INEL 5207 - Spring 2009
Solutions to review problems

1. For the circuit shown below, a power supply of $\pm 15V$ is used. The opamp utilizes a bias current $I_Q = 50mA$ and exhibits a short-circuit current $I_{ss} = 20mA$ but can otherwise be considered ideal. If $i_S = 1mA$, $R_2 = 10k\Omega$ and $R_1 = R_L = 1k\Omega$, determine the following quantities:

   (a) output voltage v_O,
   ANSWER: $v_O = -i_S R_2 = -1mA \times 10k\Omega = -10V$

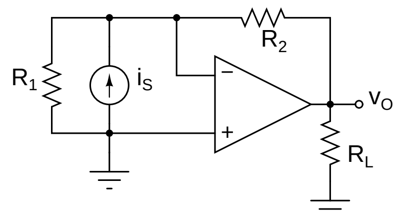
   (b) opamp output current and direction,
   ANSWER: A current of $10V/1k\Omega = 10mA$ flows upward through R_L. The opamp output current is $i_S + i_L = 11mA$ flowing into the opamp.

   (c) power dissipated by the opamp,
   ANSWER: Since $i_S = I_{ss}$, the opamp won't limit the current. Thus

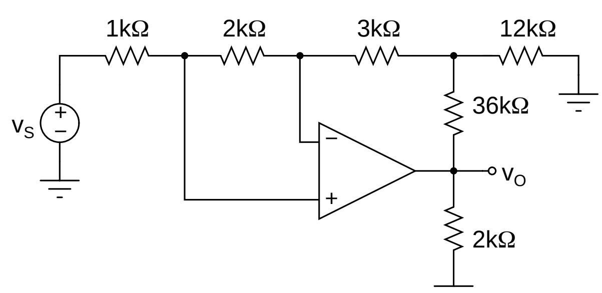
   $$P_{opamp} = I_Q \times 30V + (-10V - (-15V))i_O = 50mA \times 30V + 11mA \times 5V = 1555mW$$

   (d) power dissipated by the whole circuit.

   $$P_{total} = P_{opamp} + i_L^2 R_L + i_S^2 R_2 = 1555mW + 110mW = 1660mW$$



2. Assuming the opamp of the following circuit has an open-loop gain $a = 3000V/V$, $r_d = \infty$ and $r_o = 0$, find the voltage gain $A_v = \frac{v_O}{v_S}$ for the following circuit.



ANSWER: Let v_A be the voltage ate the node common to the $3k$, $12k$ and $36k$ resistors.

$$
\begin{aligned}
i_{2k} &= \frac{v_d}{2k} = i_{1k} = i_{3k} \\
v_A &= v_S - i_{2k} \times 6k = v_S - 3v_d \\
i_{12k} &= v_A/12k \rightarrow \\
v_O &= v_A - (i_{2k} - i_{12k})36k \\
&= v_S - 3v_d - 36\left(\frac{v_d}{2} - \frac{v_S}{12} + \frac{3v_d}{12}\right) \\
&= v_S - 3v_d - 18v_d + 3v_S - 9v_d \\
&= 4v_S - 30v_d = 4v_S - \frac{30v_O}{3000} = 4v_S - 0.01 \times v_O \\
\frac{v_O}{v_S} &= \frac{4}{1.01}
\end{aligned}
$$

3. For the circuit shown in problem 2, determine the loop gain T using the same parameters for the opamp.

   ANSWER:

$$\beta = \frac{2}{6} \times \frac{12 \parallel 6}{12 \parallel 6 + 36} = \frac{1}{3} \times \frac{4}{40} = \frac{1}{30}$$

$$T = a\beta = \frac{3000}{30} = 100V/V$$

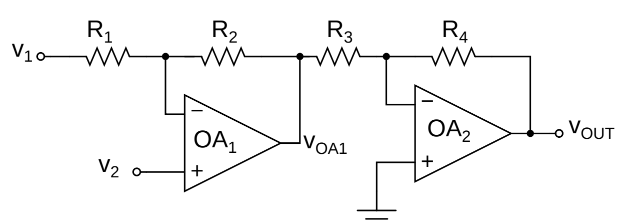
4. Show that the result obtain in problem 2 is consistent with the feedback formula $A_V = A_{ideal}\frac{1}{1+\frac{1}{T}}$.

   ANSWER:

$$A_{ideal} = \frac{v_S + 36 \times v_S/12}{v_S} = 4V/V$$

$$A_V = 4V/V \times \frac{1}{1 + \frac{1}{100}} = \frac{4}{1.01}$$

5. For the following circuit,

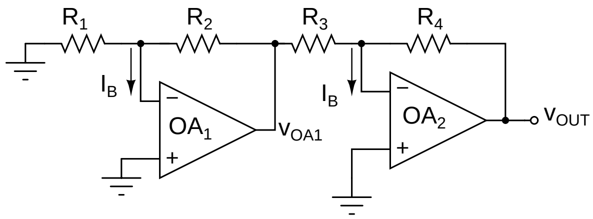


let both v_1 and v_2 be connected to ground and consider only the effect of each transistor's bias current I_B. Assume that current I_B flows into the + and - inputs of each opamp and that the opamps are matched (i.e. identical).

(a) Find the relationship between the resistance values that causes the cancelation of the error due to the bias current. Consider only the resistors shown in the above figure.

ANSWER:

The circuit looks as follows:



So $v_{OA1} = i_B R_2$ and $i_{R_3} = \frac{R_2}{R_3} I_B$. If $i_{R_3} = I_B$, then no current flows through R_4 and $v_{OUT} = 0$. So the relationship that we are seeking is

$$\boxed{R_2 = R_3}$$

(b) Determine the worse-case error due to the offset voltage $\mid V_{OS} \mid \leq 1mV$ if R_1, R_2, R_3 and R_4 are chosen so that: (i) the overall voltage gain is 25V/V; (ii) the input is v_1 and (iii) no resistor is less than $1k\Omega$; and (iv) the relationship found in part (a) is satisfied.

ANSWER:

To have an overall gain of 25V/V, select $R_1 = 1k\Omega$, $R_2 = R_3 = 5k\Omega$ and $R_4 = 25k\Omega$.

The first stage V_{OS} will be amplified by a factor $6 \times 5 = 30$. The gain for the second stage V_{OS} is 6. Thus

$$\boxed{E_O = 36mV}$$