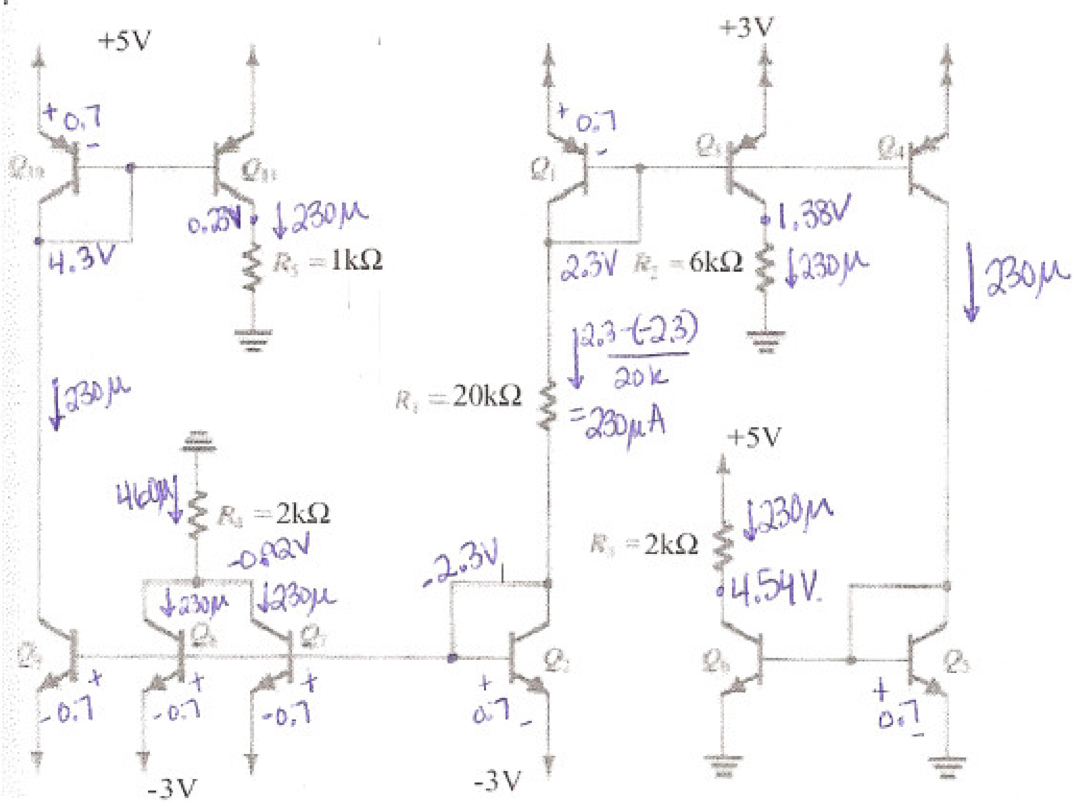
(Due Sept. 7 by 6pm in homework locker)

1. Design the circuit of Fig. 6.4 to obtain an output current whose nominal value is 25μA. Find R when Q_1 and Q_2 are matched with channel lengths of 1μm, channel widths of 10μm, V_t=1V, k'_n=100μA/V^2, V_A=20V, V_{DD}= 3V and I_{REF}=25μA. What is the minimum allowable value of Vo for proper operation? What is the output resistance? What is the change in the output current when Vo is changed by +1V?

2. Design the circuit of Fig. 6.10 to obtain an output current whose nominal value is 100μA when V_o is 2V. Find R, I_{REF}, V_{omin} when I_s=10^{-15}A, β=100, V_{CC}=6V, and V_A=60V. If V_o is changed to 5V, what is I_o?

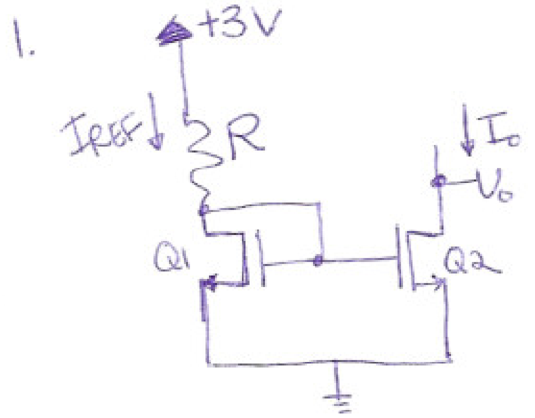
3. Find voltages at all nodes and currents through all branches in the circuit below. Assume $|V_{BE}| = 0.7V$ and β=∞.



4. Design a current source that generates a constant current I_o=50μA that operates from a 3V supply. State all values if resistors are used. Assume that V_{BE} is 0.7V at a current of 1mA and neglect the effect of a finite β. You can only use resistors that are less than 50kΩ.

HW #2 solution

1.



Want $I_o = 25\mu A$,

$$\left(\frac{W}{L}\right)_{Q_1} = \left(\frac{W}{L}\right)_{Q_2} = \frac{10\mu m}{1\mu m} = 10$$

Let $I_{REF} = I_o = 25\mu$

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

$$\sqrt{\frac{25\mu(2)}{(100\mu \cdot 10)}} = (V_{GS}-V_t)$$

$$.22 + V_t = V_{GS}$$

$$\therefore V_{GS} = 1.22V$$

$$R = \frac{3-V_{GS}}{I_{REF}} = \frac{(3-1.22)}{100\mu} = \boxed{17.8K\Omega}$$

V_{omin} will occur when $V_{DS} = V_{GS}-V_t$

$$\therefore \boxed{V_{omin} = 0.22V}$$

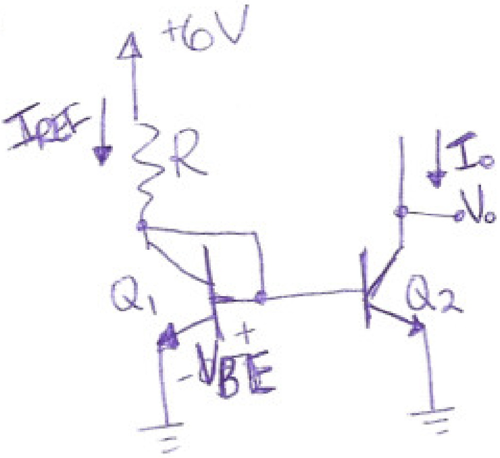
$$R_{out} = r_{o2} = \frac{V_A}{I_D} = \frac{20}{25\mu} = \boxed{800K\Omega}$$

The output current will be $25\mu A$ at $V_o = 0.22V$. If V_o changes by +1V, then I_o will change

$$\Delta I_o = \frac{\Delta V_o}{r_{o2}} = \frac{1V}{800k} = \boxed{1.25\mu A}$$

$$\therefore I_o = 26.25\mu \text{ at } V_o = 1.22V$$

2.



$I_o = 100\mu A$

$V_o = 2V$

Assume $V_{BE} = 0.7$

$$I_o = \frac{I_{REF}}{1+2/\beta}\left[1 + \frac{(V_o - V_{BE})}{V_A}\right]$$

$$I_o = 100\mu A = \frac{I_{REF}}{1+2/100}\left[1 + \frac{(2-0.7)}{60}\right]$$

$$\therefore I_{REF} = 100\mu \cdot 1.02 \cdot (.9788)$$

$$I_{REF} = \boxed{99.8\mu A}$$

$$R = \frac{V_{CC} - V_{BE}}{I_{REF}} = \boxed{53.1K\Omega}$$

$V_o = 5V$:

$$I_o = \frac{99.8\mu}{1+2/100}\left[1 + \frac{(5-0.7)}{60}\right] = 97.8\mu \cdot 1.072 = \boxed{104.8\mu A}$$

V_{omin} occurs when Q_2 goes from active to another state. This happens when

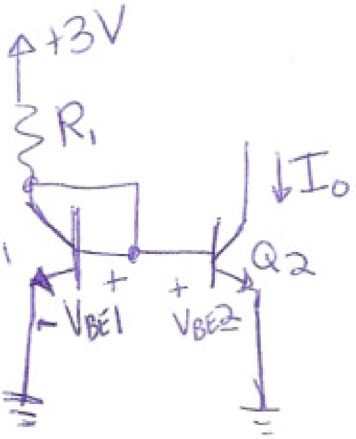
$V_{CE} = 0.3V$ (see Table 6.3)

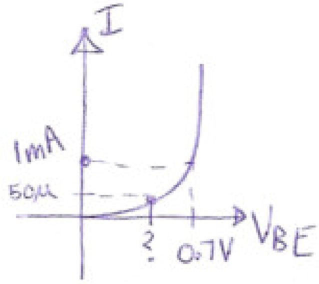
Since $V_E = 0V$ (gnd).

$\therefore V_{omin} = \boxed{0.3V}$

4.

TRADITIONAL ⇒ We know that it is given that $V_{BE} = 0.7$ at 1mA.



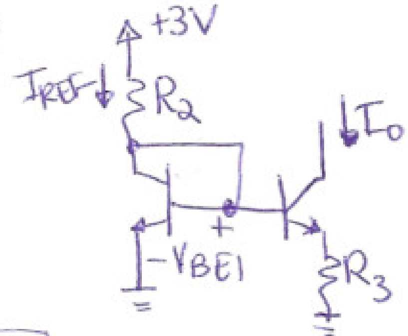


To find V_{BE} at a lesser current,

$$V_{BE1} = 0.7 + V_T \ln\left(\frac{I_{REF}=50\mu}{1m}\right) = 0.625V$$

$$R_1 = \frac{3 - 0.625}{50\mu} = \boxed{47.5k\Omega} < 50K$$

Widlar ⇒



Choose $I_{REF} = 1mA$ So that $V_{BE1} = 0.7$

$$R_2 = \frac{3-0.7}{1m} = \boxed{23K}$$

$$I_0 R_3 = V_T \ln\left(\frac{I_{REF}}{I_0}\right)$$

$$R_3 = \frac{25m}{50\mu} \ln\left(\frac{1m}{50\mu}\right)$$

$$R_3 = \boxed{1.5k\Omega}$$

∴ R's < 5kΩ