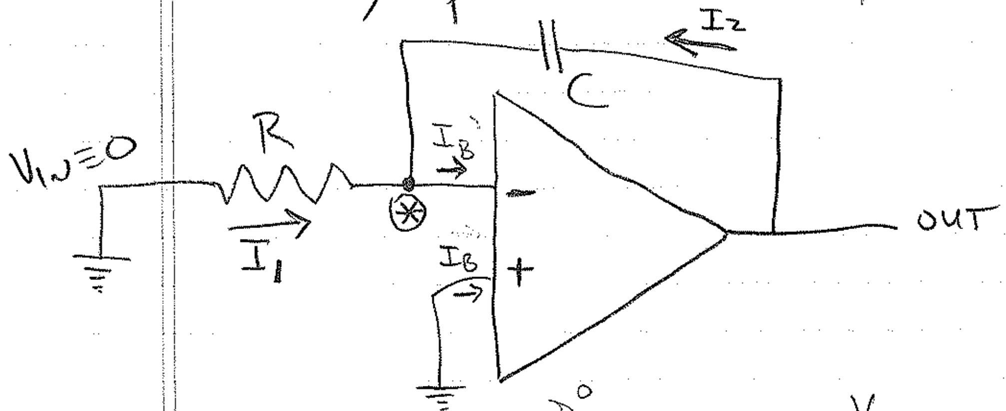
PHYSICS 364, 2010-10-05 BILL ASHMANSKAS

Lab 4, part 1 analysis



$$V_{OUT} = A \cdot (\cancel{V_+}^{\,0} - V_- + V_{OS}) \Rightarrow \frac{V_{OUT}}{A} = V_{OS} - V_- \Rightarrow V_- = V_{OS} - \frac{V_{OUT}}{A}$$

K.C.L. at node ⊛ $\Rightarrow I_1 + I_2 - I_B = 0$

$$\Rightarrow \frac{V_{IN} - V_-}{R} + C\frac{d}{dt}(V_{OUT} - V_-) - I_{Bias} = 0$$

(use $A \to \infty$)

$$\frac{V_{IN}}{R} - \frac{V_{OS}}{R} + \cancel{\frac{V_{OUT}}{AR}}^{\,0} + C\frac{dV_{OUT}}{dt} + \cancel{\frac{C}{A}\frac{dV_{OUT}}{dt}}^{\,0} - I_B = 0$$

$$C\frac{dV_{OUT}}{dt} = \frac{V_{OS}}{R} + I_B - \frac{V_{IN}}{R}$$

$$\frac{dV_{OUT}}{dt} = \frac{V_{OS}}{RC} - \cancel{\frac{V_{IN}}{RC}}^{\,0} + \frac{I_{Bias}}{C}$$

On Quiz #3, 100K, 1μF

$$\frac{V_{OS}}{RC} \sim \frac{1\,mV}{100\,ms} \sim 10\,mV/s$$

$$I_B/C \sim \frac{100\,nA}{1\,\mu F} \sim \frac{100\,mV}{s}$$

$\Rightarrow$ output saturates in $\mathcal{O}(100s)$

for Lab 4 #1, 1K, 1μF

$$I_B/C \sim \frac{100\,nA}{1\,\mu F} \sim 0.1\,V/s$$

$$V_{OS}/RC \sim \frac{1\,mV}{1\,ms} \sim 1\,V/s$$

$\Rightarrow$ output saturates in $\mathcal{O}(10s)$

Note: You can model unplugging/floating V_{IN} as limit $R \to \infty$.

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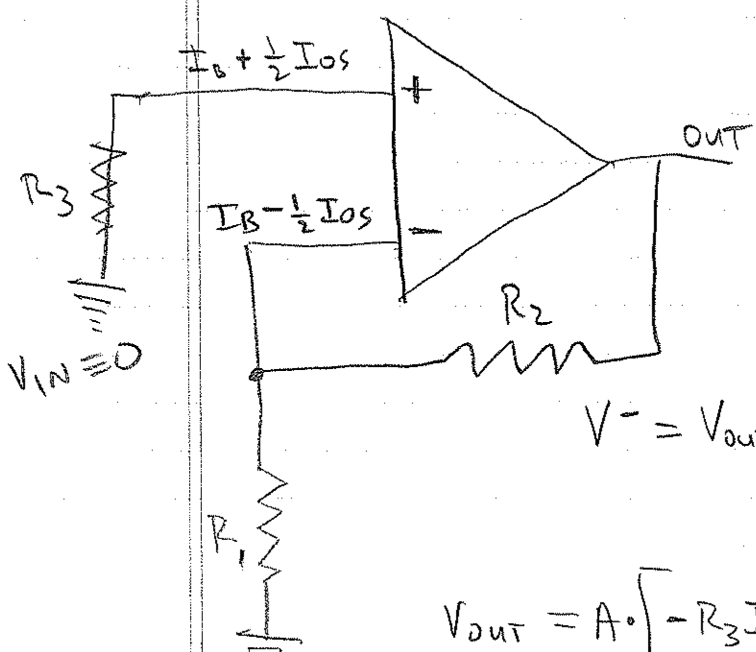
Lab4, part 2 analysis



$$V_{OUT} = A \cdot \left(V^+ - V^- + V_{os} \right)$$

$$V^+ = \overset{0}{\cancel{V_{IN}}} - R_3 \cdot \left(I_B + \tfrac{1}{2} I_{os} \right) = -R_3 \cdot \left(I_B + \tfrac{1}{2} I_{os} \right)$$

$$V^- = V_{OUT} \cdot \frac{R_1}{R_1 + R_2} - \underbrace{(R_1 // R_2)}_{\to R_1 \text{ because } R_1 \ll R_2 \text{ in lab}} \cdot \left(I_B - \tfrac{1}{2} I_{os} \right)$$

$$V_{OUT} = A \cdot \left[-R_3 I_B - \tfrac{1}{2} R_3 I_{os} - V_{OUT} \cdot \frac{R_1}{R_1 + R_2} + R_1 I_B - \tfrac{1}{2} R_1 I_{os} + V_{os} \right]$$

$$\overset{0 \text{ as } A \to \infty}{\cancel{\frac{V_{OUT}}{A}}} = -\frac{R_1 + R_3}{2} I_{os} + V_{os} - V_{OUT} \frac{R_1}{R_1 + R_2} + (R_1 - R_3) I_B$$

$$V_{OUT} = \left(\frac{R_2 + R_1}{R_1} \right) \left[V_{os} + (R_1 - R_3) I_B - \frac{R_1 + R_3}{2} I_{os} \right]$$

Lab4 values: $\frac{R_2 + R_1}{R_1} = 1001$

$V_{os} \sim 1\,mA$
$I_B \sim 100\,mA$
$I_{os} \sim 10\,mA$

for $R_1 = R_3 = 100\,\Omega$, I_B is invisible, and
I_{os} contributes $\sim 1001 \cdot 100\,\Omega \cdot 10\,nA \sim 1\,mV$
V_{os} contributes $\sim 1001 \cdot 1\,mV \sim \underline{1\,V}$

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for $R_3 = 10K$, I_B contributes $\sim 1001 \cdot 10K\Omega \cdot 100\,nA \sim 1\,V$

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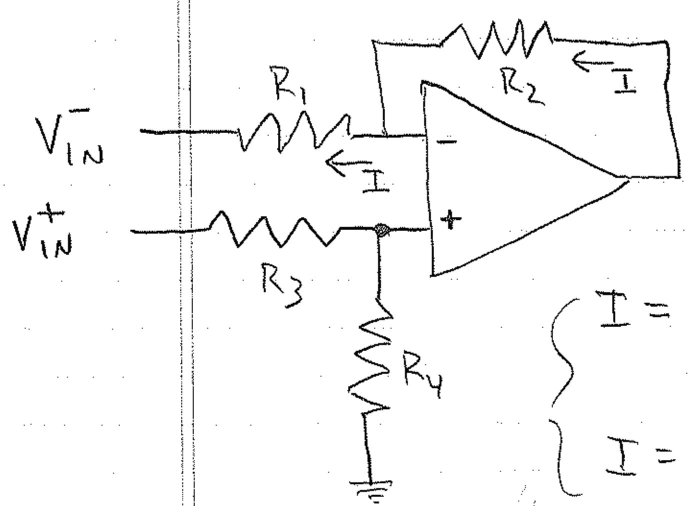
Golden-Rule derivation for opamp differential amplifier



$$V^+ = V_{IN}^+ \cdot \frac{R_4}{R_3+R_4}$$

$$G.R.\ \#1 \Rightarrow V^- = V^+$$

$$\left\{\begin{array}{l} I = \dfrac{V_{OUT} - V_-}{R_2} = \dfrac{V_{OUT}}{R_2} - \dfrac{V_{IN}^+}{R_2} \cdot \dfrac{R_4}{R_3+R_4} \\[2ex] I = \dfrac{V_- - V_{IN}^-}{R_1} = \dfrac{V_{IN}^+}{R_1} \cdot \dfrac{R_4}{R_3+R_4} - \dfrac{V_{IN}^-}{R_1} \end{array}\right.$$

$$\frac{V_{OUT}}{R_2} = \frac{V_{IN}^+}{R_2} \cdot \frac{R_4}{R_3+R_4} + \frac{V_{IN}^+}{R_1} \cdot \frac{R_4}{R_3+R_4} - \frac{V_{IN}^-}{R_1}$$

$$V_{OUT} = V_{IN}^+ \left(1 + \frac{R_2}{R_1}\right) \frac{R_4}{R_3+R_4} - V_{IN}^- \cdot \frac{R_2}{R_1}$$

$$V_{OUT} = V_{IN}^+ \left(\frac{1 + R_2/R_1}{1 + R_3/R_4}\right) - \frac{R_2}{R_1} V_{IN}^-$$

Now if $R_4/R_3 = R_2/R_1$ then

$$V_{OUT} = V_{IN}^+ \left(\frac{1 + R_2/R_1}{1 + R_1/R_2}\right) - \frac{R_2}{R_1} V_{IN}^-$$

$$= V_{IN}^+ \cdot \frac{R_2}{R_1} \cdot \frac{R_1+R_2}{R_2+R_1} - \frac{R_2}{R_1} V_{IN}^-$$

$$V_{OUT} = \frac{R_2}{R_1}\left(V_{IN}^+ - V_{IN}^-\right)$$