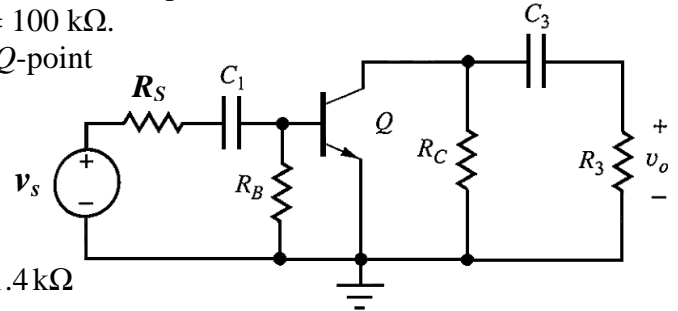


Homework 4 Solutions

Problem 1 (Text 13.60)Compute A_{V_s}

The ac equivalent circuit for an amplifier is shown. Assume the capacitors have infinite value and that $R_S = 750 \Omega$, $R_B = 100 \text{ k}\Omega$, $R_C = 100 \text{ k}\Omega$, and $R_3 = 100 \text{ k}\Omega$. Calculate the voltage gain of the amplifier if the BJT Q -point is $\{50 \mu\text{A}, 10 \text{ V}\}$. Assume $\beta_0 = 100$ and $V_A = 75 \text{ V}$.



$$r_d = \frac{75 \text{ V} + 10 \text{ V}}{50 \mu\text{A}} = 1.70 \text{ M}\Omega$$

$$g_m = 38.92 (50 \mu\text{A}) = 1.95 \text{ mS} \quad \text{and} \quad r_\pi = \frac{100}{1.95 \text{ mS}} = 51.4 \text{ k}\Omega$$

$$A_{V_i} = -g_m (R_C \parallel R_3 \parallel r_d) = -1.95 \text{ m} \times 48.6 \text{ k} = -94.8$$

$$A_{V_s} = \frac{R_B \parallel r_\pi}{R_S + R_B \parallel r_\pi} A_{V_i} = \frac{33.9}{.75 + 33.9} (-94.8) = -92.8$$

Problem 2 (Text 13.61)For $\beta_0 = 100$ see Problem 1 above (Text problem 13.60)

$$r_\pi = \frac{60}{1.95 \text{ mS}} = 30.8 \text{ k}\Omega \quad \text{and} \quad R_{BB} = R_B \parallel r_\pi = 100 \text{ k}\Omega \parallel 30.8 \text{ k}\Omega = 23.6 \text{ k}\Omega$$

$$A_{V_i} = -g_m (R_C \parallel R_3 \parallel r_d) = -1.95 \text{ m} \times 48.6 \text{ k} = -94.8$$

$$A_{V_s} = \frac{R_{BB} \parallel r_\pi}{R_S + R_{BB} \parallel r_\pi} A_{V_i} = \frac{23.6}{.75 + 23.6} (-94.8) = -91.9$$

Problem 3

Design a four resistor bias network to achieve the operating point given in Text problem 13.60 with the following restrictions, $R_{th} = R_B$, $R_C = R_C$, and $V_{CC} = 20 \text{ V}$. Assume $V_{BE} = V_0 = 0.7 \text{ V}$.

$$V_{R_C} = 100 \text{ k}\Omega \times 50 \mu\text{A} = 5 \text{ V} \quad \Rightarrow \quad V_{R_E} = 5 \text{ V}$$

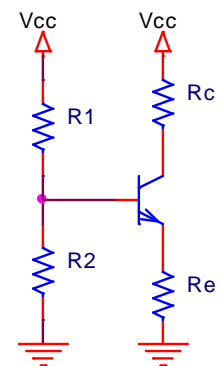
$$V_{R_E} = (I_C + I_B) R_E = (50.5 \mu\text{A}) R_E = 5 \text{ V} \quad \Rightarrow \quad R_E = 99 \text{ k}\Omega$$

To determine R_1 and R_2 we have the following relationships:

$$R_{th} = R_1 \parallel R_2 = 100 \text{ k}\Omega, \quad R_1 = \frac{V_{CC} - V_{BE} - V_{R_E}}{I_{R_1}} = \frac{(20 - 0.7 - 5) \text{ V}}{I_{R_1}}, \quad \text{and} \quad R_2 = \frac{V_{BE} + V_{R_E}}{I_{R_1} - I_B} = \frac{(0.7 + 5) \text{ V}}{I_{R_1} - 0.5 \mu\text{A}}$$

Since $R_1 > 2 \times R_2$, R_2 can not be larger than $150 \text{ k}\Omega$. (Why?)

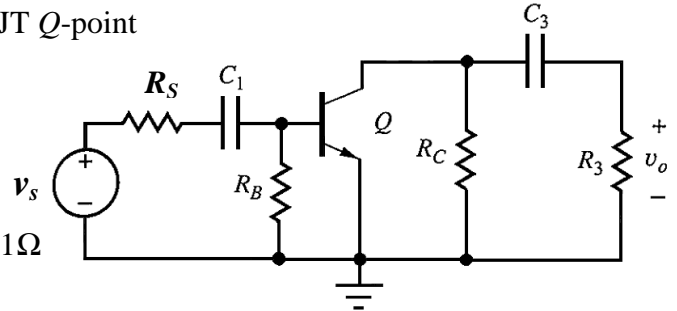
$$\text{Check. If } R_2 = 150 \text{ k}\Omega, \text{ then } I_{R_1} = \frac{5.7}{150} + .0005 = 38.5 \mu\text{A} \text{ and } R_1 = \frac{14.3}{.0385} = 371 \text{ k}\Omega \Rightarrow R_{th} = 107 \text{ k}\Omega$$

Close! Try $R_2 = 140 \text{ k}\Omega \Rightarrow I_{R_1} = 41.2 \mu\text{A}$ and $R_1 = 347 \text{ k}\Omega \Rightarrow R_{th} = 99.8 \text{ k}\Omega$ close enough!

Problem 4 (Text 13.62)Compute A_{v_s}

The ac equivalent circuit for an amplifier is shown. Assume the capacitors have infinite value and that $R_S = 50 \Omega$, $R_B = 4.7 \text{ k}\Omega$, $R_C = 4.3 \text{ k}\Omega$, and $R_3 = 10 \text{ k}\Omega$.

Calculate the voltage gain, A_{v_s} , of the amplifier if the BJT Q -point is $\{2.5 \text{ mA}, 7.5 \text{ V}\}$. Assume $\beta_0 = 75$ and $V_A = 50 \text{ V}$.



$$r_d = \frac{50 \text{ V} + 7.5 \text{ V}}{2.5 \text{ mA}} = 23 \text{ k}\Omega$$

$$g_m = 38.92 (2.5 \text{ mA}) = 97.3 \text{ mS} \quad \text{and} \quad r_\pi = \frac{75}{97.3 \text{ mS}} = 771 \Omega$$

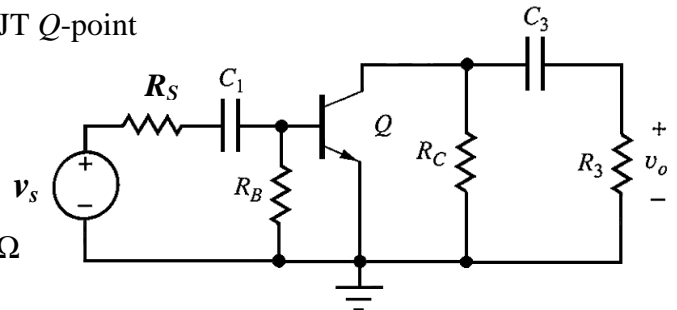
$$A_{v_i} = -g_m (R_C \parallel R_3 \parallel r_d) = -97.3 \text{ m} \times 2.66 \text{ k} = -259$$

$$A_{v_s} = \frac{R_B \parallel r_\pi}{R_S + R_B \parallel r_\pi} A_{v_i} = \frac{662}{50 + 662} (-259) = -241$$

Problem 5 (Text 13.63)Compute A_{v_s}

The ac equivalent circuit for an amplifier is shown. Assume the capacitors have infinite value and that $R_S = 10 \text{ k}\Omega$, $R_B = 5 \text{ M}\Omega$, $R_C = 1.5 \text{ M}\Omega$, and $R_3 = 3.3 \text{ M}\Omega$.

Calculate the voltage gain, A_{v_s} , of the amplifier if the BJT Q -point is $\{1 \mu\text{A}, 1.5 \text{ V}\}$. Assume $\beta_0 = 40$ and $V_A = 50 \text{ V}$.



$$r_d = \frac{50 \text{ V} + 1.5 \text{ V}}{1 \mu\text{A}} = 51.5 \text{ M}\Omega$$

$$g_m = 38.92 (1 \mu\text{A}) = 38.9 \mu\text{S} \quad \text{and} \quad r_\pi = \frac{40}{38.9 \mu\text{S}} = 1.03 \text{ M}\Omega$$

$$A_{v_i} = -g_m (R_C \parallel R_3 \parallel r_d) = -38.9 \mu \times 1.01 \text{ M} = -39.3$$

$$A_{v_s} = \frac{R_B \parallel r_\pi}{R_S + R_B \parallel r_\pi} A_{v_i} = \frac{854}{10 + 854} (-39.3) = -38.8$$

Problem 6

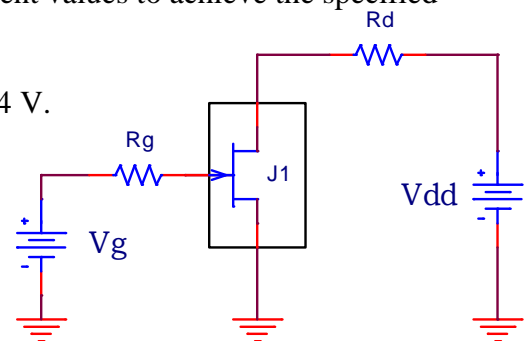
Using the information provided for each FET select all component values to achieve the specified operating points.

The device is an n-channel JFET with $I_{DSS} = 25 \text{ mA}$ and $|V_P| = 4 \text{ V}$.

The desired operating point is to be $I_D = 16 \text{ mA}$ and $V_{DS} = 5 \text{ V}$.

$$I_D = \frac{25}{4^2} [V_{GS} - (-4)]^2 = 16 \text{ mA}$$

$$\pm 16 = 5(V_{GS} + 4) \Rightarrow V_{GS} = -4 \pm 3.2 \text{ V}$$



If $V_{GS} = -7.2 \text{ V}$, the FET would be cut-off. Therefore, $V_{GS} = -0.8 \text{ V}$. We should have known that V_{GS} would be small and negative since the required drain current is close to I_{DSS} .

Since the source terminal of the JFET is grounded, $V_G = V_{GS} = -0.8 \text{ V}$

V_{DD} clearly has to be larger than V_{DS} and also has to provide for the voltage drop across R_D .

Pick V_{DD} to be a convenient value such as 15 V. Then $R_D = \frac{(15-5) \text{ V}}{16 \text{ mA}} = 625 \Omega$.

The only element remaining is R_G . Since $I_G \approx 0$, the value of R_G should not matter.

NOTE: In a real circuit, when the power is initially applied, all of the voltages around the circuit do not magically and instantly achieve their steady-state values. To prevent the gate junction of an FET from being momentarily forward biased, and consequently conducting large currents, it is good practice to insert a large resistance in series with the gate. Therefore, we often see $R_G = 1 \text{ M}\Omega$ to provide protection of the gate junction in a JFET.

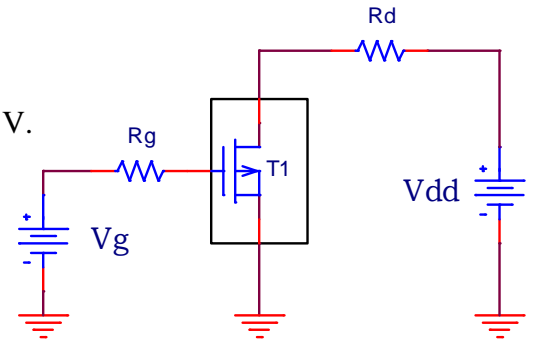
Problem 7

The device is a p-channel depletion-mode MOSFET with $|I_{DSS}| = 30 \text{ mA}$ and $|V_P| = 4 \text{ V}$.

The desired operating point is to be $|I_D| = 7.5 \text{ mA}$ and $|V_{DS}| = 8 \text{ V}$.

$$I_D = \frac{-30}{4^2} [V_{GS} - 4]^2 = -7.5 \text{ mA}$$

$$\pm 2 = (V_{GS} - 4) \Rightarrow V_{GS} = +4 \pm 2 \text{ V}$$



If $V_{GS} = 6 \text{ V}$, the MOSFET would be cut-off. Therefore, $V_{GS} = 2 \text{ V} = V_G$.

Pick V_{DD} to be a convenient value such as -15 V . Then $R_D = \frac{(-15+8) \text{ V}}{-7.5 \text{ mA}} = 933 \Omega$

Since $I_G \approx 0$, the value of R_G should not matter.

Problem 8

The device is an n-channel enhancement-mode MOSFET with $|V_T| = 3 \text{ V}$ and a known operating point in the Beyond-Pinch-Off region at $I_D = 10 \text{ mA}$ when $V_{GS} = 5 \text{ V}$.

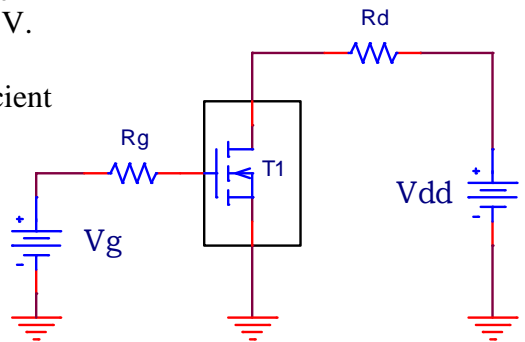
The desired operating point is to be $I_D = 20 \text{ mA}$ and $V_{DS} = 10 \text{ V}$.

Using the known operating point we can determine the coefficient of the nonlinear equation governing B.P.O. operation.

$$I_D = K(5-3)^2 = 10 \text{ mA} \quad \therefore K = 2.5 \text{ mA/V}^2$$

$$I_D = 2.5 (V_{GS} - 3)^2 = 20 \text{ mA}$$

$$\pm 2\sqrt{2} = (V_{GS} - 3) \Rightarrow V_{GS} = +3 \pm 2\sqrt{2} \text{ V}$$



If $V_{GS} = +3 - 2\sqrt{2} \text{ V}$, the MOSFET would be cut-off. $\therefore V_{GS} = +3 + 2\sqrt{2} \text{ V} = 5.828 \text{ V} = V_G$

Pick V_{DD} to be a convenient value such as 15 V. Then $R_D = \frac{(15-10) \text{ V}}{20 \text{ mA}} = 250 \Omega$

Since $I_G \approx 0$, the value of R_G should not matter.

Problem 9

The FET in the circuit below is characterized by $|I_{DSS}| = 22.5 \text{ mA}$ and $|V_p| = 3.6 \text{ V}$. Determine suitable values for the external circuit elements to obtain an operating point of $|I_D| = 15 \text{ mA}$ and $|V_{DS}| = 6 \text{ V}$.

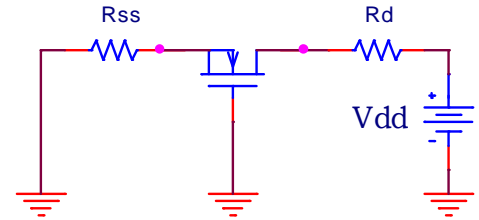
$$I_D = \frac{22.5}{(-3.6)^2} [V_{GS} + 3.6]^2 = 15 \text{ mA}$$

$$\pm 3.6 \sqrt{\frac{15}{22.5}} = (V_{GS} + 3.6) \Rightarrow V_{GS} = -3.6 \left(1 \mp \sqrt{\frac{15}{22.5}} \right) \text{ V}$$

$$V_{GS} = -3.6(1 - 0.8165) \text{ V or } V_{GS} = -3.6(1 + 0.8165) \text{ V}$$

If $V_{GS} = -6.5394 \text{ V}$, the MOSFET would be cut-off. $\therefore V_{GS} = -0.6606 \text{ V}$

$$R_{SS} = \frac{0.66 \text{ V}}{15 \text{ mA}} = 44 \Omega \quad \text{If we pick } V_{DD} = 20 \text{ V, then } R_D = \frac{(20 - 6 - .66) \text{ V}}{15 \text{ mA}} = 889.3 \Omega$$



Problem 10

Determine suitable values for R_1 and V_{DD} in the circuit below to provide an operating point of $|I_D| = 12 \text{ mA}$ and $|V_{DS}| = 8 \text{ V}$, if the FET is satisfactorily described by the nonlinear relationship

$$|I_D| = 4(V_{GS} + 2)^2 \text{ mA}$$

$$|I_D| = 4(V_{GS} + 2)^2 = 12 \text{ mA} \Rightarrow V_{GS} = -2 \pm \sqrt{3}$$

$$\text{Therefore, } V_{GS} = -2 - \sqrt{3} = -3.732 \text{ V} = V_G$$

$$V_{DD} = V_{DS} + I_D R_D = -8 - 12 \times 2 = -32 \text{ V}$$

$$V_G = \frac{100}{100 + R_1} V_{DD} = -3.732 = \frac{100}{100 + R_1} (-32) \Rightarrow R_1 = 757.4 \text{ k}\Omega$$

