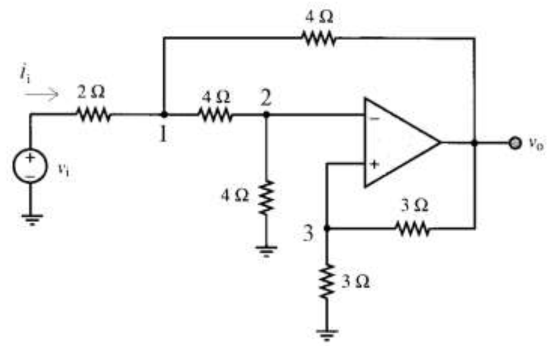
ELG 3736

Liste des problèmes suggérés pour les Amplificateurs Opérationnels (OP-AMPs)

Problem 8.9

Note: The +/- terminals of the op amp are inverted in Figure P8.9.

Solution:



Known quantities:

The circuit of Figure P8.9.

Find:

The overall gain $A_v = v_o/v_i$; input conductance $G_{in} = i_i/i_o$

Analysis:

Applying KVL at node 1:

$$\frac{v_1 - v_i}{2} + \frac{v_1 - v_2}{4} + \frac{v_1 - v_o}{4} = 0$$

Or $-2v_i + 4v_1 - v_2 = v_o$ (1)

Again, at node 2:

$$\frac{v_2 - v_1}{4} + \frac{v_2}{4} = 0$$

Or $2v_2 = v_1$ (2)

Similarly, at node 3:

$$\frac{v_2}{3} + \frac{v_2 - v_o}{3} = 0$$

Or $v_2 = \frac{1}{2}v_o$ (3)

Substituting (3) into (2):

$v_o = v_1$

Substituting (2) and (3) into (3):

$$-2v_i = v_o + \frac{1}{2}v_o - 8\left(\frac{1}{2}v_o\right)$$

Or $\frac{v_o}{v_i} = \frac{4}{5}$

$\therefore A_v = \frac{4}{5}$

Now, since

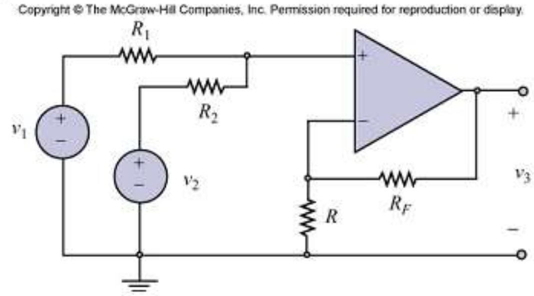
$$i_i = \frac{v_i - v_1}{2} = \frac{v_i - v_o}{2} = \frac{v_i - \frac{4}{5}v_i}{2} = \frac{1}{8}v_i$$

then

$$G = \frac{i_i}{v_i} = \frac{1}{8}S$$

Problem 8.19

Note: The +/- terminals of the op amp are inverted in Figure P8.19.



Solution:

Known quantities:

The circuit of Figure P8.19.

Find:

Show that this circuit is a noninverting summer.

Analysis:

Applying KCL at the inverting terminal: $V_3 = (1 + \frac{R_f}{R})V^-$

Applying KCL at the noninverting terminal:

$$(\frac{1}{R_2} + \frac{1}{R_1})V^+ - \frac{V_2}{R_2} - \frac{V_1}{R_1} = 0$$

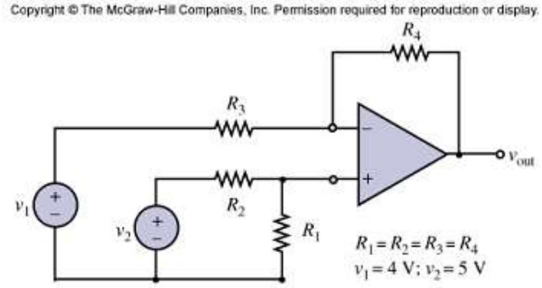
or $$V^+ = \frac{R_1}{R_1 + R_2}V_2 + \frac{R_2}{R_1 + R_2}V_1$$

therefore,

$$V_3 = (1 + \frac{R_f}{R})(\frac{R_1}{R_1 + R_2}V_2 + \frac{R_2}{R_1 + R_2}V_1)$$

and the circuit does indeed compute the weighted sum of the inputs.

Problem 8.20



Solution:

Known quantities:

The circuit of Figure P8.20.

Find:

The voltage v and the current i.

Analysis:

The circuit is shown on the right:

Applying nodal analysis to V^+, $\frac{V_2 - V^+}{R_2} = \frac{V^+}{R_1}$ So $V^+ = \frac{V_2}{2} = 2.5$ V

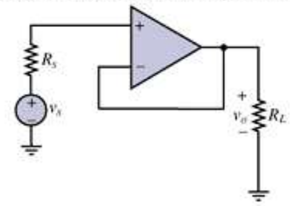
Applying nodal analysis to V^-,

$$\frac{V_1 - V^-}{R_3} = \frac{V^- - V_{out}}{R_4}$$ and $V^+ = V^-$, So $V_{out} = V_1 - 2V^- = 1\text{V}$

Problem 8.31

Solution:

Known quantities:



For the circuit shown in Figure P8.31:

$v_S(t) = 0.05 + 30 \cdot 10^{-3}\cos(\omega t)\text{V}$, $R_S = 50\Omega$, $R_L = 200\Omega$.

Find:

The output voltage v_o.

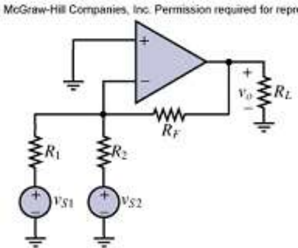
Analysis:

It is a particular case of a noninverting amplifier where $v_0 = v_S$.

Problem 8.34

Solution:

Known quantities:



If, in the circuit shown in Figure P8.34:

$v_{S1} = v_{S2} = 7\text{ mV} \quad R_1 = 850\,\Omega \quad R_2 = 1.5\text{ k}\Omega \quad R_F = 2.2\text{ k}\Omega$

Op Amp: *Motorola MC1741C*

$r_i = 2\text{ M}\Omega \quad \mu = 200{,}000 \quad r_o = 25\,\Omega$

Find:

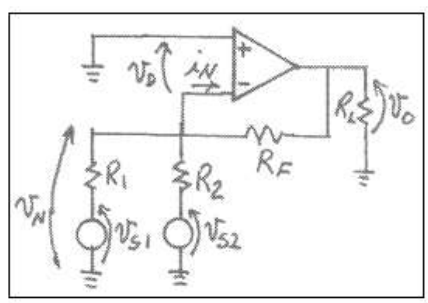
a) The output voltage.
b) The voltage gain for the two input signals.

Analysis:

a) The op amp has a very large input resistance, a very large "open loop gain" [μ], and a very small output resistance. Therefore, it can be modeled with small error as an ideal op amp with:

$$KVL: \; v_D + v_N = 0$$

$$v_D \approx 0 \quad \Rightarrow \quad v_N \approx 0$$



$$KCL:$$

$$i_N + \frac{v_N - v_{S2}}{R_2} + \frac{v_N - v_{S1}}{R_1} + \frac{v_N - v_O}{R_F} = 0$$

$$v_N \approx 0 \quad i_N \approx 0$$

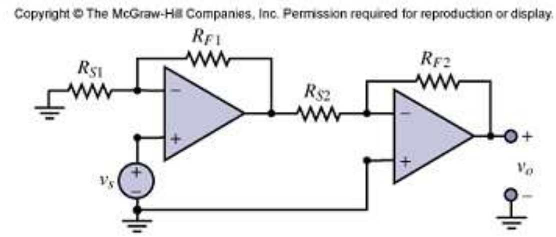
$$\Rightarrow v_O = -\frac{R_F}{R_1}v_{S1} - \frac{R_F}{R_2}v_{S2} = [-\frac{2.2}{0.85}][7\text{ mV}] + [-\frac{2.2}{1.5}][7\text{ mV}]$$

$$= [-2.588][7\text{ mV}] + [-1.467][7\text{ mV}] = -28.38\text{ mV}$$

b) Using the results above: $A_{V1} = -2.588$ $\qquad A_{V2} = -1.467$.
Note: The output voltage and gain are not dependent on either the op amp parameters or the load resistance. This result is extremely important in the majority of applications where amplification of a signal is required.

Problem 8.44

Solution:



Known quantities:

Circuit in Figure P8.44.

Find:

The output voltage v_o.

Analysis:

The circuit is a cascade of a noninverting op-amp with an inverting op-amp. Assuming ideal op-amps, the input-output voltage gain is equal to the product of the single gains, therefore

$$v_0 = -\frac{R_{F2}}{R_{S2}}\left(1+\frac{R_{F1}}{R_{S1}}\right)v_S$$

P 6.3-14 ⊕ Determine the node voltages at nodes a, b, c, and d of the circuit shown in Figure P 6.3-14.

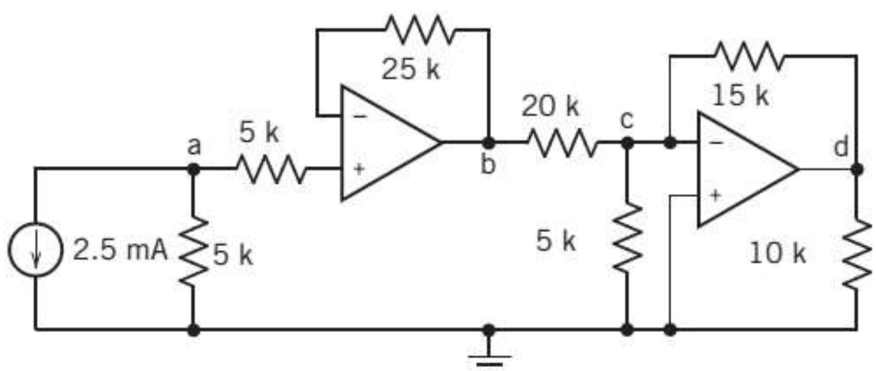
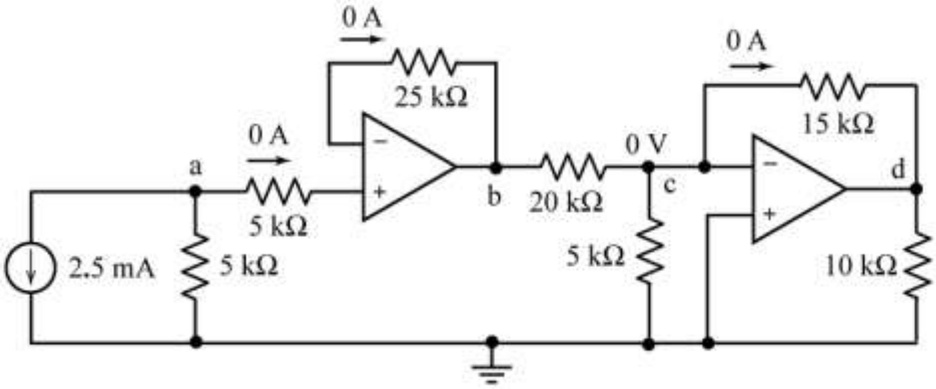


Figure P 6.3-14

Solution:

Label the circuit as shown, noticing that some resistor currents are zero because these currents are also input currents of op amps:



Now $v_a = -2.5(5) = -12.5$ V, $v_b = v_a = -12.5$ V, $v_c = 0$ V

Apply KCL to get

$$\frac{v_b - 0}{20} = 0 + \frac{0 - v_d}{15} \Rightarrow v_d = -\frac{15}{20} v_b = -\frac{3}{4}(-12.5) = 9.375 \text{ V}$$

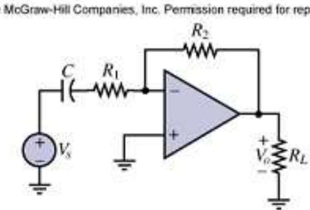
Problem 8.53

Solution:

Known quantities:

For the circuit shown in Figure P8.53: $C = 1\,\mu\text{F} \quad R_1 = 1.8\text{k}\Omega \quad R_2 = 8.2\text{k}\Omega \quad R_L = 333\Omega$.

Find:



a) Whether the circuit is a low- or high-pass filter.
b) The gain V_0/V_S in decibel in the passband.
c) The cutoff frequency.

Analysis:

a) From Figure 8.25, it results that the amplifier in Figure P8.53 is a high-pass filter.

In fact, the output voltage is $\mathbf{V}_0(j\omega) = -\dfrac{j\omega CR_2}{1 + j\omega CR_1}\mathbf{V}_S(j\omega)$

b) $\lim\limits_{\omega\to\infty}\left|\dfrac{\mathbf{V}_0(j\omega)}{\mathbf{V}_S(j\omega)}\right|_{dB} = 20\,\text{Log}\dfrac{R_2}{R_1} = 20\,\text{Log}\dfrac{8.2}{1.8} = 13.17 \text{ dB}$

c) $\omega_0 = \dfrac{1}{CR_1} = \dfrac{1}{1\cdot 10^{-6}\cdot 1.8\cdot 10^3} = 5555 \text{ rad/s}$

Problem 8.57

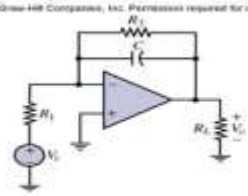
Solution:

Known quantities:

For the circuit shown in Figure P8.57: $C = 0.47\ \mu\text{F} \quad R_1 = 9.1\text{k}\Omega \quad R_2 = 22\text{k}\Omega \quad R_L = 2.2\text{k}\Omega$.

Find:

a) Whether the circuit is a low- or high-pass filter.
b) An expression in standard form for the voltage transfer function.
c) The gain in decibels in the passband, that is, at the frequencies being passed by the filter, and the cutoff frequency.



Analysis:

a).From Figure 8.22, it results that the amplifier in Figure P8.57 is a low-pass filter.In fact, the output voltage is

$$\mathbf{V}_0(j\omega) = -\frac{R_2}{R_1}\frac{1}{1 + j\omega CR_2}\mathbf{V}_S(j\omega)$$

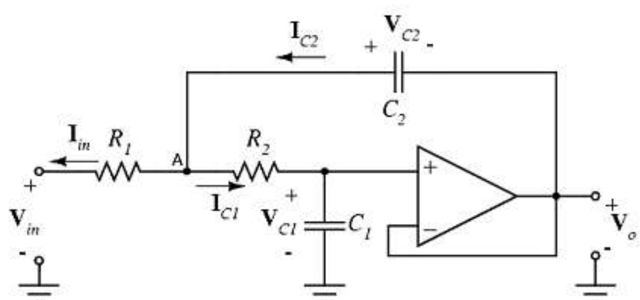
b). $H_v(j\omega) = \dfrac{\mathbf{V}_0(j\omega)}{\mathbf{V}_i(j\omega)} = -\dfrac{R_2}{R_1}\dfrac{1}{1 + j\omega CR_2}$

c) The gain in decibel is obtained by evaluating $|H_v(j\omega)|$ at ω=0, $|H_v(j0)|_{dB} = 20\,\text{Log}\dfrac{R_2}{R_1} = 20\,\text{Log}\dfrac{22}{9.1} = 7.66$ dB.

The cutoff frequency is $\omega_0 = \dfrac{1}{CR_2} = \dfrac{1}{0.47 \cdot 10^{-6} \cdot 22 \cdot 10^3} = 96.71$ rad/s

Problem 8.64

Solution:



Known quantities:

For the circuit shown in Figure P8.64, let

$C = C_1 = C_2 = 100\ \mu\text{F} \quad R_1 = 3\text{k}\Omega \quad R_2 = 2\text{k}\Omega$.

Find:

Determine an expression for the gain.

Analysis:

With reference to the Figure shown above, we have

$$\mathbf{V}_{C1}(j\omega) = \mathbf{V}_O(j\omega) \Rightarrow \mathbf{I}_{C1}(j\omega) = j\omega C_1\mathbf{V}_O(j\omega),$$

$$\mathbf{V}_A(j\omega) = R_2\mathbf{I}_{C1}(j\omega) + \mathbf{V}_O(j\omega) = (1 + j\omega C_1R_2)\mathbf{V}_O(j\omega),$$

$$\mathbf{I}_{C2}(j\omega) = j\omega C_2(\mathbf{V}_O(j\omega) - \mathbf{V}_A(j\omega)) = -(j\omega)^2 C_1C_2R_2\,\mathbf{V}_O(j\omega),$$

$$\mathbf{V}_{in}(j\omega) = \mathbf{V}_A(j\omega) - R_1(\mathbf{I}_{C2}(j\omega) - \mathbf{I}_{C1}(j\omega)) = \left(1 + j\omega C_1(R_1 + R_2) + (j\omega)^2 C_1C_2R_1R_2\right)\mathbf{V}_O(j\omega)$$

And finally, the expression for the gain is

$$A_v(j\omega) = \frac{\mathbf{V}_O(j\omega)}{\mathbf{V}_{in}(j\omega)} = \frac{1}{1 + j\omega C(R_1 + R_2) + (j\omega)^2 C^2R_1R_2} = \frac{1}{(1 + j\omega CR_1)(1 + j\omega CR_2)}$$

Problem 8.81

Solution:

Known quantities:

Find:

Consider a differential amplifier. We would desire the common-mode output to be less than 1% of the differential-mode output. Find the minimum dB common-mode rejection ratio (*CMRR*) that fulfills this requirement if the differential mode gain $A_{dm} = 1{,}000$. Let

$$v_1 = \sin(2{,}000\pi t) + 0.1\sin(120\pi)\text{V}$$

$$v_2 = \sin(2{,}000\pi t + 180^o) + 0.1\sin(120\pi)\text{V}$$

$$v_0 = A_{dm}(v_1 - v_2) + A_{cm}\left(\frac{v_1 + v_2}{2}\right)$$

Analysis:

We first determine which is the common mode and which is the differential mode signal:

$$v_1 - v_2 = 2\sin(2{,}000\pi t)$$

$$\frac{v_1 + v_2}{2} = 0.1\sin(120\pi t)$$

Therefore, $v_{out} = A_{dm} 2\sin(2000\pi t) + A_{cm} 2$ [illegible] $20\pi t)$

Since we desire the common mode output to be less than 1% of the differential mode output, we require:

$A_{cm}(0.1) \le 0.01(2)$ or $A_{cm} \le 0.2$.

$CMRR = \dfrac{A_{dif}}{A_{cm}}$ So $CMRR_{\min} = \dfrac{1000}{0.2} = 5000 = 74 \text{ dB}$.

P 6.3-9 Determine the voltage v_o for the circuit shown in Figure P 6.3-9.

Answer: $v_o = -8$ V

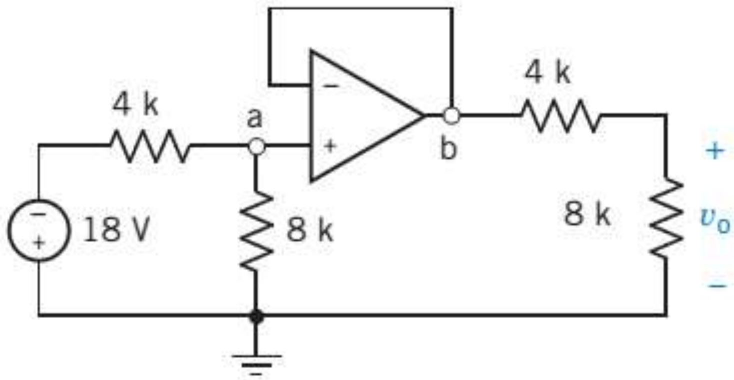


Figure P 6.3-9

P 6.4-2 Find v_o and i_o for the circuit of Figure P 6.4-2.

Answer: $v_o = -4$ V and $i_o = 1.33$ mA

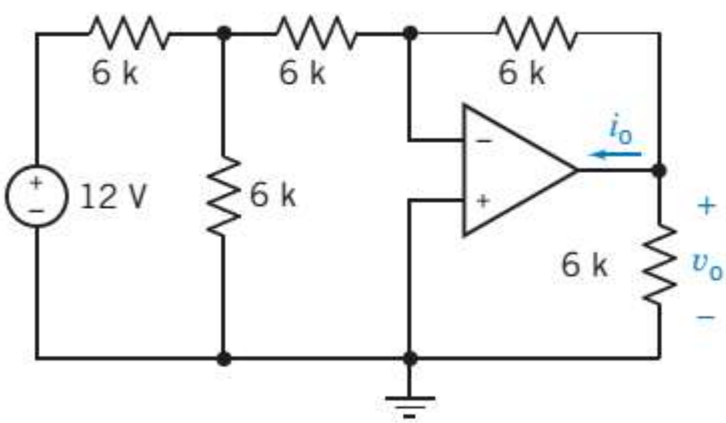


Figure P 6.4-2