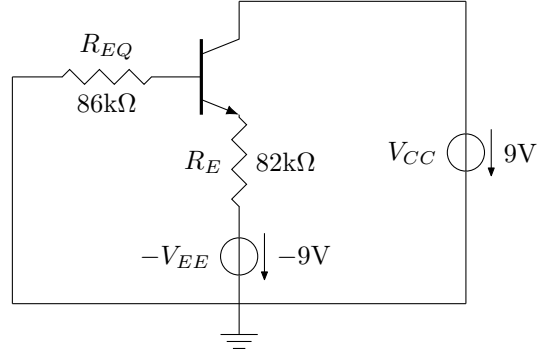
$$I_C = \frac{V_{EQ} - V_{BE}}{\frac{R_{EQ}}{\beta_F} + \frac{\beta_F + 1}{\beta_F} R_E} = \frac{20/3 \text{ V} - 0.7 \text{ V}}{\frac{10/3 \text{ k}\Omega}{75} + \frac{75 + 1}{75} \cdot 4 \text{ k}\Omega} \approx 1.456 \text{ mA}$$

$$I_E = \frac{V_{EQ} - V_{BE}}{\frac{R_{EQ}}{\beta_F + 1} + R_E} = \frac{20/3 \text{ V} - 0.7 \text{ V}}{\frac{10/3 \text{ k}\Omega}{75 + 1} + 4 \text{ k}\Omega} \approx 1.475 \text{ mA}$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E = 20 \text{ V} - 1.456 \text{ mA} \cdot 6 \text{ k}\Omega - 1.475 \text{ mA} \cdot 4 \text{ k}\Omega = 5.364 \text{ V}$$

So the Q point is (1.456 mA, 5.364 V).

Problem 3.



Suppose $V_{BE} = 0.7V$,

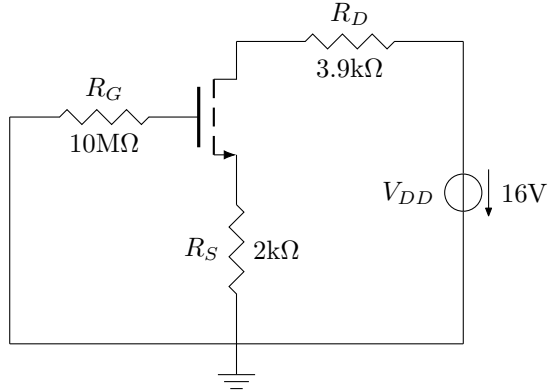
$$I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{9V - 0.7V}{82k\Omega} \approx 101 \mu A$$

$$I_C = \frac{\beta_F}{\beta_F + 1} I_E = \frac{100}{100 + 1} \cdot 100 \mu A$$

$$V_{CE} = V_{CC} - I_C R_C - (-V_{BE}) = 9V + 0.7V = 9.7V$$

So the Q point is $(100 \mu A, 9.7V)$.

Problem 4.



According to the equations,

$$I_D = \frac{K_n}{2} (V_{GS} - V_{TN})^2$$

$$V_{GS} + I_D R_s = 0$$

We can get

$$V_{GS} + \frac{K_n R_s}{2} (V_{GS} - V_{TN})^2 = 0$$

$$V_{GS} = V_{TN} = \frac{1}{K_n R_s} \left(\sqrt{1 - 2K_n R_s V_{TN}} - 1 \right)$$

$$\begin{aligned}
I_D &= \frac{1}{2K_n R_s^2} \left(\sqrt{1 - 2K_n R_s V_{TN}} - 1 \right)^2 \\
&= \frac{1}{2 \cdot 400 \mu\text{A}/\text{V}^2 \cdot (2 \text{ k}\Omega)^2} \left(\sqrt{1 - 2 \cdot 400 \mu\text{A}/\text{V}^2 \cdot 2 \text{ k}\Omega \cdot -5 \text{ V}} - 1 \right)^2 \\
&= 1.25 \text{ mA}
\end{aligned}$$

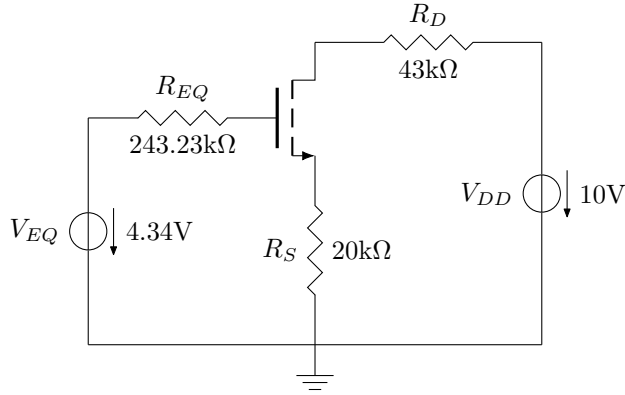
$$V_{DS} = V_{DD} - I_D(R_D + R_S) = 16 \text{ V} - 1.25 \text{ mA} \cdot (3.9 \text{ k}\Omega + 2 \text{ k}\Omega) = 8.625 \text{ V}$$

$$\begin{aligned}
V_{GS} - V_{TN} &= \frac{1}{K_n R_s} \left(\sqrt{1 - 2K_n R_s V_{TN}} - 1 \right) \\
&= \frac{1}{2 \cdot 400 \mu\text{A}/\text{V}^2 \cdot 2 \text{ k}\Omega} \left(\sqrt{1 - 2 \cdot 400 \mu\text{A}/\text{V}^2 \cdot 2 \text{ k}\Omega \cdot -5 \text{ V}} - 1 \right) \\
&= 1.25 \text{ V} < V_{DS}
\end{aligned}$$

So the Q point is (1.25 mA, 8.625 V), and it is in the saturated region.

Problem 5.

First, we draw the dc equivalent circuit:



According to the equations,

$$\begin{aligned}
I_D &= \frac{K_n}{2} (V_{GS} - V_{TN})^2 \\
V_{GS} + I_D R_s &= V_{EQ}
\end{aligned}$$

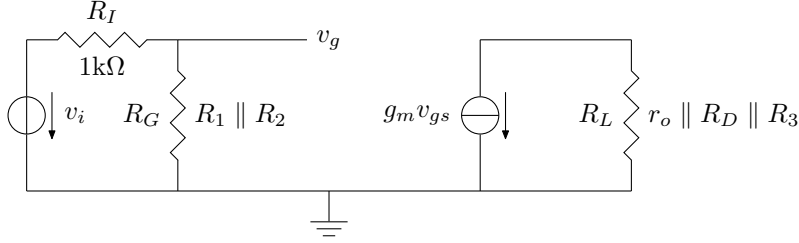
We can get

$$\begin{aligned}
V_{GS} + \frac{K_n R_s}{2} (V_{GS} - V_{TN})^2 &= V_{EQ} \\
V_{GS} &= V_{TN} + \frac{1}{K_n R_s} \left(\sqrt{1 + 2K_n R_s (V_{EQ} - V_{TN})} - 1 \right) \\
I_D &= \frac{1}{2K_n R_s^2} \left(\sqrt{1 + 2K_n R_s (V_{EQ} - V_{TN})} - 1 \right)^2 \\
&= \frac{1}{2 \cdot 0.5 \text{ mA}/\text{V}^2 \cdot (20 \text{ k}\Omega)^2} \left(\sqrt{1 + 2 \cdot 0.5 \text{ mA}/\text{V}^2 \cdot 20 \text{ k}\Omega \cdot (4.34 \text{ V} - 1 \text{ V})} - 1 \right)^2 \\
&\approx 131 \mu\text{A}
\end{aligned}$$

$$V_{DS} = V_{DD} - I_D(R_D + R_S) = 10 \text{ V} - 131 \mu\text{A} \cdot (43 \text{ k}\Omega + 20 \text{ k}\Omega) \approx 1.75 \text{ V}$$

$$\begin{aligned} V_{GS} - V_{TN} &= \frac{1}{K_n R_s} \left(\sqrt{1 + 2K_n R_s (V_{EQ} - V_{TN})} - 1 \right) \\ &= \frac{1}{0.5 \text{ mA/V}^2 \cdot 20 \text{ k}\Omega} \left(\sqrt{1 + 2 \cdot 0.5 \text{ mA/V}^2 \cdot 20 \text{ k}\Omega \cdot (4.34 \text{ V} - 1 \text{ V})} - 1 \right) \\ &\approx 0.717 \text{ V} < V_{DS} \end{aligned}$$

So the Q point is $(131 \mu\text{A}, 1.75 \text{ V})$, and it is in the saturated region. Then we can draw the ac equivalent circuit:



$$g_m = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{2 \cdot 131 \mu\text{A}}{0.717 \text{ V}} \approx 3.65 \times 10^{-4} \Omega^{-1}$$

$$r_o = \frac{1}{\frac{1}{\lambda} + V_{DS}} = \frac{1}{\frac{0.0133 \text{ V}^{-1}}{131 \mu\text{A}} + 1.75 \text{ V}} \approx 587 \text{ k}\Omega$$

$$R_G = R_1 \parallel R_2 \approx 243.23 \text{ k}\Omega$$

$$R_L = r_o \parallel R_D \parallel R_3 \approx 28.6 \text{ k}\Omega$$

The voltage gain is

$$\begin{aligned} A_v^{CS} &= -g_m R_L \left(\frac{R_G}{R_G + R_I} \right) \\ &= -3.65 \times 10^{-4} \Omega^{-1} \cdot 28.6 \text{ k}\Omega \cdot \left(\frac{243.23 \text{ k}\Omega}{243.23 \text{ k}\Omega + 1 \text{ k}\Omega} \right) \\ &\approx -10.4 \text{ dB} \end{aligned}$$

Problem 6.

(a)

$$\begin{aligned} g_d &= \frac{I_S}{V_T} \exp\left(\frac{V_D}{V_T}\right) = \frac{8 \text{ fA}}{0.025 \text{ V}} \exp\left(\frac{0.6 \text{ V}}{0.025 \text{ V}}\right) \approx 8.48 \times 10^{-3} \Omega^{-1} \\ r_d &= \frac{1}{g_d} = \frac{1}{8.48 \times 10^{-3} \Omega^{-1}} \approx 118 \Omega \end{aligned}$$

(b)

$$\begin{aligned} g_d &= \frac{I_S}{V_T} \exp\left(\frac{V_D}{V_T}\right) = \frac{8 \text{ fA}}{0.025 \text{ V}} \exp\left(\frac{0 \text{ V}}{0.025 \text{ V}}\right) \approx 3.2 \times 10^{-13} \Omega^{-1} \\ r_d &= \frac{1}{g_d} = \frac{1}{3.2 \times 10^{-13} \Omega^{-1}} \approx 3.125 \times 10^{12} \Omega \end{aligned}$$

(c)

$$g_d = \frac{I_S}{V_T} \exp\left(\frac{V_D}{V_T}\right) = \frac{1}{r_d}$$
$$V_D = V_T \ln\left(\frac{V_T}{I_S r_d}\right) = 0.025 \text{ V} \ln\left(\frac{0.025 \text{ V}}{8 \text{ fA} \cdot 10^{12} \Omega}\right) \approx 2.85 \times 10^{-2} \text{ V}$$

Problem 7.

$$r_\pi = \frac{\beta_o V_T}{I_C} = \frac{100 \cdot 0.025 \text{ V}}{40 \mu\text{A}} = 62.5 \text{ k}\Omega$$
$$g_m = \frac{I_C}{V_T} = \frac{40 \mu\text{A}}{0.025} = 1.6 \times 10^{-3} \Omega^{-1}$$
$$r_o = \frac{1}{g_o} = \frac{V_A + V_{CE}}{I_C} = \frac{75 \text{ V} + 10 \text{ V}}{40 \mu\text{A}} = 2125 \text{ k}\Omega$$
$$R_L = r_o \parallel R_C \parallel R_3 \approx 48.85 \text{ k}\Omega$$

The input resistance is

$$R_B \parallel r_\pi \approx 38.46 \text{ k}\Omega$$

The voltage gain is

$$A_v^{CE} = -g_m R_L \left[\frac{R_B \parallel r_\pi}{R_I + (R_B \parallel r_\pi)} \right]$$
$$= -1.6 \times 10^{-3} \Omega^{-1} \cdot 48.85 \text{ k}\Omega \cdot \left(\frac{38.46 \text{ k}\Omega}{750 \Omega + 38.46 \text{ k}\Omega} \right)$$
$$\approx 76.7 \text{ dB}$$