Subject: ECE221 Fall'12 PS 6 Solution
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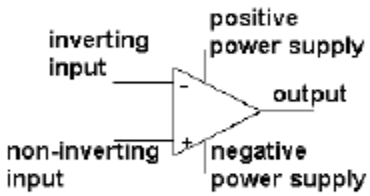
ECE221 Fall'12 PS 6 Solution
(5.1, 5.6, 5.9, 5.13, 5.16, 5.27, 5.34, 5.41)

P 5.1 [a] The five terminals of the op amp are identified as follows:



[b] The input resistance of an ideal op amp is infinite, which constrains the value of the input currents to 0. Thus, $i_n = 0$ A.

[c] The open-loop voltage gain of an ideal op amp is infinite, which constrains the difference between the voltage at the two input terminals to 0. Thus, $(v_p - v_n) = 0$.

[d] Write a node voltage equation at v_n:

$$\frac{v_n + 3}{5000} + \frac{v_n - v_o}{15{,}000} = 0$$

But $v_p = 0$ and $v_n = v_p = 0$. Thus,

$$\frac{3}{5000} - \frac{v_o}{15{,}000} = 0 \quad \text{so} \quad v_o = 9 \text{ V}$$

P 5.6 [a] $i_2 = \dfrac{150 \times 10^{-3}}{2000} = 75\,\mu\text{A}$

$$v_1 = -40 \times 10^3 i_2 = -3\,\text{V}$$

[b] $\dfrac{v_1}{20{,}000} + \dfrac{v_1}{40{,}000} + \dfrac{v_1 - v_o}{50{,}000} = 0$

$$\therefore \quad v_o = 4.75 v_1 = -14.25 \text{ V}$$

[c] $i_2 = 75\,\mu\text{A}$, (from part [a])

[d] $i_o = \dfrac{-v_o}{25{,}000} + \dfrac{v_1 - v_o}{50{,}000} = 795\,\mu \text{ A}$

P 5.9 [a] Replace the combination of v_g, $1.6\,\text{k}\Omega$, and the $6.4\,\text{k}\Omega$ resistors with its Thévenin equivalent.

Then $v_o = \dfrac{-[12 + \sigma 50]}{1.28}(0.20)$

At saturation $v_o = -5$ V; therefore

$$-\left(\frac{12 + \sigma 50}{1.28}\right)(0.2) = -5, \quad \text{or} \quad \sigma = 0.4$$

Thus for $0 \leq \sigma \leq 0.40$ the operational amplifier will not saturate.

[b] When $\sigma = 0.272$, $v_o = \dfrac{-(12 + 13.6)}{1.28}(0.20) = -4$ V

Also $\dfrac{v_o}{10} + \dfrac{v_o}{25.6} + i_o = 0$

$$\therefore \quad i_o = -\frac{v_o}{10} - \frac{v_o}{25.6} = \frac{4}{10} + \frac{4}{25.6}\,\text{mA} = 556.25\,\mu\text{A}$$

P 5.13 We want the following expression for the output voltage:

$$v_o = -(3v_a + 5v_b + 4v_c + 2v_d)$$

This is an inverting summing amplifier, so each input voltage is amplified by a gain that is the ratio of the feedback resistance to the resistance in the forward path for the input voltage. Pick a feedback resistor with divisors of 3, 5, 4, and 2 – say 60 kΩ:

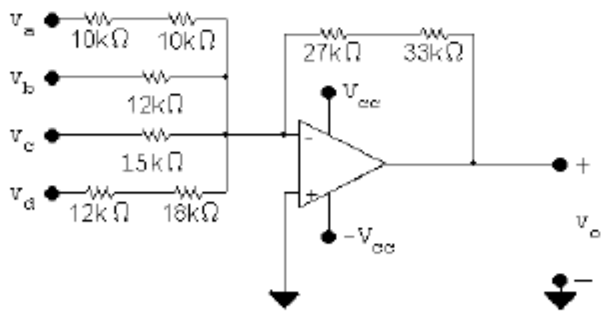
$$v_o = -\left[\frac{60\text{k}}{R_\text{a}}v_\text{a} + \frac{60\text{k}}{R_\text{b}}v_\text{b} + \frac{60\text{k}}{R_\text{c}}v_\text{c} + \frac{60\text{k}}{R_\text{d}}v_\text{d}\right]$$

Solve for each input resistance value to yield the desired gain:

$\therefore \quad R_\text{a} = 60{,}000/3 = 20\,\text{k}\Omega \qquad R_\text{c} = 60{,}000/4 = 15\,\text{k}\Omega$

$R_\text{b} = 60{,}000/5 = 12\,\text{k}\Omega \qquad R_\text{d} = 60{,}000/2 = 30\,\text{k}\Omega$

Now create the 5 resistor values needed from the realistic resistor values in Appendix H. Note that $R_\text{b} = 12\,\text{k}\Omega$ and $R_\text{c} = 15\,\text{k}\Omega$ are already values from Appendix H. Create $R_\text{f} = 60\,\text{k}\Omega$ by combining $27\,\text{k}\Omega$ and $33\,\text{k}\Omega$ in series. Create $R_\text{a} = 20\,\text{k}\Omega$ by combining two $10\,\text{k}\Omega$ resistors in series. Create $R_\text{d} = 30\,\text{k}\Omega$ by combining $18\,\text{k}\Omega$ and $12\,\text{k}\Omega$ in series. Of course there are many other acceptable possibilities. The final circuit is shown here:



P 5.16 [a] The circuit shown is a non-inverting amplifier.

[b] We assume the op amp to be ideal, so $v_n = v_p = 3$ V. Write a KCL equation at v_n:

$$\frac{3}{40{,}000} + \frac{3 - v_o}{80{,}000} = 0$$

Solving,

$v_o = 9$ V.

P 5.27 $v_p = \dfrac{v_b R_b}{R_a + R_b} = v_n$

$$\frac{v_n - v_a}{4700} + \frac{v_n - v_o}{R_f} = 0$$

$$v_n\left(\frac{R_f}{4700} + 1\right) - \frac{v_a R_f}{4700} = v_o$$

$$\therefore \quad \left(\frac{R_f}{4700} + 1\right)\frac{R_b}{R_a + R_b} v_b - \frac{R_f}{4700} v_a = v_o$$

$$\therefore \quad \frac{R_f}{4700} = 10; \qquad R_f = 47\,\text{k}\Omega \qquad \text{(a value from Appendix H)}$$

$$R_a + R_b = 220\,\text{k}\Omega$$

Thus,

$$\left(1 + \frac{47}{4700}\right)\left(\frac{R_b}{220{,}000}\right) = 10$$

$$\therefore \qquad R_b = 200\,\text{k}\Omega \qquad \text{and} \qquad R_a = 220 - 200 = 20\,\text{k}\Omega$$

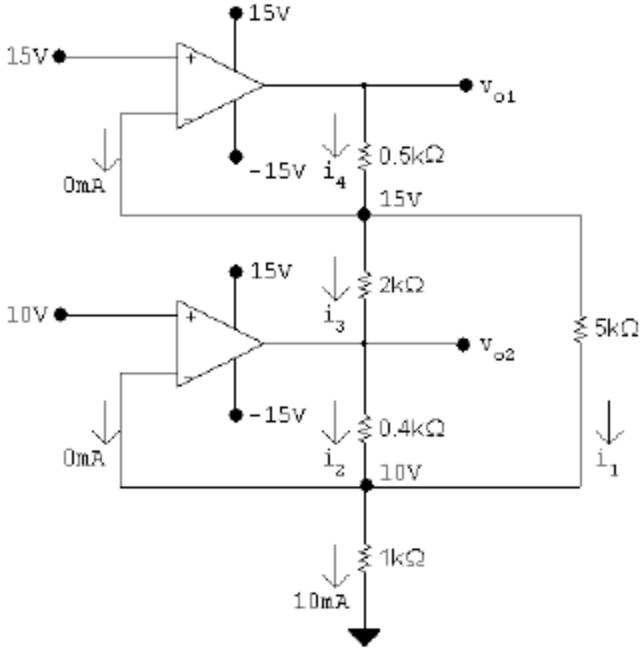
Use two $100\,\text{k}\Omega$ resistors in series for R_b and use two $10\,\text{k}\Omega$ resistors in series for R_a.

P 5.34 **[a]** $A_{dm} = \dfrac{(24)(26) + (25)(25)}{(2)(1)(25)} = 24.98$

[b] $A_{cm} = \dfrac{(1)(24) - 25(1)}{1(25)} = -0.04$

[c] $\text{CMRR} = \left|\dfrac{24.98}{0.04}\right| = 624.50$

P 5.41



$$i_1 = \frac{15 - 10}{5000} = 1\,\text{mA}$$

$$i_2 + i_1 + 0 = 10\,\text{mA}; \qquad i_2 = 9\,\text{mA}$$

$$v_{o2} = 10 + (400)(9) \times 10^{-3} = 13.6 \text{ V}$$

$$i_3 = \frac{15 - 13.6}{2000} = 0.7\,\text{mA}$$

$$i_4 = i_3 + i_1 = 1.7\,\text{mA}$$

$$v_{o1} = 15 + 1.7(0.5) = 15.85 \text{ V}$$