In the CMOS circuit shown in Fig. 1, the devices have the same characteristics: $\mu_n C_{ox} = \mu_p C_{ox} = 20 \mu A/V$, $W = 10 \mu m$, $L = 10 \mu m$, $V_{tn} = -V_{tp} = V_t = 1V$, $\lambda = 0$, $\gamma = 0$. The input voltage has zero DC bias component $V_I = 0$, and a small-signal component $v_i$. The load resistance is $R = 1M \Omega$. The DC current sources are $I_{B1} = 10 \mu A$, $I_{B2} = I_{B3} = 15 \mu A$, and the DC bias voltage is $V_{bias} = 2V$.

a) Find the DC bias currents $I_1$, $I_2$, $I_3$, $I_4$, $I_6$, and the DC bias voltages $V_1$, $V_2$, and $V_O$.

b) Find the small-signal gain $A = v_o/v_i$.

c) Find the small-signal gains $A_1 = v_1/v_i$ and $A_2 = v_2/v_i$.

d) Using an additional resistor $R_1$, and as many devices as you need, construct the DC bias sources $I_{B1}$, $I_{B2}$, $I_{B3}$, and the DC bias voltage $V_{bias}$. Sketch your circuit, label the device channel widths, and find $R_1$. Use the same $L = 10 \mu m$ for all devices.

e) Suppose that load $R$ is removed from the circuit and that the channel-length modulation effect parameter is $\lambda = 0.01 \ 1/V$. Repeat part (b), i.e., find the small-signal gain $A = v_o/v_i$. 

---

Figure 1: