Assignment #2, Total: 10 pts

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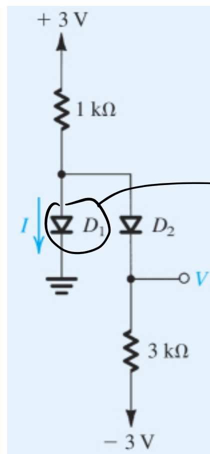
Chapter 4. Diodes

1. (0.5 pts) Assuming that the diodes in the circuits are ***ideal***, find the values of the labeled voltage and current.



Since D1 is ON and ideal, it acts like a short circuit.

Therefore, the voltage at the node where D1 connects is $\boxed{0V,}$ because it is directly connected to ground through D1.

$$V = IR$$

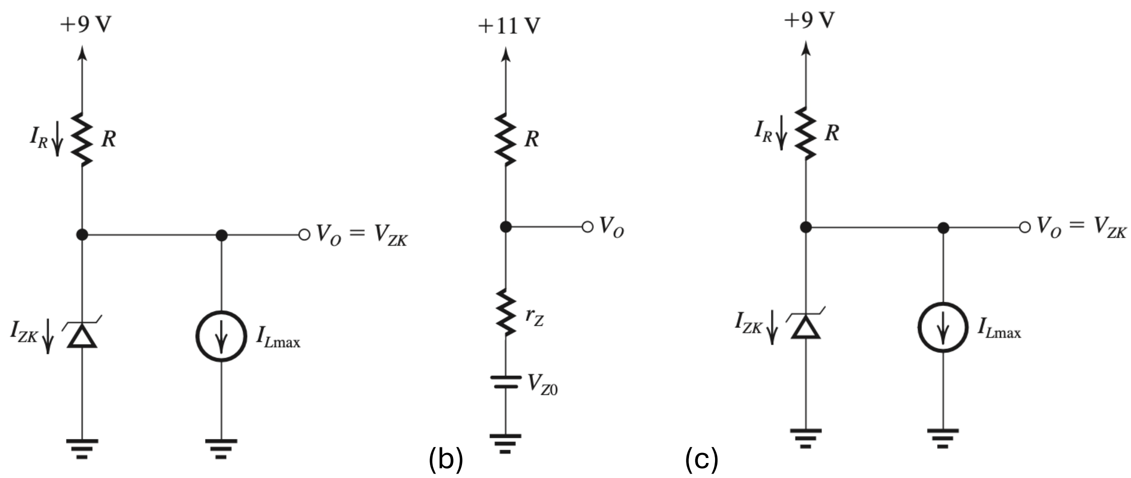
$$3 - 0 = 1(1k)$$

$$I = \frac{3}{1k}$$

$$I = 0.003 \text{ A}$$

$$\boxed{= 3 \text{ mA}}$$

2. (2 pts) Design a zener regulator circuit using a 7.5-V zener specified at 10 mA. The zener has an incremental resistance r_z = 30 Ω and a knee current of 0.5 mA. The regulator operates from a 10-V supply and delivers a nominal current of 5 mA to the load.
(a) What is the value of R you have chosen?
(b) What is the output voltage when both the supply is 10% high and the load is removed?
(c) What is the largest load current that can be delivered while the zener operates at a current no lower than the knee current while the supply is 10% low?



(a) (b) (c)

a.

$$I_R = I_Z + I_L$$
$$= 10\,mA + 5\,mA$$
$$= 15\,mA$$

$$R = \frac{V_s - V_Z}{I_R}$$
$$= \frac{10-7.5}{15 \times 10^{-3}}$$
$$= \frac{2.5}{0.015}$$
$$\boxed{= 166.67\,\Omega}$$

b.

$$V_s = 1.1 \times 10 = 11\,V$$
$$I_Z = \frac{V_s - V_Z}{R}$$
$$= \frac{11-7.5}{166.67}$$
$$= \frac{3.5}{166.67}$$
$$= 21\,mA$$

$$V_o = V_Z + (I_Z) \cdot r_z$$
$$= 7.5 + (21 \cdot 10^{-3}) \cdot 30$$
$$= 7.5 + 0.63$$
$$\boxed{= 8.13\,V}$$

c.

$$V_s = 0.9 \cdot 10$$
$$= 9\,V$$

$$I_R = \frac{V_s - V_z}{R}$$
$$= \frac{9-7.5}{166.67}$$
$$= \frac{1.5}{166.67}$$
$$= 9\,mA$$

$$I_{Zk} = 0.5\,mA$$

$$I_{L_{max}} = I_R - I_{Zk}$$
$$= 9\,mA - 0.5\,mA$$
$$\boxed{= 8.5\,mA}$$

Chapter 5. MOS Field-Effect Transistors (MOSFETs)

3. (1 pt) The PMOS transistor in the circuit has $V_t = -0.5$ V, $\mu_p C_{ox} = 100\ \mu A/V^2$, L = 0.18 μm, and λ = 0. Find the values required for W and R in order to establish a drain current of 160 μA and a voltage V_D of 0.8 V.

$V_t = -0.5\ V$

$\mu_p C_{ox} = 100 \frac{\mu A}{V^2}$

$L = 0.18 \mu m$

$V_{DD} = 1.8 V$

$V_D = 0.8 V$

$I_D = 160 \mu A$

$V_{sg} = V_{DD} - V_D$

$V_{sg} = 1.8 V - 0.8 V = 1.0 V$

$I_D = \frac{1}{2} \mu_p C_{ox} \frac{W}{L} (V_{sg} - |V_t|)^2$

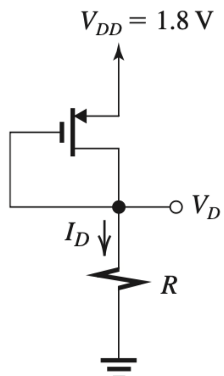
$W = \frac{2 I_D L}{\mu_p C_{ox} (V_{sg} - |V_t|)^2}$

$W = \frac{2 \cdot (160 \cdot 10^{-6}) \cdot (0.18 \cdot 10^{-6})}{(100 \cdot 10^{-6}) \cdot (1.0 - 0.5)^2}$

$W = \frac{57.6 \cdot 10^{-12}}{25 \cdot 10^{-6}}$

$= 2.304 \cdot 10^{-6}\ m$

$\boxed{= 2.304\ \mu m}$



$R = \frac{V_D}{I_D}$

$R = \frac{0.8 V}{160 \cdot 10^{-6} A}$

$\boxed{R = 5000\ \Omega}$

4. (1 pt) For a particular MOSFET operating in the saturation region at a constant v_{GS}, i_D is found to be 200 μA for v_{DS} = 1 V and 205 μA for v_{DS} = 1.5 V. Find the values of r_o, V_A, and λ.

$i_{D_1} = 200 \cdot 10^{-6}$

$i_{D_2} = 205 \cdot 10^{-6}$

$V_{DS_1} = 1.0 V$

$V_{DS_2} = 1.5 V$

$\Delta V_{DS} = V_{DS2} - V_{DS1}$
$= 1.5 - 1.0$
$= 0.5 V$

$\Delta i_D = i_{D2} - i_{D1}$
$= (205 - 200) \cdot 10^{-6}$
$= 5 \cdot 10^{-6} A$

$r_o = \frac{\Delta V_{DS}}{\Delta i_D}$

$r_o = \frac{0.5 V}{5 \cdot 10^{-6}}$

$\boxed{= 100\,000\ \Omega}$

$\lambda = \frac{1}{r_o \times i_{D1}}$

$\lambda = \frac{1}{100000 \cdot (200 \cdot 10^{-6})}$

$\lambda = \frac{1}{20}$

$\boxed{= 0.05\ V^{-1}}$

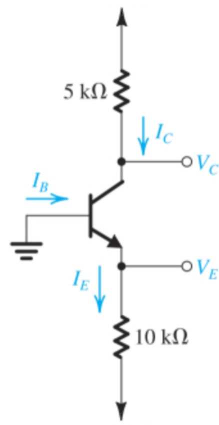
$V_A = \frac{1}{\lambda}$

$V_A = \frac{1}{0.05}$

$\boxed{= 20\ V}$

Chapter 6. Bipolar Junction Transistors (BJTs)

5. (1 pt) In the circuit shown in the figure, the power supplies are ±3 V and the voltage at the emitter was measured and found to be –0.7 V. If β = 50, find I_E, I_B, I_C, and V_C.



$V_E = -0.7\ V$

Power Supplies: ±3 V

$\beta = 50$

$R_E = 10k\Omega$

$R_C = 5k\Omega$

$$I_E = \frac{V_E - V_-}{R_E}$$

$$I_E = \frac{-0.7 - (-3)}{10000}$$

$$I_E = \frac{2.3}{10000}$$

$$I_E = 0.00023\ A$$

$$\boxed{I_E = 0.230\ mA}$$

$$I_C = \frac{\beta}{\beta + 1} I_E$$

$$I_C = \frac{50}{51} \cdot 0.00023$$

$$I_C = 0.00022549\ A$$

$$\boxed{I_C = 0.225\ mA}$$

$$I_B = \frac{I_C}{\beta}$$

$$I_B = \frac{0.00022549}{50}$$

$$I_B = 4.5098 \cdot 10^{-6}\ A$$

$$\boxed{I_B = 4.510\ \mu A}$$

$$V_C = V_+ - (I_C \cdot R_C)$$

$$V_C = 3 - (0.00022549 \cdot 5000)$$

$$V_C = 3 - 1.12745$$

$$V_C = 1.8725\ V$$

$$\boxed{V_C = 1.873\ V}$$

Chapter 7. Transistor Amplifiers

6. (1 pt) A designer wants to create a BJT amplifier with a gm of 20 mA/V and a base input resistance of 4000 Ω or more. What collector-bias current should she choose? What is the minimum β she can tolerate for the transistor used?

$g_M = \frac{I_C}{V_T}$

$I_C = g_M \cdot V_T$

$I_C = (20 \cdot 10^{-3}) \cdot (25 \cdot 10^{-3})$

$I_C = 0.5 \cdot 10^{-3}$

$\boxed{I_C = 0.5 \text{ mA}}$

$r_\pi \frac{\beta}{g_M}$

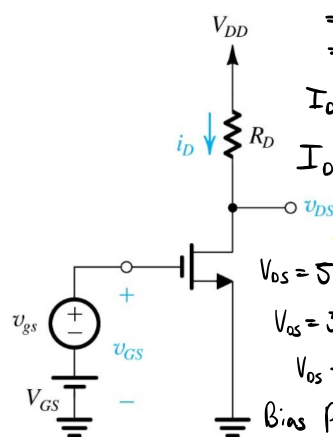
$\beta = r_\pi \cdot g_M$

$\beta = 4000 \cdot (20 \cdot 10^{-3})$

$\beta = 4000 \cdot 0.02$

$\boxed{\beta = 80}$

7. (1.5 pt) Consider the amplifier of the following circuit: V_{DD} = 5 V, R_D = 24 kΩ, (W/L) = 1 mA/V², and V_t = 1 V.
(a) Find the coordinates of the two end points of the saturation-region segment of the amplifier transfer characteristic, that is, points A and B.
(b) If the amplifier is biased to operate with an overdrive voltage V_{OV} of 0.5 V, find the coordinates of the bias point Q on the transfer characteristic. Also, find the value of I_D and of the incremental gain A_v at the bias point.



a.

$V_{gs} = V_t = 1 \text{ V}$

$I_D = 0$

$V_{DS} = V_{DD} - I_D R_D$

$= 5 - 0$

$= 5$

$\boxed{\text{Point A: } (V_{GS}, V_{DS}) = (1 \text{ V}, 5 \text{ V})}$

$V_{DS} = V_{GS} - V_t$

$V_{DS} = V_{DD} - i_D R_D$ and $i_D = \frac{1}{2} k' \left(\frac{W}{L}\right)(V_{GS} - V_t)^2$

$V_{DD} - \left(\frac{1}{2} k' \left(\frac{W}{L}\right)(V_{GS} - V_t)^2\right) R_D = V_{GS} - V_t$

$5 - \left(\frac{1}{2}(1 \cdot 10^{-3})(1)(V_{GS} - 1)^2\right)(24 \cdot 10^3) = V_{GS} - 1$

$5 - (12)(V_{GS} - 1)^2 = V_{GS} - 1$

$-12 V_{GS}^2 + 24 V_{GS} - 7 = V_{GS} - 1$

$-12 V_{GS}^2 + 23 V_{GS} - 6 = 0$

$V_{GS} = 0.311 \text{ V}$

$I_D = \frac{1}{2}(1 \cdot 10^{-3})(0.311 - 1)^2$

$I_D = \frac{1}{2}(1 \cdot 10^{-3})(-0.689)^2$

$I_D = 0.5 \cdot 1 \cdot 10^{-3} \cdot 0.474$

$I_D = 0.237 \text{ mA}$

$V_{DS} = 5 - (0.237 \cdot 10^{-3})(24 \cdot 10^3)$

$V_{DS} = 5 - 5.688$

$V_{DS} = -0.688 \text{ V}$

$\boxed{\text{Point B: } (V_{GS}, V_{DS}) = (0.311 \text{ V}, -0.689 \text{ V})}$

b.

$V_{ov} = 0.5 \text{ V}$

$V_{GS} = V_t + V_{ov}$

$= 1 + 0.5$

$= 1.5$

$I_D = \frac{1}{2}(1 \cdot 10^{-3})(1)(0.5)^2$

$I_D = 0.5 \cdot 1 \cdot 10^{-3} \cdot 0.25$

$\boxed{I_D = 0.125 \text{ mA}}$

$V_{DS} = 5 - (0.125 \cdot 10^{-3})(24 \cdot 10^{-3})$

$V_{DS} = 5 - 3$

$V_{DS} = 2 \text{ V}$

Bias Point Q:

$\boxed{(V_{GS}, V_{DS}) = (1.5 \text{ V}, 2.0 \text{ V})}$

$g_M = k' \left(\frac{W}{L}\right) V_{ov}$

$g_M = (1 \cdot 10^{-3})(1)(0.5)$

$= 0.5 \frac{\text{mA}}{\text{V}}$

$A_v = -g_M R_D$

$A_v = -(0.5 \cdot 10^{-3})(24 \cdot 10^{-3})$

$A_v = -12$

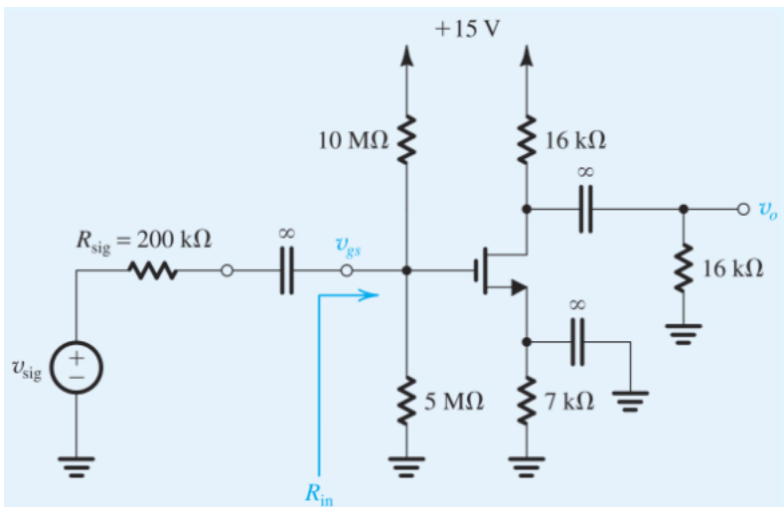
$\boxed{A_v = -12}$

8. (2 pts) The following figure shows a discrete-circuit amplifier. The input signal v_{sig} is coupled to the gate through a very large capacitor (shown as infinite). The transistor source is connected to ground at signal frequencies via a very large capacitor (shown as infinite). The output voltage signal that develops at the drain is coupled to a load resistance via a very large capacitor (shown as infinite). All capacitors behave as short circuits for signals and as open circuits for dc.

(a) If the transistor has $V_t = 1$ V, and $k_n = 4$ mA/V^2, verify that the bias circuit establishes $V_{GS} = 1.5$ V, $I_D = 0.5$ mA, and $V_D = +7.0$ V. That is, assume these values, and verify that they are consistent with the values of the circuit components and the device parameters.

(b) Find gm and r_o if $V_A = 100$ V.

(c) Find R_{in}, v_{gs}/v_{sig}, v_o/v_{gs}, and v_o/v_{sig}.



a.

$V_t = 1\ V$

$k_n = 4\ \frac{mA}{V^2} = 0.004\ \frac{A}{V^2}$

$V_{GS} = 1.5\ V$

$I_D = 0.5\ mA$

$V_D = 7.0\ V$

$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$

$I_D = \frac{0.004}{2}(1.5 - 1)^2$

$= 0.002(0.5)^2$

$= 0.002(0.25)$

$= 0.0005\ A$

$\boxed{= 0.5\ mA}$

$R_S = \left(\frac{1}{5\,M\Omega} + \frac{1}{7\,k\Omega}\right)^{-1}$

$R_S = \left(\frac{1}{5\cdot 10^6} + \frac{1}{7\cdot 10^3}\right)^{-1}$

$= (2\cdot 10^{-7} + 1.4286\cdot 10^{-4})$

$= (1.4306\cdot 10^{-4})$

$= 6990\ \Omega$

$V_S = I_D \cdot R_S$

$= (0.5\cdot 10^{-3})\cdot 6990$

$\boxed{= 3.495\ V}$

$V_D = 15\ V - I_D R_D$

$= 15 - (0.5\cdot 10^{-3})(16\cdot 10^3)$

$= 15 - 8$

$\boxed{= 7.0\ V}$

b.

$g_m = \frac{2 I_D}{V_{GS} - V_t}$

$g_m = \frac{2\cdot 0.5\cdot 10^{-3}}{1.5 - 1}$

$= \frac{10^{-3}}{0.5}$

$= 2\cdot 10^{-3}\ \frac{A}{V}$

$\boxed{= 2.0\ mA\ \frac{A}{V}}$

$r_o = \frac{V_A}{I_D}$

$= \frac{100}{0.5\cdot 10^{-3}}$

$= 200\cdot 10^3$

$\boxed{= 200\ k\Omega}$

c.

$R_{in} = R_{G1} \| R_{G2} = \left(\frac{1}{10\ M\Omega} + \frac{1}{200\ k\Omega}\right)^{-1}$

$\boxed{R_{in} = 196.08\ k\Omega}$

$\frac{V_{gs}}{V_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}}$

$\frac{V_{gs}}{V_{sig}} = \frac{196.08}{196.08 + 200}$

$= \frac{196.08}{396.08}$

$\boxed{\frac{V_{gs}}{V_{sig}} = 0.495}$

$\frac{V_o}{V_{gs}} = -g_m(R_D \| R_L \| r_o)$

$R_D \| R_L \| r_o = \left(\frac{1}{16k} + \frac{1}{16k} + \frac{1}{200k}\right)^{-1}$

$= 7692\ \Omega$

$\frac{V_o}{V_{gs}} = -2\cdot 10^{-3}\cdot 7692$

$\boxed{= -15.3846}$

$\frac{V_o}{V_{sig}} = \left(\frac{V_o}{V_{gs}}\right)\left(\frac{V_{gs}}{V_{sig}}\right)$

$= (-15.385)(0.495)$

$\boxed{= -7.616}$