DR. GYURCSEK ISTVÁN

Exercises with Operational Amplifiers

Sources and additional materials (recommended)

- *Dr. Gyurcsek – Dr. Elmer: Theories in Electric Circuits, GlobeEdit, 2016, ISBN:978-3-330-71341-3*
- *Ch. Alexander, M. Sadiku: Fundamentals of Electric Circuits, 6th Ed., McGraw Hill NY 2016, ISBN: 978-0078028229*
- *Simonyi K.: Villamosságtan. AK Budapest 1983, ISBN:9630534134*
- *Dr. Selmeczi K. – Schnöller A.: Villamosságtan 1. MK Budapest 2002, TK szám: 49203/I*
- *Dr. Selmeczi K. – Schnöller A.: Villamosságtan 2. TK Budapest 2002, ISBN:9631026043*

AMP.01 – Calculate the closed-loop gain (v_0/v_S) and i_0 when v_s = 1V.

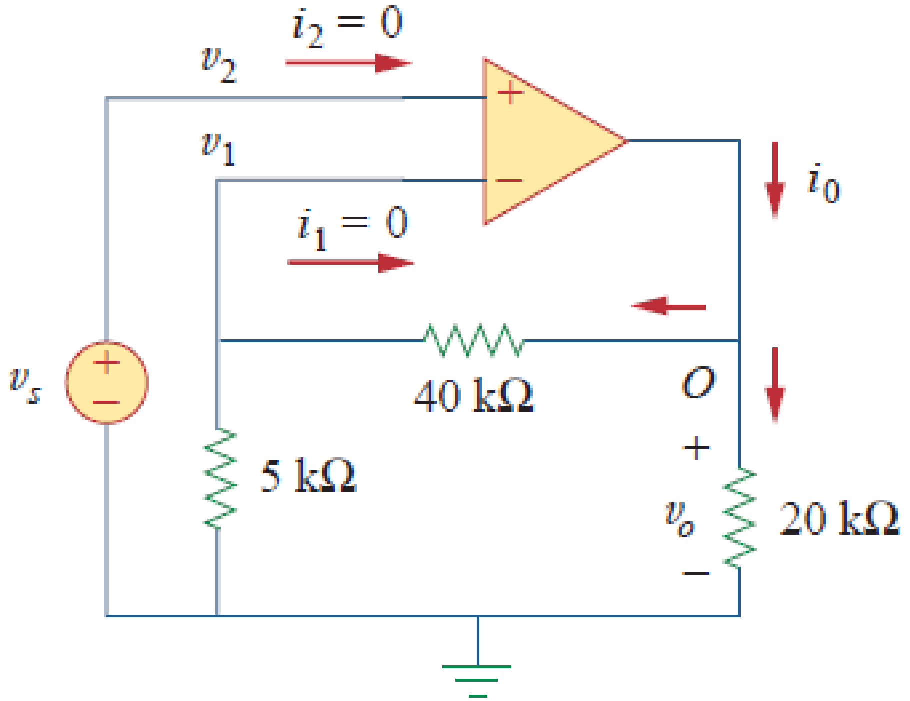
Solution

$$v_2 = v_S\,, v_1 = \frac{5}{5+40}\cdot v_0 = \frac{v_0}{9}$$

$$v_2 = v_1 \rightarrow v_S = \frac{v_0}{9} \rightarrow \frac{v_0}{v_S} = 9$$

$$i_0 = \left(\frac{v_0}{40+5} + \frac{v_0}{20}\right) mA$$

$$v_S = 1\,V\} \rightarrow \begin{cases} v_0 = 9\,V \\ i_0 = 0.2 + 0.45 = 0.65\,mA \end{cases}$$



Recall AMP.02 example (real op amp):

A = 2 10^5, R_i = 2 MΩ, R_o = 50 Ω → closed-loop gain = 9.00041 and , i_0 = 0.657 mA. when v_s = 1V.

Inverter Example

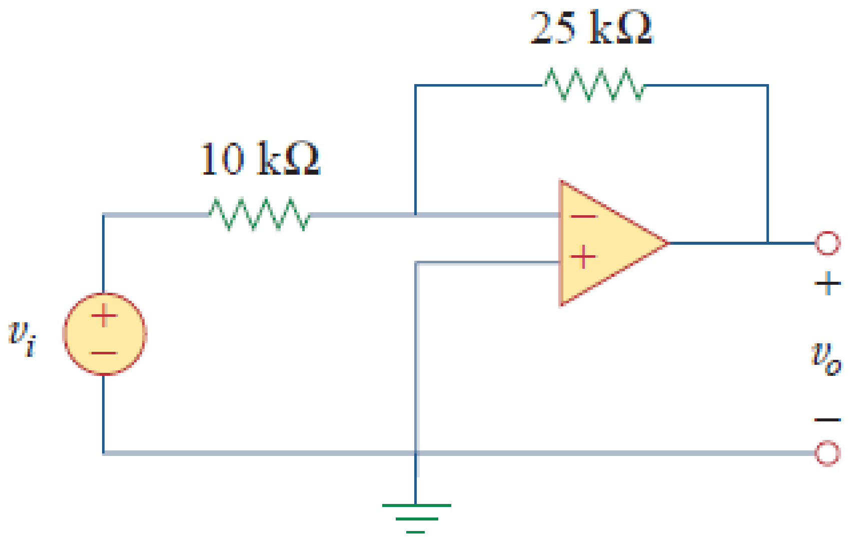
AMP.02 – v_i = 0.5 V. Calculate the output voltage and the input current.

Solution

$$v_0 = -\frac{R_f}{R_1} v_i = -\frac{25}{10} \cdot 0.5 = -1.25\,V$$

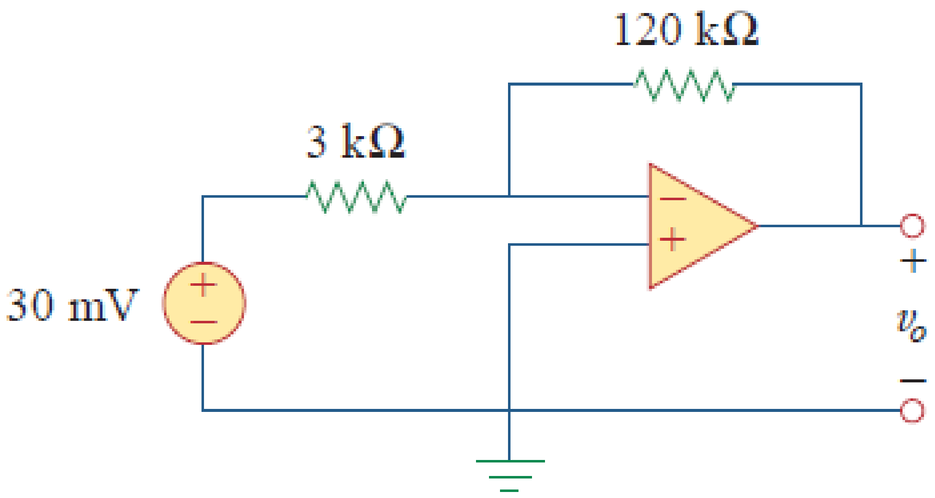
Closed-loop amplification is ‚– 2.5’.

$$i_i = -\frac{v_i - 0}{R_1} = -\frac{0.5}{10 \cdot 10^3} = 50\,\mu A$$



Inverter Example

AMP.03 – Calculate the output voltage and the current through the feedback resistor.



Solution $v_o = -1.2\ V\ ,\ i_f = 10\ \mu A$

Inverter Example

AMP.04 – Calculate the output voltage.

Solution

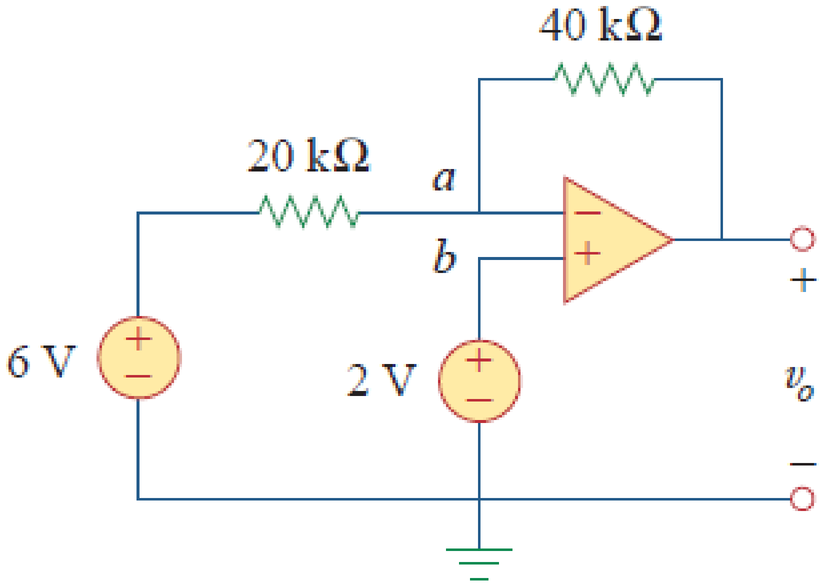
$$\frac{v_a - v_0}{40k} = \frac{6 - v_a}{20k}$$

$$v_a - v_0 = 12 - 2v_a$$

$$v_0 = 3v_a - 12$$

$$v_a = v_b = 2\ V$$

$$v_0 = 6 - 12 = -6\ V$$



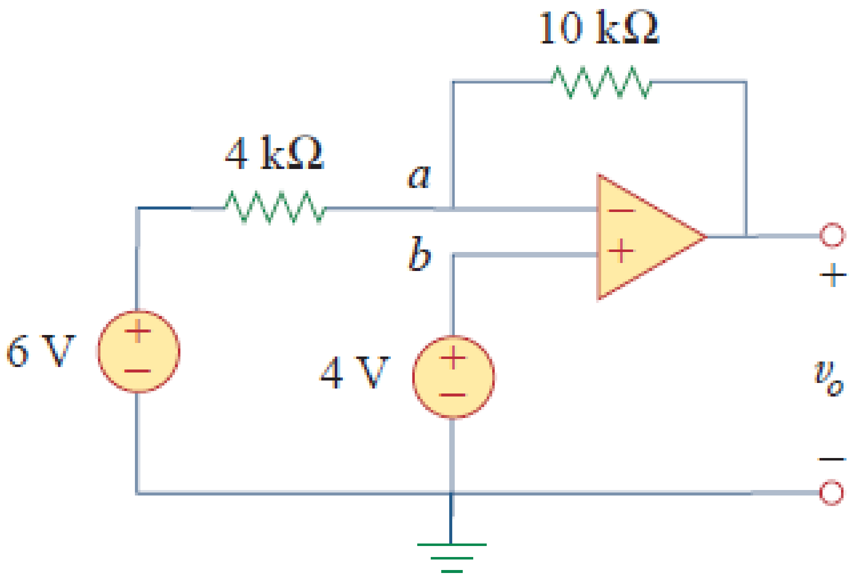
AMP.05 – Find the output voltage.

Solution 1 (by superposition)

$$v_{o1} - \frac{10}{4} \cdot 6 = -15\ V$$

$$v_{o2} \left(1 + \frac{10}{4}\right) \cdot 4 = 14\ V$$

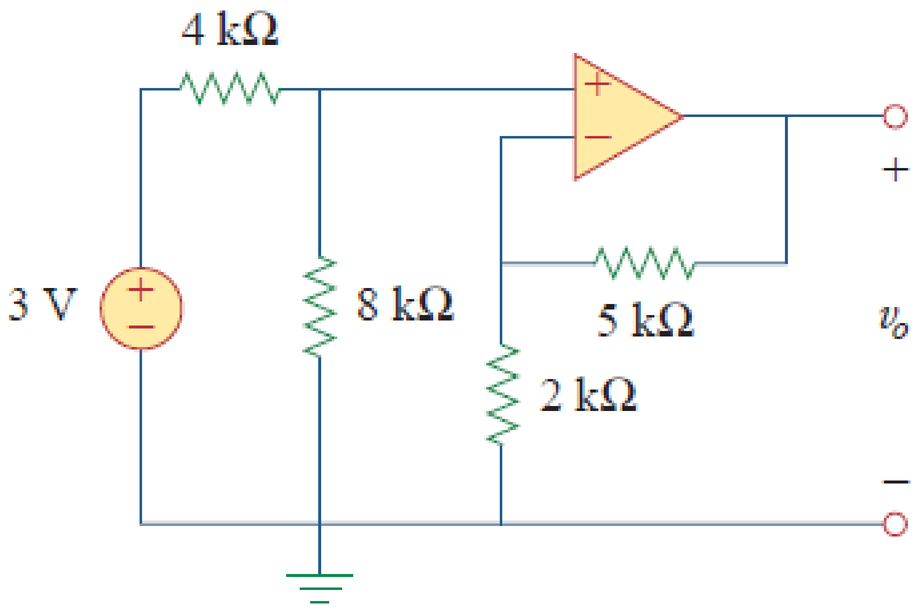
$$v_o = v_{o1} + v_{o2} = -15 + 14 = -1\ \mathrm{V}$$



Solution 2 (by nodal analysis)

$$(\boldsymbol{node\ a}): \frac{6 - v_a}{4} = \frac{v_a - v_o}{10} \qquad v_a = v_b = 4 \rightarrow \frac{6-4}{4} = \frac{4 - v_o}{10} \rightarrow 5 = 4 - v_o \rightarrow v_o = -1\ V$$

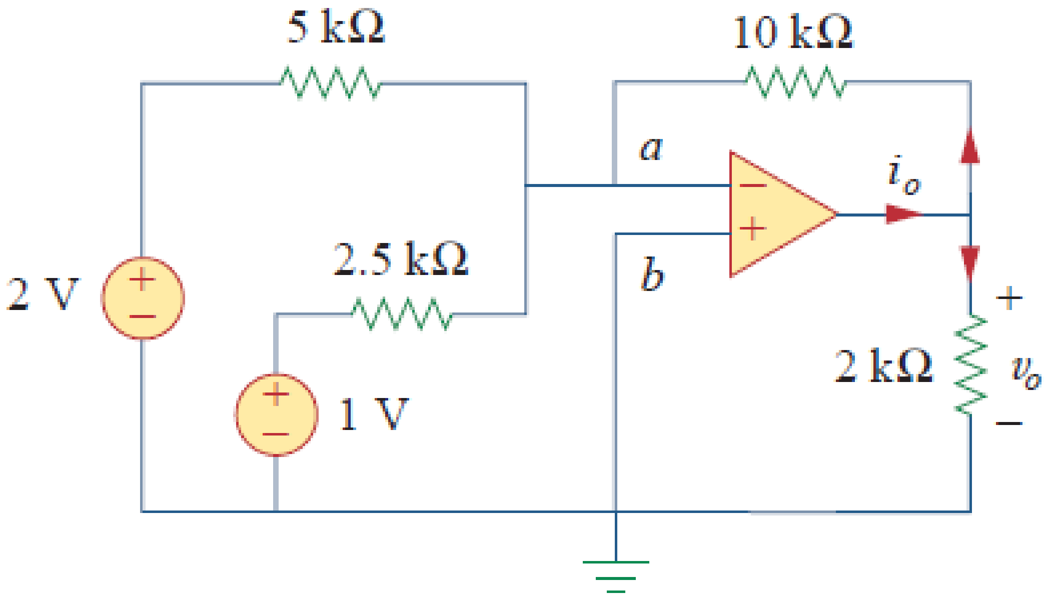
AMP.06 – Find the output voltage.



Solution $v_o = 7\ V$

Summing Amplifier Example

AMP.07 – $v_0 = ?$, $i_0 = ?$



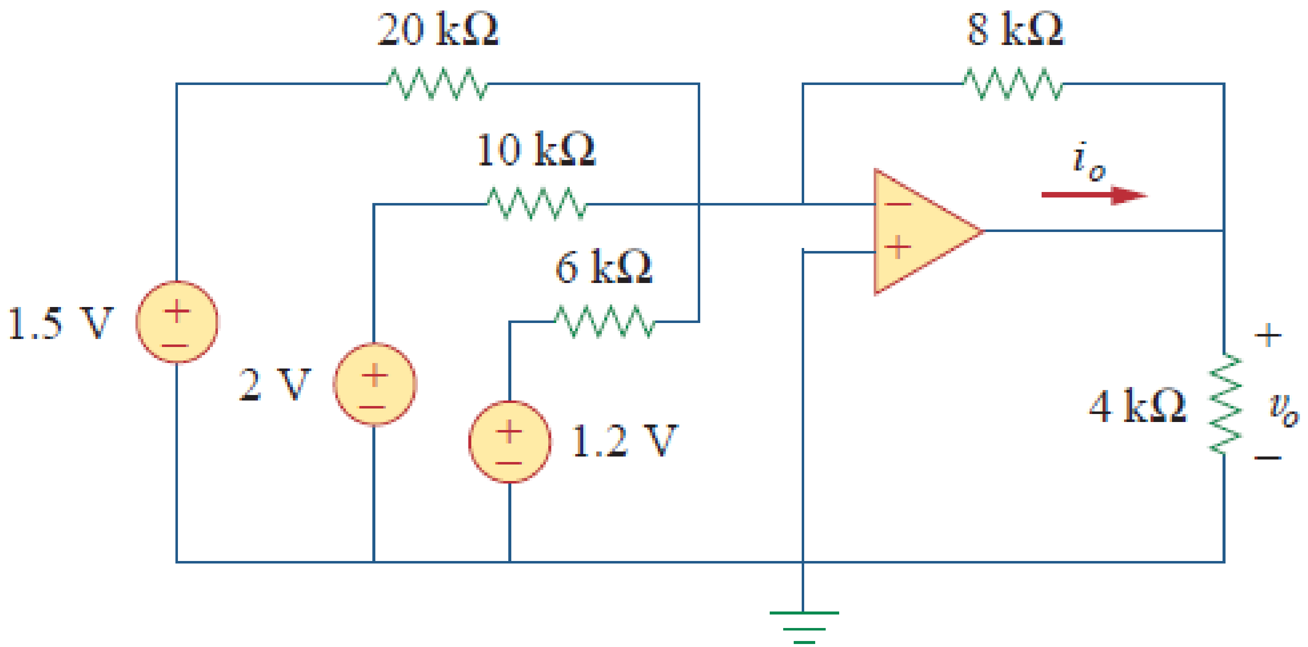
Solution

$$v_0 = -\left(\frac{10}{5} \cdot 2 + \frac{10}{2{,}5} \cdot 1\right) = -8\ V$$

$$i_0 = \frac{v_o - 0}{10} + \frac{v_0 - 0}{2} = -0.8 - 4 = -4.8\ mA$$

Summing Amplifier Example

AMP.08 – v_0 = ?, i_0 = ?



Solution v_0 = - 3.8 V, i_0 = - 1.425 mA

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Difference Amplifier Example

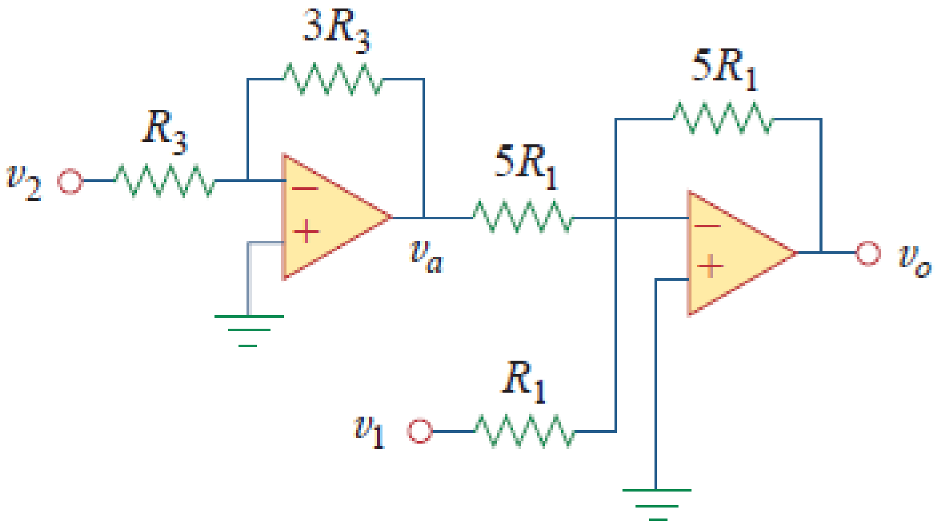
AMP.09 – Design an op amp with output $v_0 = -5v_1 + 3v_2$

Solution (with an iverter AND a summer)

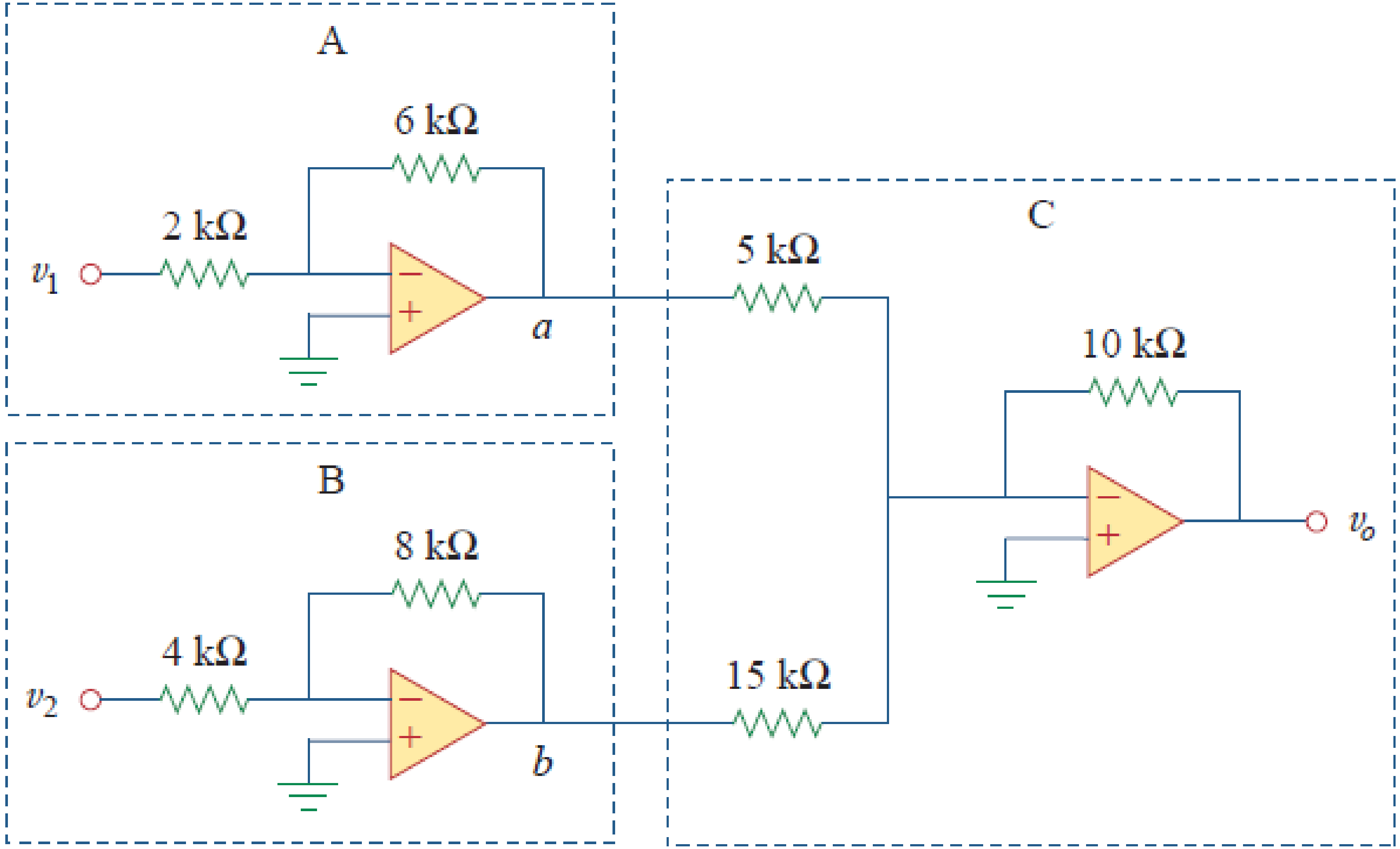
$(\boldsymbol{inverter})$: $v_a = -3v_2$

$(\boldsymbol{summer})$: $v_0 = -(v_a + 5v_1) = 3v_2 - 5v_1$

Let's select $\rightarrow R_1 = R_3 = 10\ k\Omega$



AMP.10 – Find v_0 if v_1 = 1 V and v_2 = 2 V in the circuit.



Solution

$(\boldsymbol{inverter\ 1})$:

$$v_a = -\frac{6k}{2k}v_1 = -3 \cdot 1 = -3\ V$$

$(\boldsymbol{inverter\ 2})$:

$$v_b = -\frac{8k}{4k}v_2 = -2 \cdot 2 = -4\ V$$

$(\boldsymbol{summer})$:

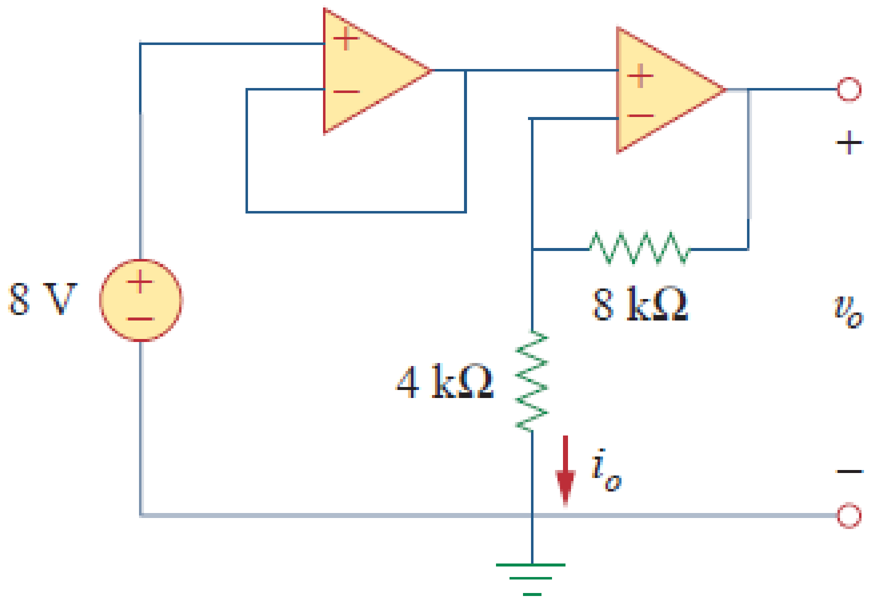
$$v_0 = -\frac{10k}{5k}v_a + \left(-\frac{10k}{15k}v_b\right) =$$

$$v_0 = (-2)(-3) + \left(-\frac{2}{3}\right)(-4) =$$

$$v_0 = 8.67\ V$$

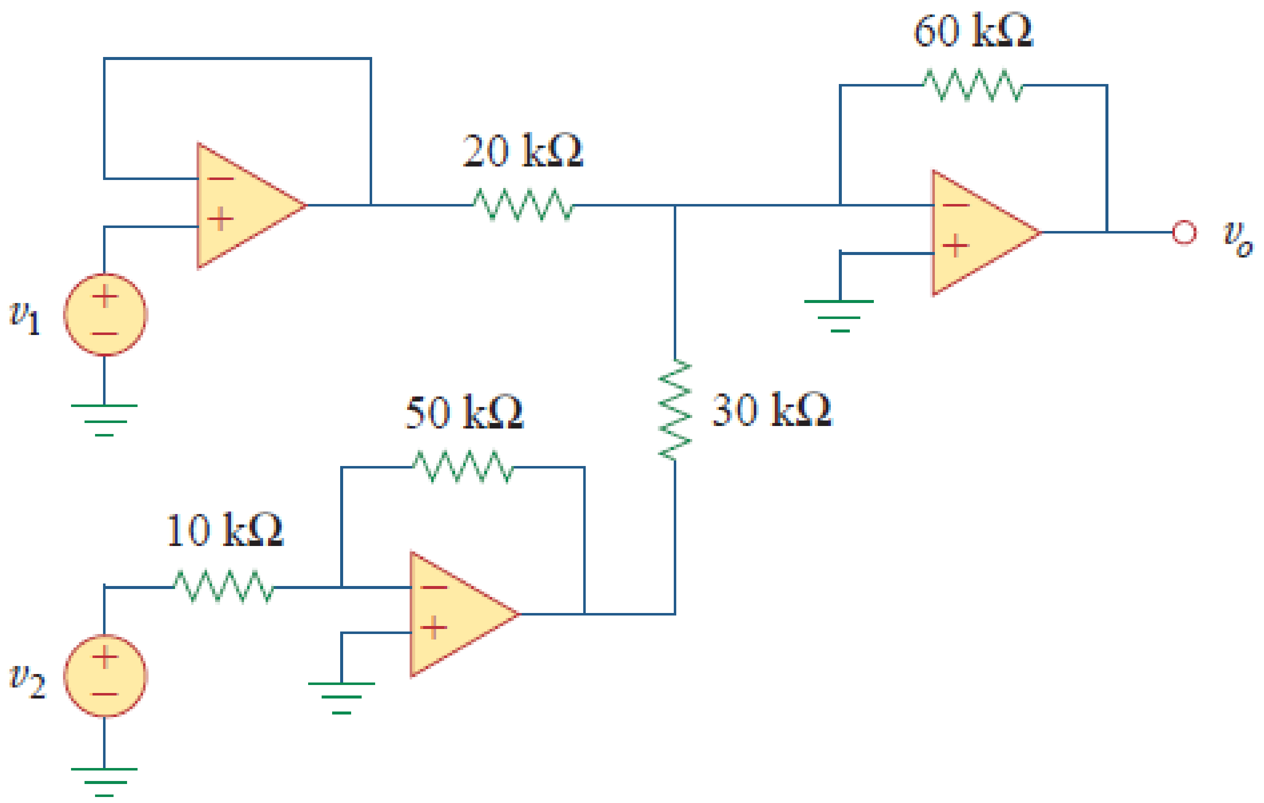
Cascaded Op Amps Example

AMP.11 – Find v_0 and i_0 in the circuit.



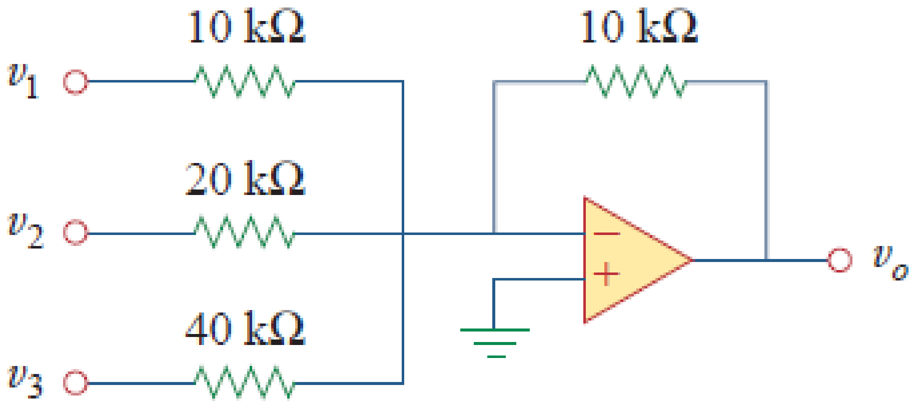
Solution $v_0 = 24\ V$, $i_0 = 2\ mA$

AMP.12 – Find v_0 if v_1 = 4 V and v_2 = 3 V in the circuit.



Solution $v_0 = 18\ V$

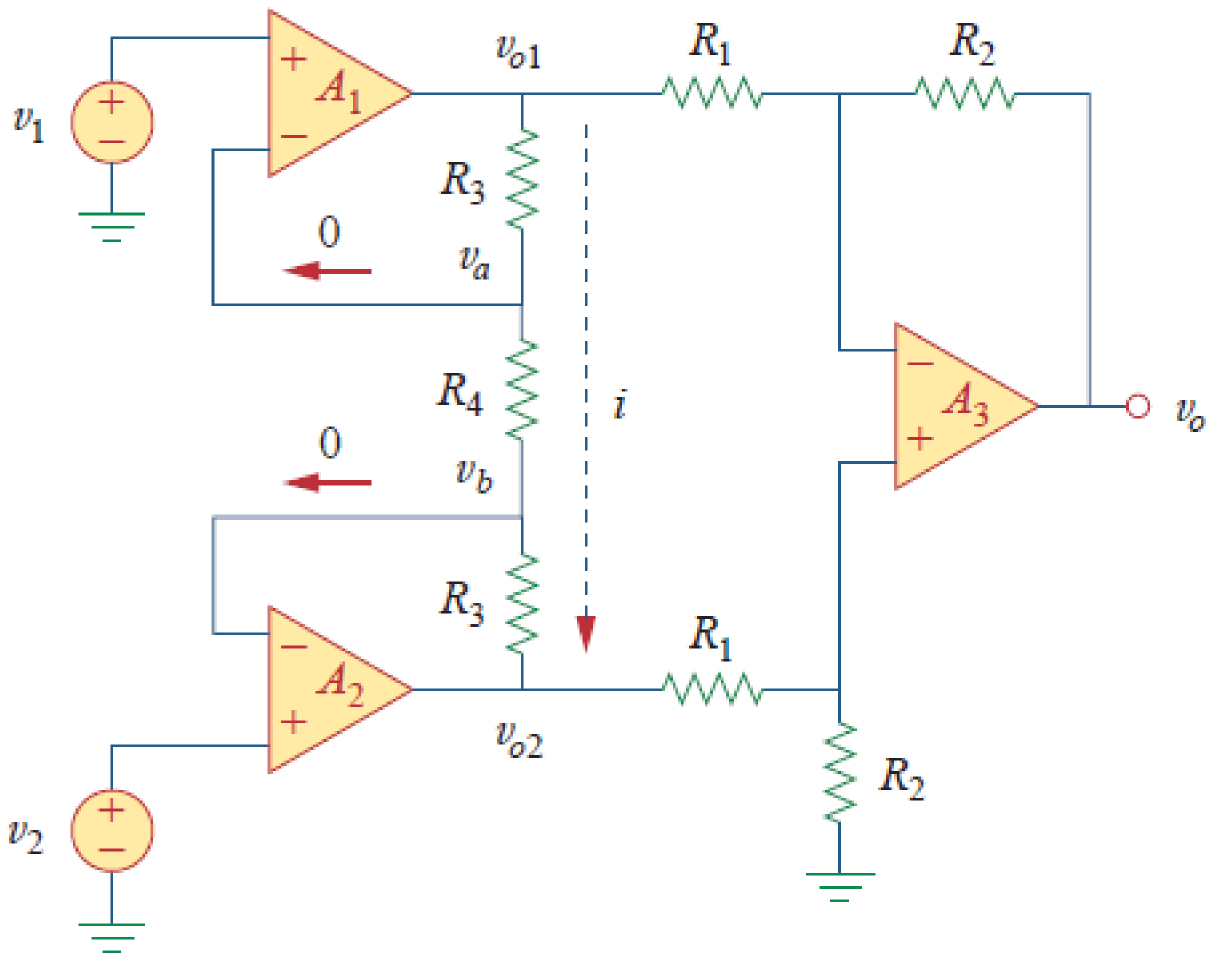
AMP.13 – Determine the analog output signal values for the three-bit DAC in Figure if the input is
[000], [001], [010], [011],
[100], [101], [110], [111]



Solution *(homework)*

Instrumentation Amplifier (single-package unit)

AMP.14 – Determine the output voltage vs. input voltages



Solution

A_3 diff. Amp → $(\mathbf{1})$: $v_0 = \frac{R_2}{R_1}(v_{o2} - v_{o1})$

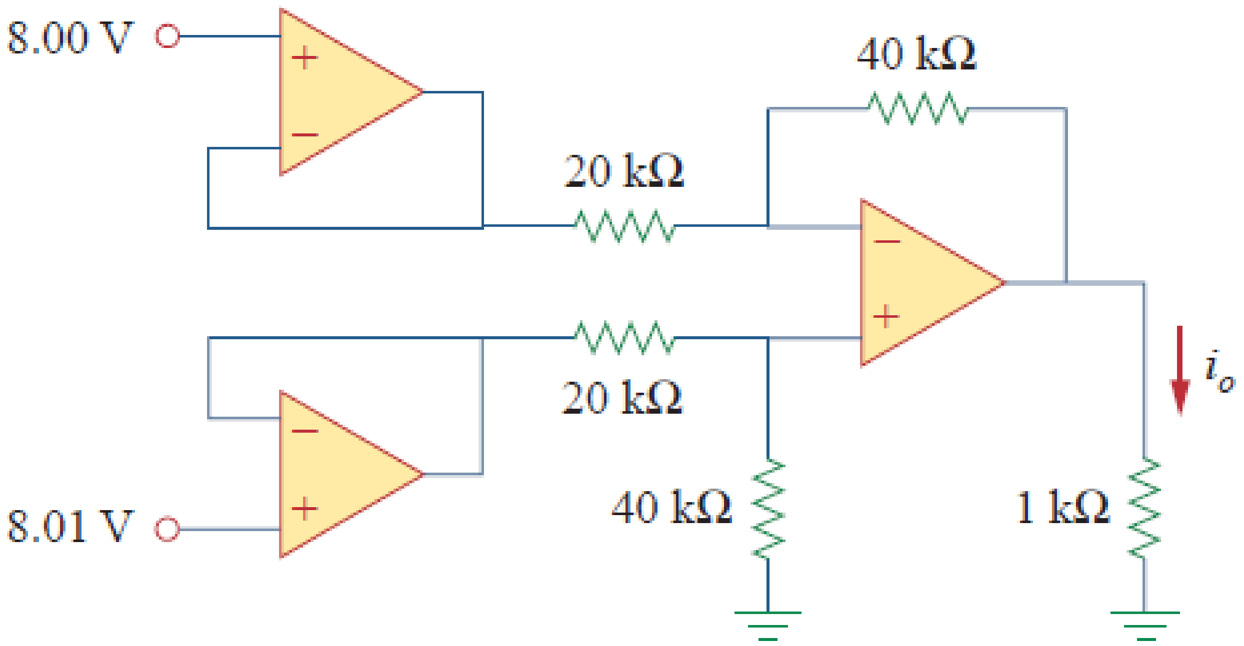
$(\mathbf{2})$: $v_{o1} - v_{o2} = i(R_3 + R_4 + R_3) = i(2R_3 + R_4)$

$(\mathbf{3})$: $i = \frac{v_a - v_b}{R_4}, v_a = v_1, v_b = v_2 \rightarrow i = \frac{v_1 - v_2}{R_4}$

$(\mathbf{2,3} \rightarrow \mathbf{1})$: $v_0 = \frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_4}\right)(v_2 - v_1)$

Very high common mode rejection (CMR)

AMP.15 – Calculate output current.



Solution $i_0 = 20\ \mu A$

Questions