



DR. GYURCSEK ISTVÁN

Exercises with Op Amps

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*

Ideal Op Amp Example



AMP.01 – Calculate the closed-loop gain (v_o/v_s) and i_o when $v_s = 1V$.

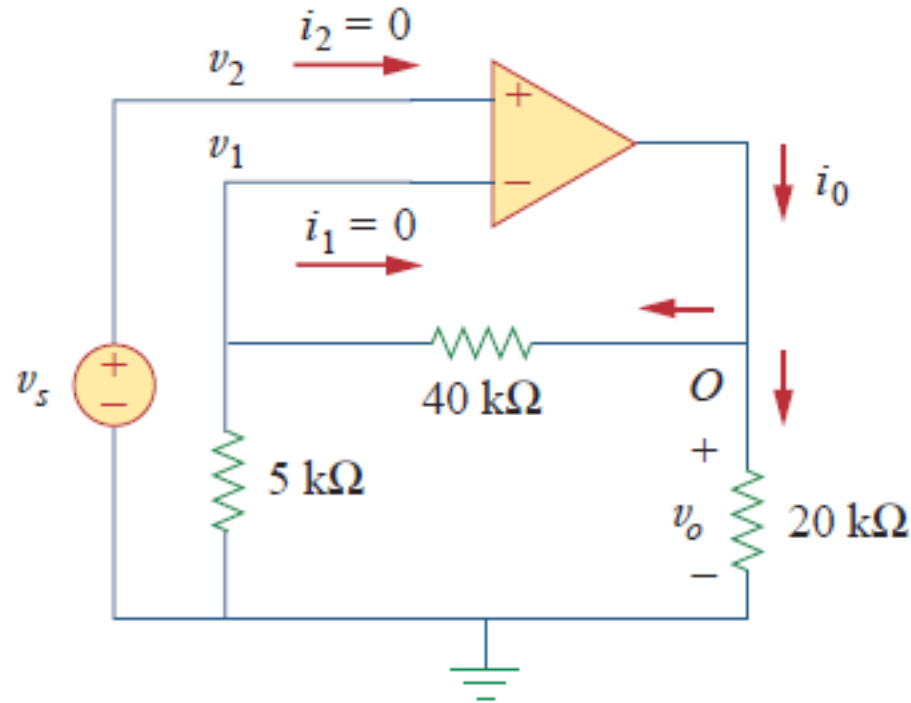
Solution

$$v_2 = v_s, v_1 = \frac{5}{5 + 40} \cdot v_o = \frac{v_o}{9}$$

$$v_2 = v_1 \rightarrow v_s = \frac{v_o}{9} \rightarrow \frac{v_o}{v_s} = 9$$

$$i_o = \left(\frac{v_o}{40 + 5} + \frac{v_o}{20} \right) mA$$

$$v_s = 1V \} \rightarrow \begin{cases} v_o = 9V \\ i_o = 0.2 + 0.45 = 0.65 mA \end{cases}$$



Recall AMP.02 example (real op amp):

$A = 2 \cdot 10^5$, $R_i = 2 M\Omega$, $R_o = 50 \Omega \rightarrow$ closed-loop gain = **9.00041** and , $i_o = 0.657$ mA. when $v_s = 1V$.

Inverter Example



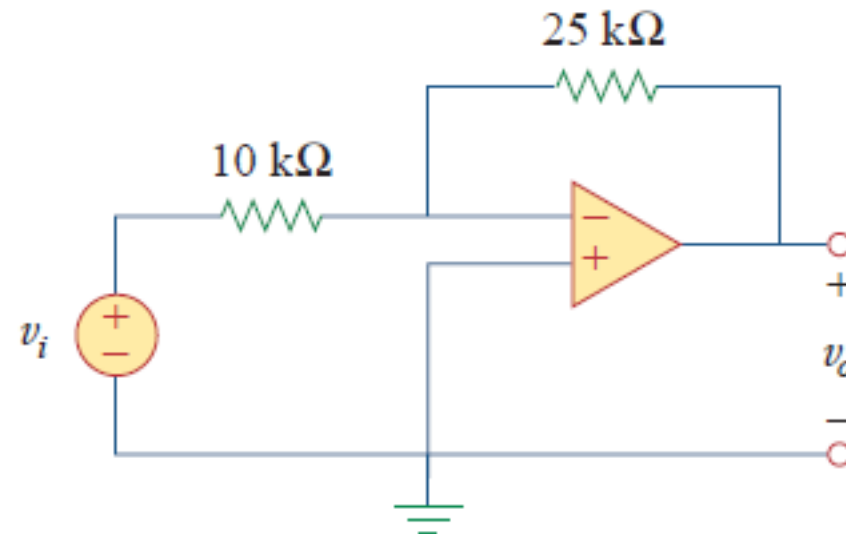
AMP.02 – Lets have $v_i = 0.5$ V. Calculate the output voltage and the input current.

Solution

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

Closed-loop amplification is -2.5 .

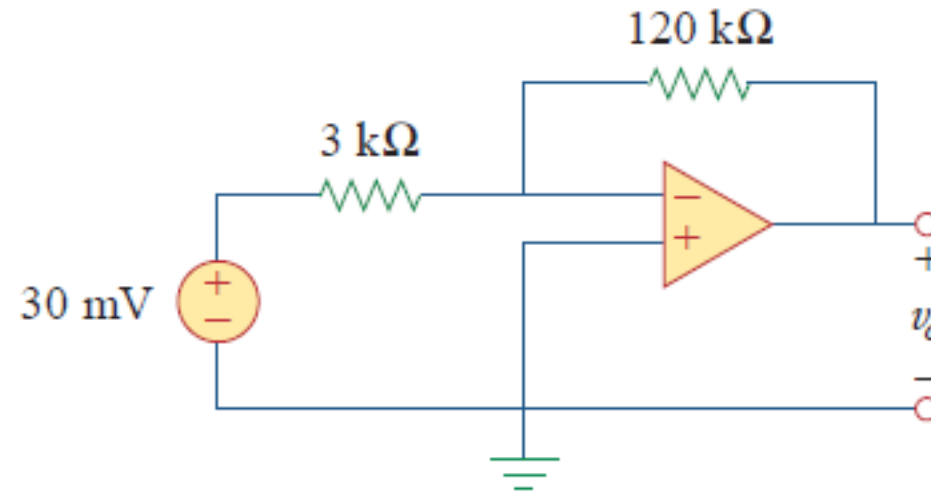
$$i_i = \frac{v_i - 0}{R_1} = \frac{0.5}{10 \cdot 10^3} = 50 \mu\text{A}$$



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

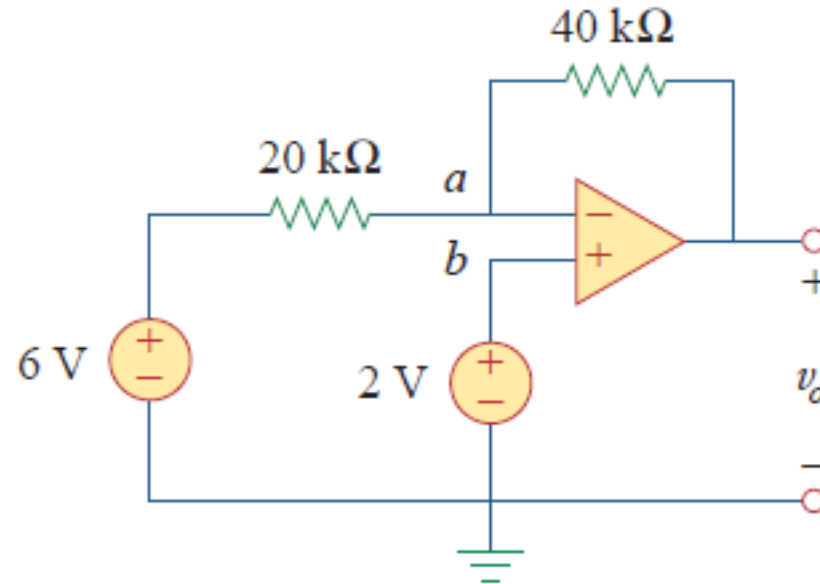
$$\frac{v_a - v_0}{40k} = \frac{6 - v_a}{20k}$$

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

$$v_0 = 3v_a - 12$$

$$v_a = v_b = 2V$$

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



Op Amp Example



AMP.05 – Find the output voltage.

Solution 1 (by superposition)

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

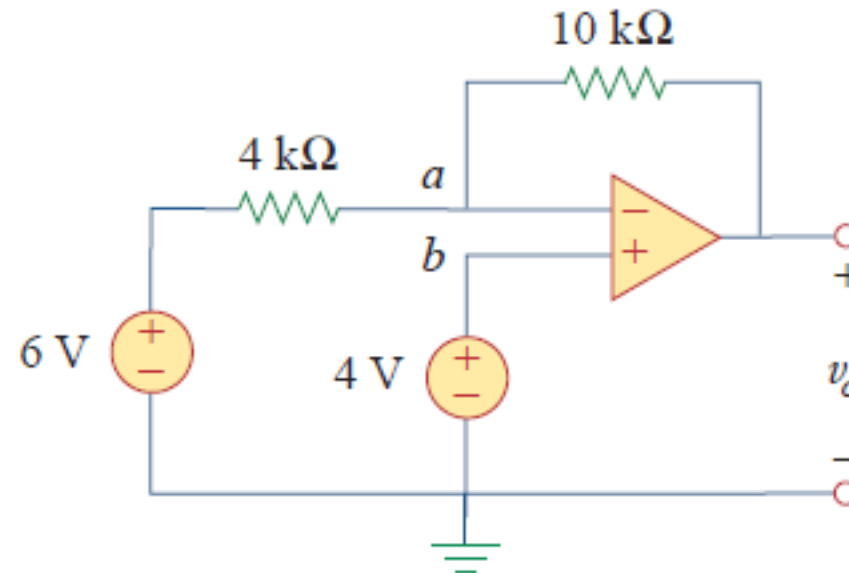
$$v_{o2} \left(1 + \frac{10}{4} \right) \cdot 4 = 14 \text{ V}$$

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

Solution 2 (by nodal analysis)

$$\text{(node a): } \frac{6 - v_a}{4} = \frac{v_a - v_o}{10}$$

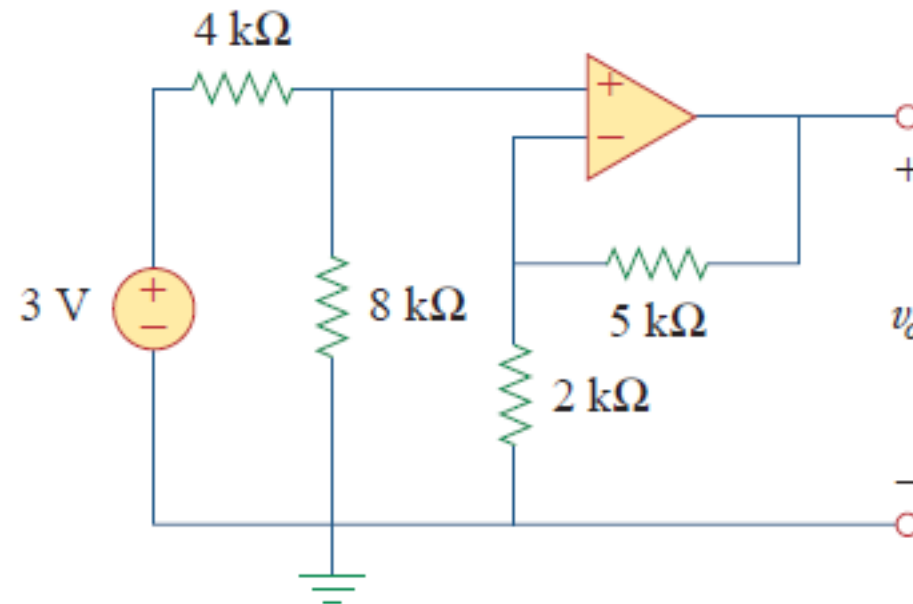
$$v_a = v_b = 4 \rightarrow \frac{6 - 4}{4} = \frac{4 - v_o}{10} \rightarrow 5 = 4 - v_o \rightarrow v_o = -1 \text{ V}$$



Op Amp Example



AMP.06 – Find the output voltage.

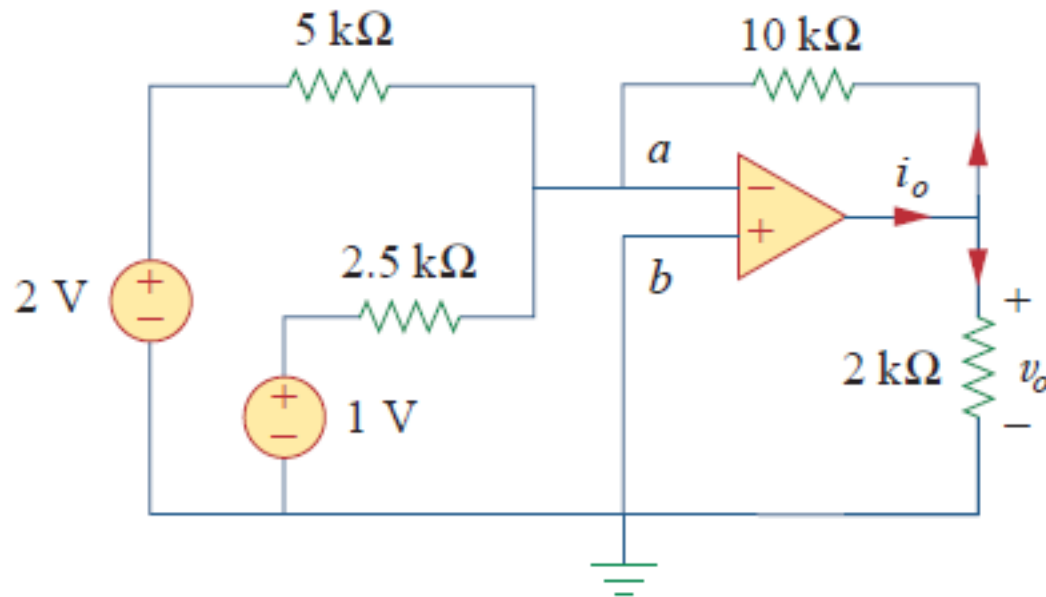


Solution $v_o = 7 V$

Summing Amplifier



AMP.07 – $v_o = ?$, $i_o = ?$

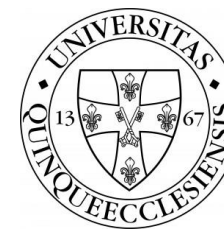


Solution

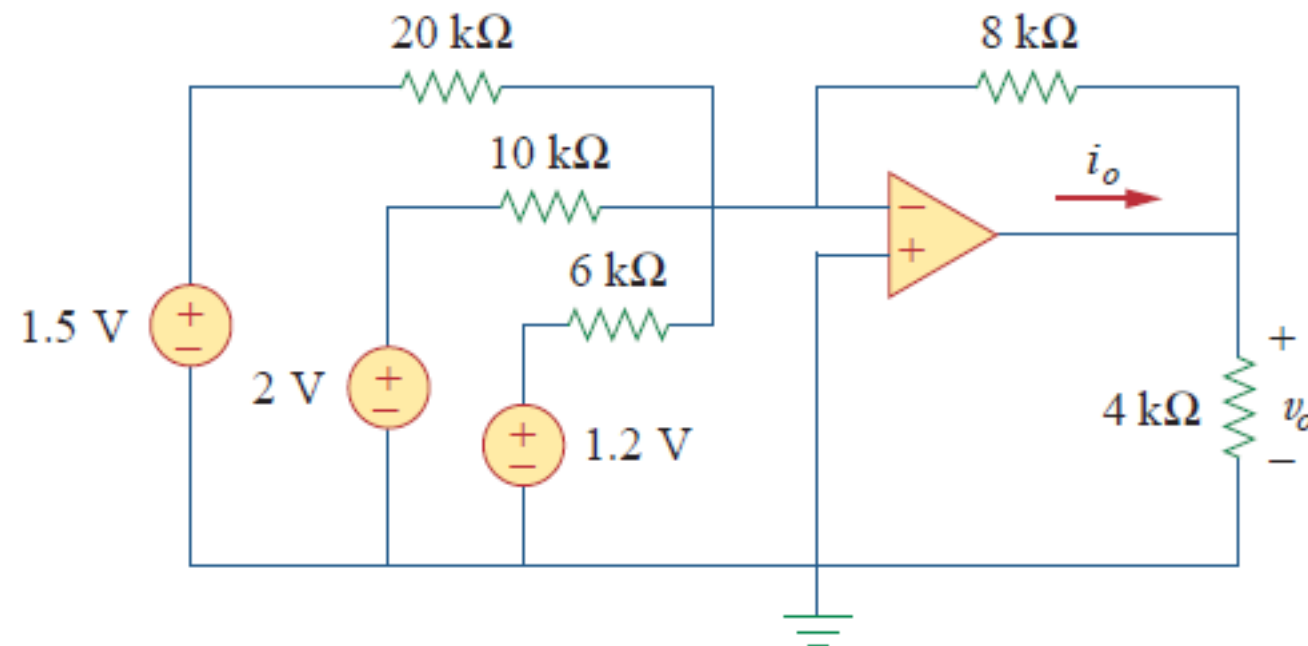
$$v_o = -\left(\frac{10}{5} \cdot 2 + \frac{10}{2,5} \cdot 1\right) = -8 \text{ V}$$

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

Summing Amplifier



AMP.08 – $v_o = ?$, $i_o = ?$



Solution $v_o = -3.8$ V, $i_o = -1.425$ mA

Difference Amplifier



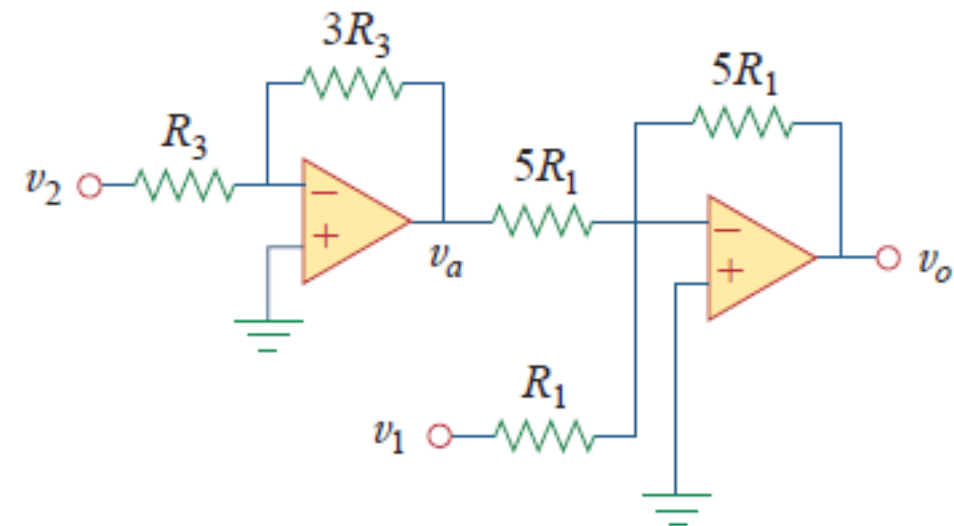
AMP.09 – Design an op amp with output $v_o = -5v_1 + 3v_2$

Solution (with an inverter AND a summer)

(*inverter*): $v_a = -3v_2$

(*summer*): $v_o = -(v_a + 5v_1) = 3v_2 - 5v_1$

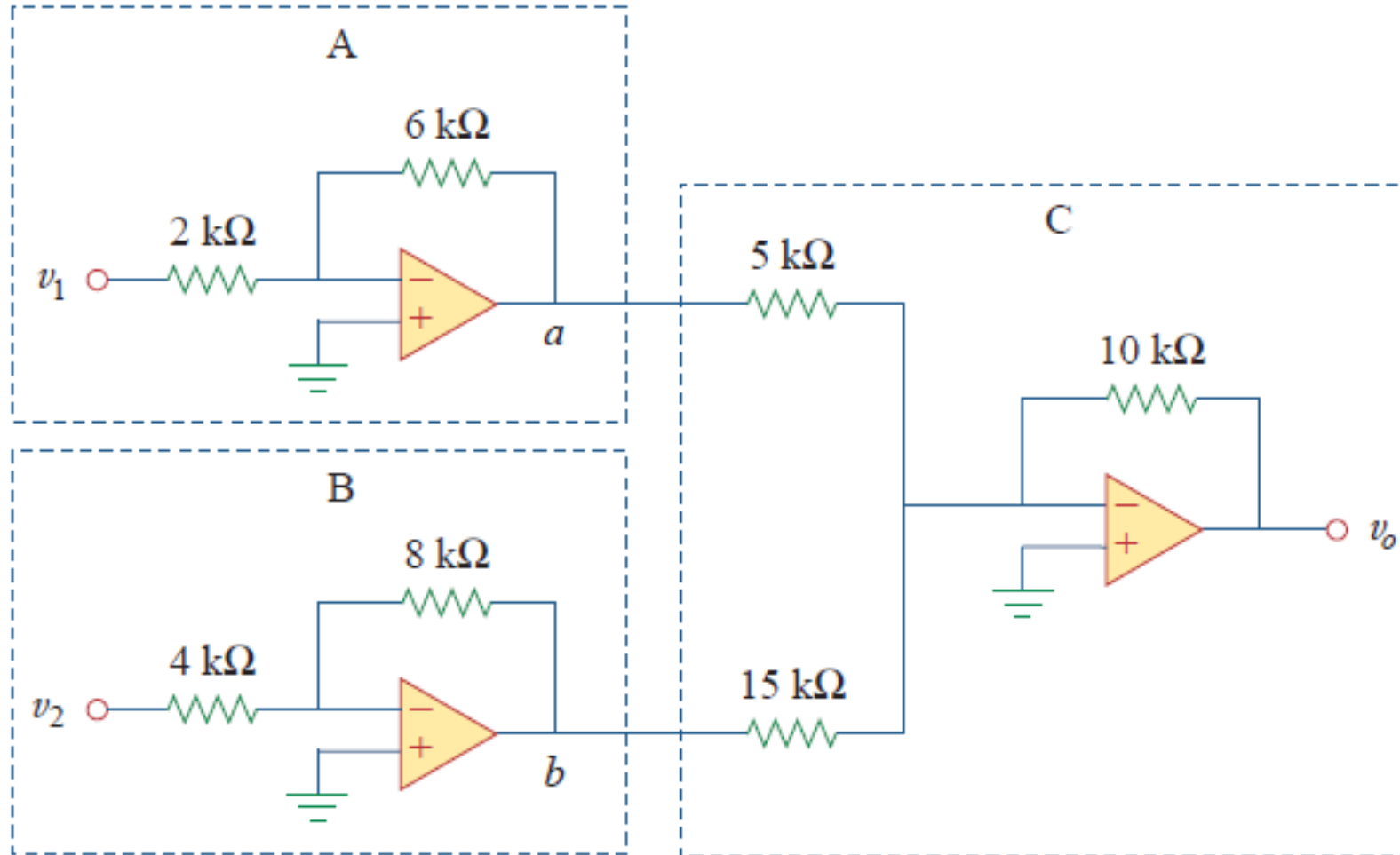
Let's select $\rightarrow R_1 = R_3 = 10 \text{ k}\Omega$



Cascaded Op Amps



AMP.10 – Find v_0 if $v_1 = 1\text{ V}$ and $v_2 = 2\text{ V}$ in the circuit.



Solution

(*inverter 1*):

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

(*inverter 2*):

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

(*summer*):

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

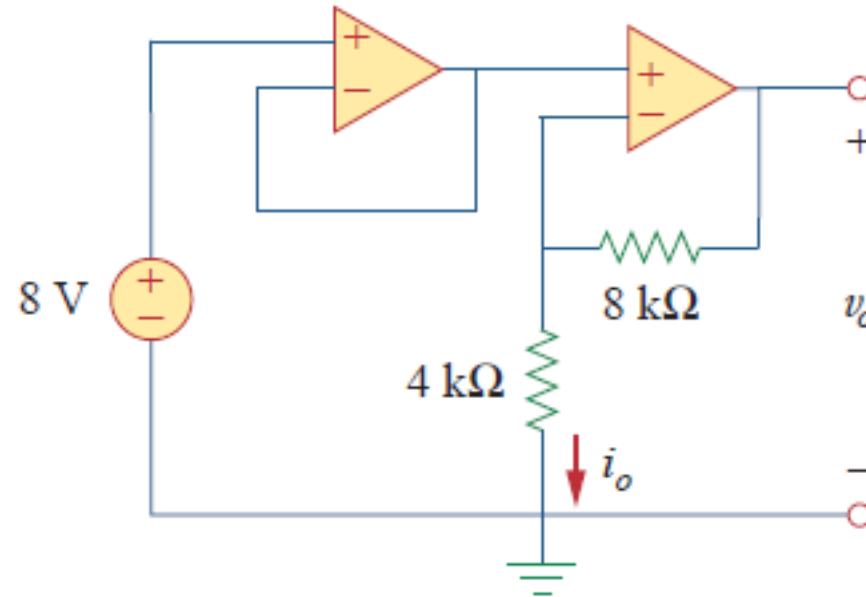
$$v_0 = (-2)(-3) + \left(-\frac{2}{3} \right) (-4) =$$

$$v_0 = 8.67\text{ V}$$

Cascaded Op Amps



AMP.11 – Find v_o and i_o in the circuit.

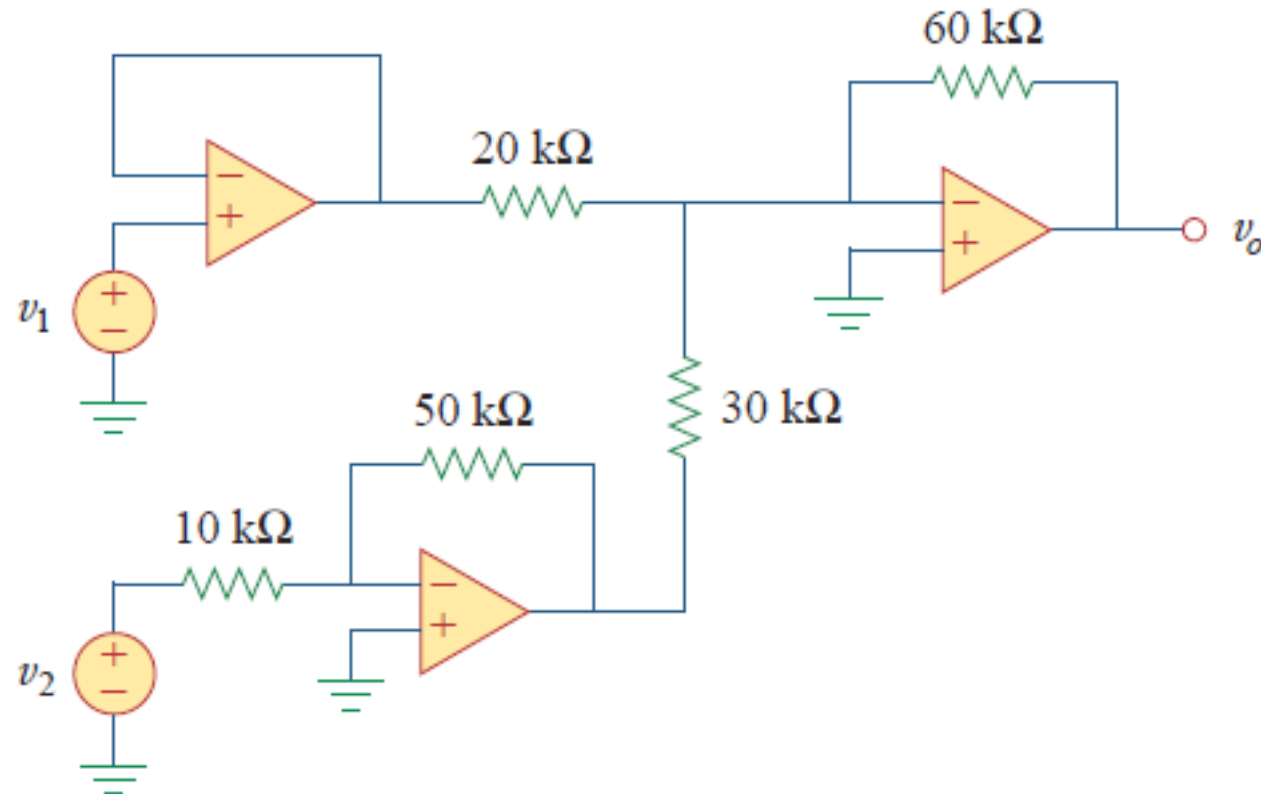


Solution $v_o = 24 V$, $i_o = 2 mA$

Cascaded Op Amps

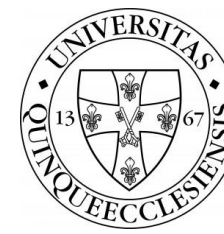


AMP.12 – Find v_0 if $v_1 = 4\text{ V}$ and $v_2 = 3\text{ V}$ in the circuit.



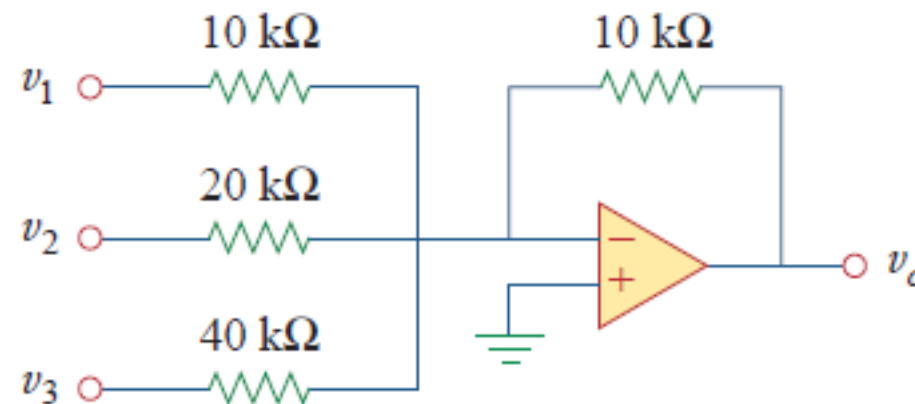
Solution $v_0 = 18\text{ V}$

DA Converter



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



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

Solution

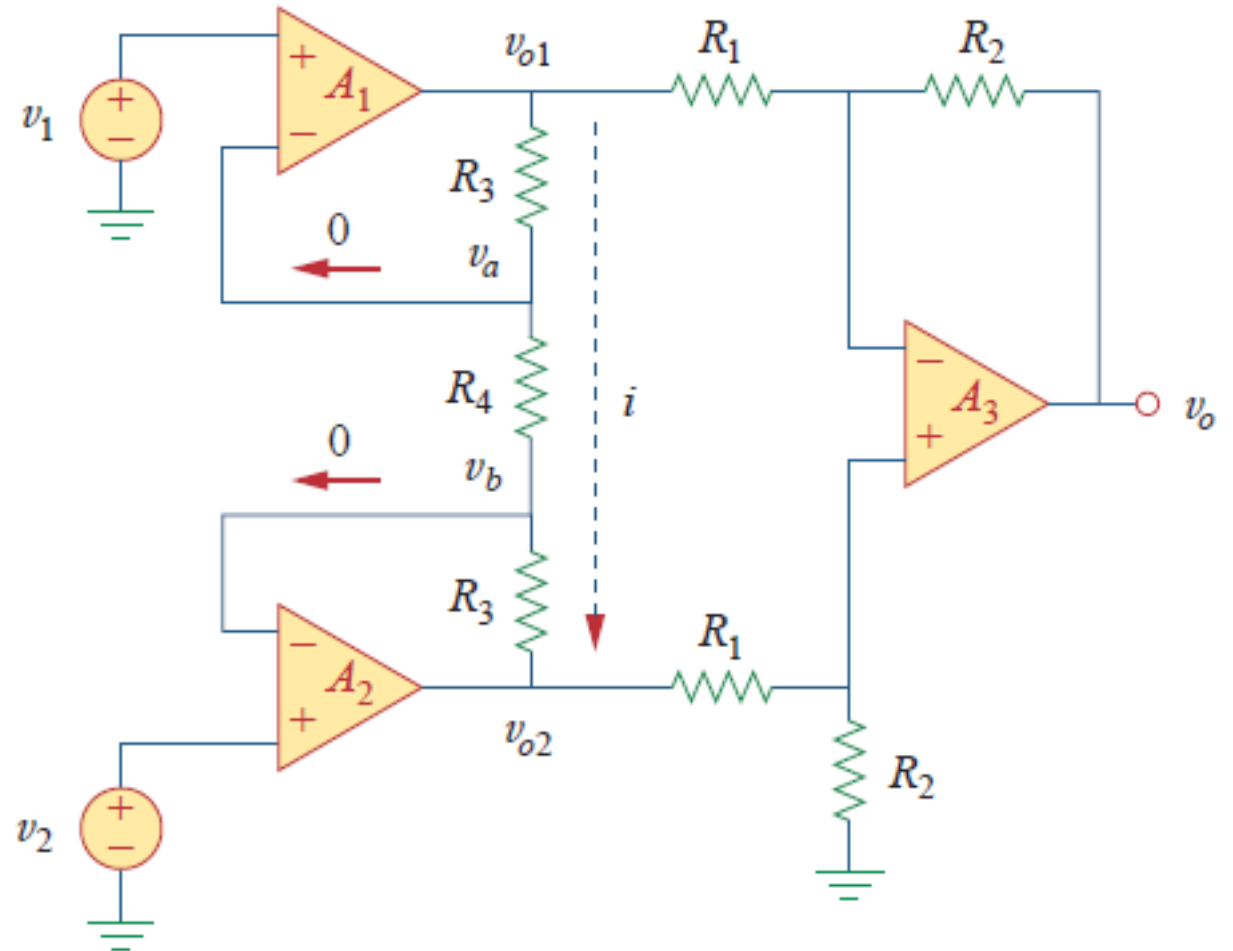
$$A_3 \text{ diff. Amp} \rightarrow (1): v_0 = \frac{R_2}{R_1} (v_{o2} - v_{o1})$$

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

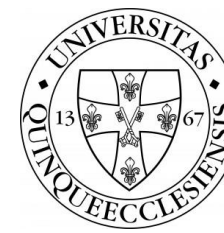
$$(3): i = \frac{v_a - v_b}{R_4}, v_a = v_1, v_b = v_2 \rightarrow i = \frac{v_1 - v_2}{R_4}$$

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

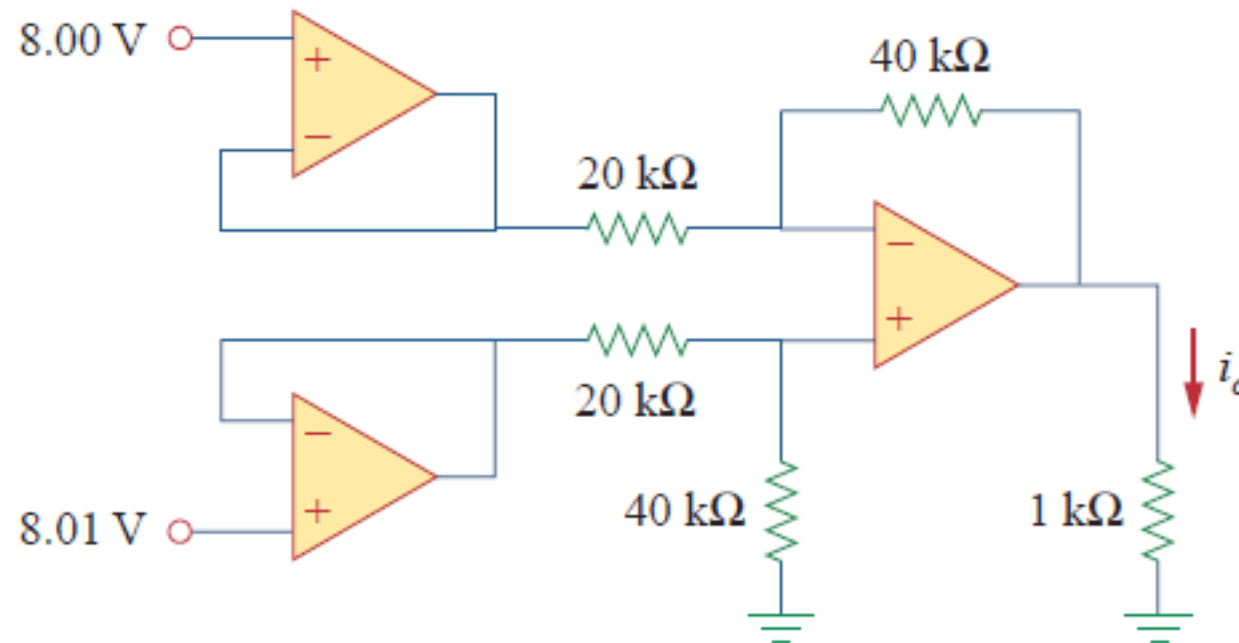
Very high common mode rejection (CMR)



Instrumentation Amplifier



AMP.15 – Calculate output current.



Solution $i_o = 20 \mu A$

Questions

