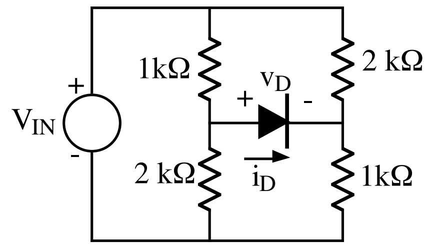
Homework Assignment No. 1 – Solutions

Problem 1

(a.) The first thing to do is to find Thevenin's equivalent circuit seen from the diode.



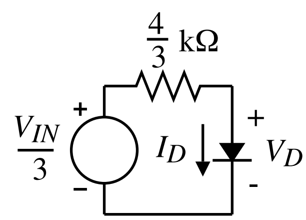
The Thevenin voltage is,

$$V_{TH} = V_{IN}\left(\frac{2}{3} - \frac{1}{3}\right) = \frac{V_{IN}}{3}$$

The Thevenin resistance is,

$$R_{TH} = 1k\Omega||2k\Omega + 1k\Omega||2k\Omega = \frac{4}{3}\ k\Omega$$

The equivalent circuit now becomes,



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Now , with V_{IN} = 10V, we know the diode is forward biased. Therefore, replacing it with a short-circuit gives,

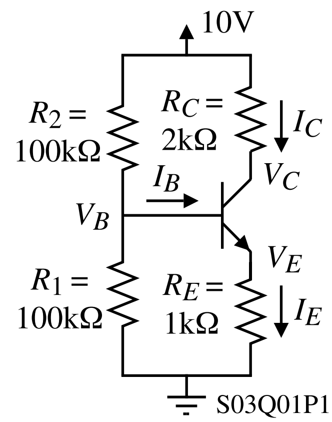
$$V_D = \underline{\underline{0V}} \quad \text{and } I_D = \frac{10}{3} \text{x} \frac{3}{4k\Omega} = \underline{\underline{2.5\text{ mA}}}$$

(b.) With V_{IN} = -10V, we know the diode is reverse biased. Therefore replacing it with an open-circuit gives,

$$V_D = \underline{\underline{-3.33V}} \quad \text{and } I_D = \underline{\underline{0\text{ mA}}}$$

Problem 2

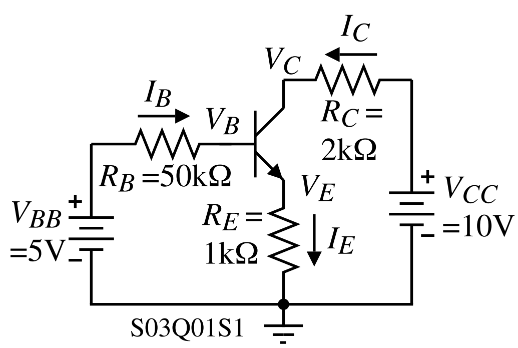
If $\beta_F = 100$ and $V_{BEQ} = 0.6$V, solve for the dc values of I_B, I_C, I_E, V_B. V_C. and V_E of the transistor circuit shown.



Solution

The first step is to find a Thevenin equivalent circuit seen from the base to ground. This circuit is shown below where

$$V_{BB} = \frac{10 \cdot R_1}{R_1 + R_2} = 5\text{V} \quad \text{and} \quad R_B = R_1 \| R_2 = 50\text{k}\Omega$$



The base current, I_B, can be found from the base-emitter voltage loop.

$$V_{BB} = I_B R_B + V_{BEQ} + I_B\,(1+\beta_F)R_E \;\rightarrow\; I_B = \frac{V_{BB} - 0.6}{R_B + (1+\beta_F)R_E} = \frac{4.4\text{V}}{151\text{k}\Omega} = \underline{\underline{29.14\mu\text{A}}}$$

$$\therefore \quad I_C = \beta_F I_B = \underline{\underline{2.914\text{mA}}} \quad \text{and} \quad I_E = I_C + I_B = \underline{\underline{2.943\text{mA}}}$$

The voltages of the transistor can be found as follows.

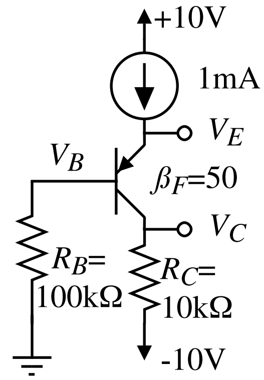
$$V_C = 10\text{V} - I_C R_C = 10 - 2.914\text{mA} \cdot 2\text{k}\Omega = 10 - 5.83 = \underline{\underline{4.17\text{V}}}$$

$$V_E = I_E R_E = 2.942\text{mA} \cdot 1\text{k}\Omega = \underline{\underline{2.942\text{V}}}$$

$$V_B = V_E + V_{BEQ} = 2.942 + 0.6 = \underline{\underline{3.543\text{V}}}$$

Problem 3

A pnp BJT circuit is shown. (a.) Find the dc values of I_E, I_C, I_B, V_E, V_C and V_B if $\beta = 50$ and $V_{EB}(\text{on}) = 0.65\text{V}$. (b.) For what value of R_C does the BJT become saturated? (Recall that saturation of a BJT corresponds to the *BE* and *BC* junctions forward biased.)



Solution

(a.) Note that $\boxed{I_E = 1\text{mA}}$ $\alpha_F = \frac{\beta_F}{1+\beta_F} = \frac{50}{51} = 0.98$

$\therefore I_C = \alpha_F I_E = 0.98 \cdot 1\text{mA} = 0.98\text{mA} \Rightarrow \boxed{I_C = 0.98\text{mA}}$

$$I_B = \frac{I_C}{\beta_F} = \frac{0.98\text{mA}}{50} = 19.6\mu\text{A} \Rightarrow \boxed{I_B = 19.6\mu\text{A}}$$

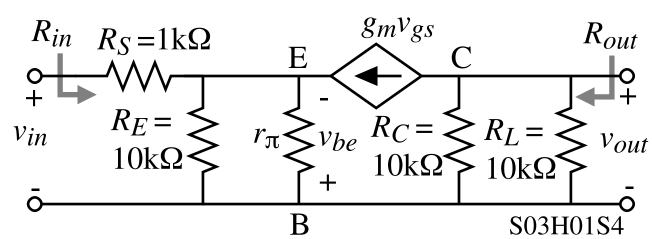
Now, $V_B = I_B \cdot 100\text{k}\Omega = 1.96\text{V} \Rightarrow \boxed{V_B = 1.96\text{V}}$

$V_E = V_B + V_{EB}(\text{on}) = 1.96\text{V} + 0.65\text{V} = 2.61\text{V} \Rightarrow \boxed{V_E = 2.61\text{V}}$

Finally, $V_C = -10\text{V} + I_C \cdot 10\text{k}\Omega = -10\text{V} + 0.98\text{mA} \cdot 10\text{k}\Omega = -0.2\text{V} \Rightarrow \boxed{V_C = -0.2\text{V} \approx 0\text{V}}$

(b.) Saturation occurs when $V_{BC} = 0$ of $V_B = V_C$. Therefore, $V_C = 1.96\text{V}$. The current through R_C is still 0.98mA, so solving for R_C gives,

$$R_C = \frac{V_C + 10\text{V}}{I_C} = \frac{11.96\text{V}}{0.98\text{mA}} = 12.20\text{k}\Omega \Rightarrow \boxed{R_C = 12.2\text{k}\Omega}$$

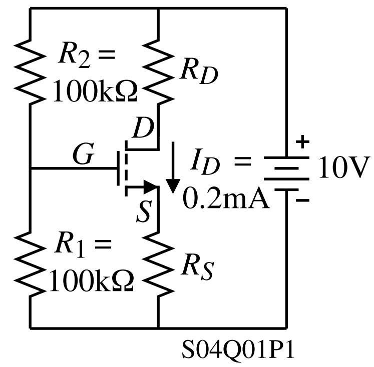


Problem 4

The NMOS transistor shown has the parameters of K_n = 1mA/V^2, V_{TN} = 1V and λ_N = 0V^{-1}. In saturation, the large signal model is $i_D = 0.5K_n(v_{GS}\text{-}V_T)^2$.

a.) Assume the NMOS transistor is saturated and find the value of R_S that gives a drain current of 0.2mA.

b.) What value of R_D will cause the MOSFET to go from the saturation to the active region when I_D = 0.2mA?



Solution

a.) Let us solve for the value of V_{GS} that gives I_D = 0.2mA when the MOSFET is saturated.

$$I_D = 0.5K_n(V_{GS} - V_{TN})^2 = 0.5(V_{GS} - 1)^2 = 0.2$$

$$0.4 = V_{GS}{}^2 - 2V_{GS} + 1 \quad \rightarrow \quad V_{GS}{}^2 - 2V_{GS} + 0.6 = 0$$

$$\therefore \quad V_{GS} = 1 \pm 0.5\sqrt{4\text{-}0.6(4)} = 1 \pm 0.5\sqrt{1.6} = 1 \pm 0.632\text{V} \quad \rightarrow \quad V_{GS} = 1.632\text{V} \; (2)$$

Since we know that V_G = 5V (1), then V_S = 5 – 1.632 = 3.367V

Therefore, $$R_S = \frac{V_S}{I_D} = \frac{3.367}{0.2\text{mA}} = \underline{\underline{16.84\text{k}\Omega}} \; (3)$$

b.) To find the value of *RD* that will cause the MOSFET to leave the saturation region and enter the active region, we will use the following relationship that gives the conditions at the boundary of the two regions.

$$V_{DS} = V_{GS} - V_{TN} \quad (1)$$

This relationship can be rewritten as,

$$V_D - V_S = V_G - V_S - V_{TN} \quad \rightarrow \quad V_D = V_G - V_{TN} = V_G - 1 \quad (1)$$

Therefore, V_D = 5-1 = 4V is when the MOSFET will be at the boundary of the two regions. Thus, the voltage drop across R_D is 6V and the current through it is 0.2mA. From Ohm's law, we get,

$$R_D = \frac{(10\text{-}V_D)}{I_D} = \frac{6\text{V}}{0.2\text{mA}} = \underline{\underline{30\text{k}\Omega}} \quad (2)$$

Problem 5

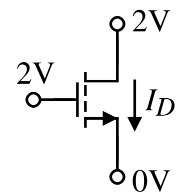
The following questions give the dc voltages at the terminals of an active device. You are to calculate the designated dc current.

a.) Find the diode current, I_D, where I_S = 100fA and V_T = 0.025V (2 pts).

Obviously, the diode is forward biased. Therefore,

$$I_D = I_S \exp\left(\frac{V_D}{V_T}\right) = 10^{-13} \exp\left(\frac{0.6}{0.025}\right) = \underline{\underline{2.65 \text{ mA}}}$$

b.) Find the drain-source current, I_{DS}, where K_n' = 25μA/V^2, V_{TN} = 1V and W/L = 10 (2 pts).



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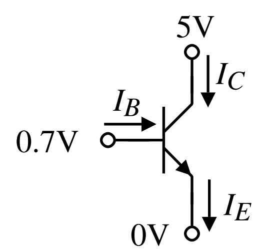
We see that the enhancement, n-channel MOSFET is in the saturation region. Therefore,

$$I_{DS} = \frac{K_n'W}{2L}\,'(V_{GS} - V_{TN})^2 = \frac{25\cdot 10}{2}(2\text{-}1)^2 = \underline{\underline{125\ \mu\text{A}}}$$

c.) Find the collector, emitter, and base currents, I_C, I_E, and I_B if I_S = 100fA, V_T = 0.025V and β_F = 100 (4 pts).



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We see that the npn BJT is in the forward active region. Therefore,

$$I_C = I_S \exp\left(\frac{V_{BE}}{V_T}\right) = 10^{-13} \exp\left(\frac{0.7}{0.025}\right) = \underline{\underline{144.6 \text{ mA}}}$$

$$I_B = \frac{I_C}{\beta_F} = \underline{\underline{1.446 \text{ mA}}} \qquad \text{and} \qquad I_E = I_C + I_B = \underline{\underline{146 \text{ mA}}}$$

d.) Repeat (b.) if V_D = 1V and V_G = 3V (2 pts).

We see that the enhancement, n-channel MOSFET is in the linear region. Therefore,

$$I_{DS} = K_n'\frac{W}{L}\left(V_{GS} - V_{TN} - \frac{V_{DS}}{2}\right)V_{DS} = 25\cdot 10(3\text{-}1\text{-}0.5)(1) = \underline{\underline{375\ \mu\text{A}}}$$