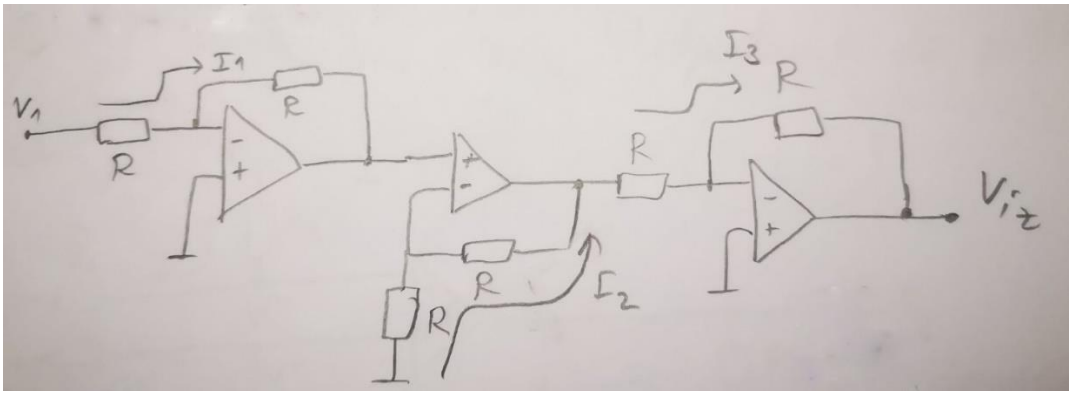
OPERACIONI POJAČAVAČI

1. Za kolo na slici izračunati izlazni napon. Poznato je $V_1 = 8V,\ R = 4k\Omega,\ V_{CC} = \pm 12V$.



Rješenje:

$V_1^+ = V_1^- = 0V$

$V_2^+ = V_2^-$

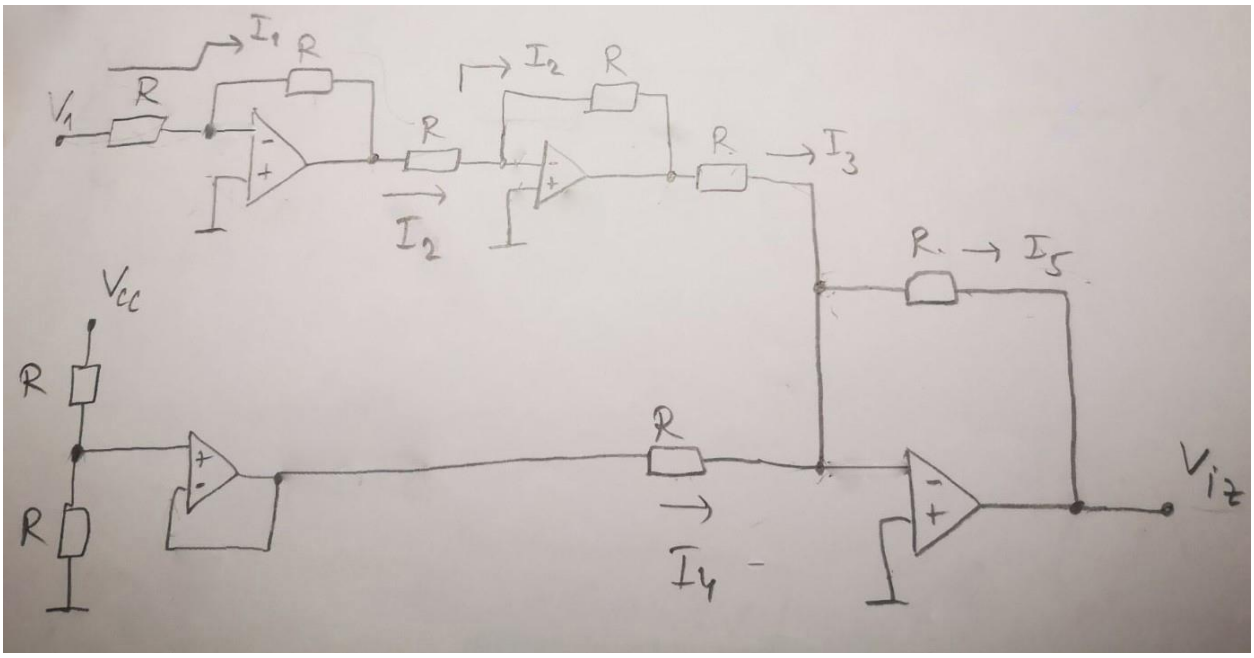
$V_3^+ = V_3^- = 0V$

$I_1 = \frac{V_1 - V_1^-}{R} = \frac{V_1^- - V_{1iz}}{R}$ tj. $\frac{V_1}{R} = \frac{-V_{1iz}}{R}$ -> $V_{1iz} = -V_1 = -8V$ -> $V_{1iz} = V_2^+ = V_2^- = -8V$

$I_2 = \frac{-V_2^-}{R} = \frac{V_2^- - V_{2iz}}{R}$ -> $V_{2iz} = 2V_2^- = -16V$ (zasićenje) -> $V_{2iz} = -12V$

$I_3 = \frac{V_{2iz} - V_3^-}{R} = \frac{V_3^- - V_{iz}}{R}$ tj. $\frac{V_{2iz}}{R} = \frac{-V_{iz}}{R}$ -> $V_{iz} = -V_{2iz} = 12V$

2. Za kolo na slici operacioni pojačavači se napajaju sa $V_{CC} = \pm 6V$. Poznato je $V_1 = -4V$ i $R = 1k\Omega$. Odrediti izlazni napon.



Rješenje:

$$I_1 = \frac{V_1}{R} = \frac{-V_{1iz}}{R} \text{ -> } V_{1iz} = -V_1 = 4V$$

$$I_2 = \frac{V_{1iz}}{R} = \frac{-V_{2iz}}{R} \text{ -> } V_{2iz} = -4V$$

$$I_3 = \frac{V_{2iz}}{R} = \frac{-4V}{R}$$

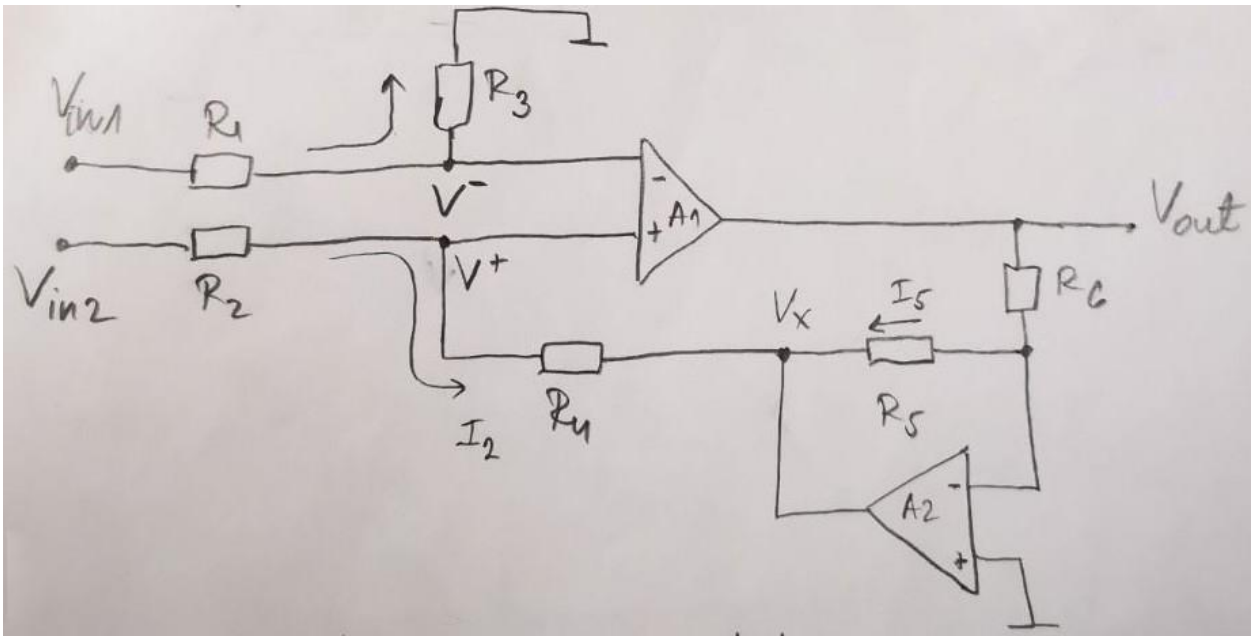
$$V_4^+ = \frac{R}{R+R}V_{CC} = \frac{V_{CC}}{2} = 3V \text{ -> } V_4^+ = V_{4iz} = 3V$$

$$I_4 = \frac{V_{4iz}}{R} = \frac{3V}{R}$$

Za čvor važi $I_3 + I_4 = I_5$ -> $I_5 = \frac{-4V}{R} + \frac{3V}{R} = \frac{-1V}{R}$

S druge strane $I_5 = \frac{-V_{iz}}{R}$ pa slijedi da je $V_{iz} = 1V$.

3. Za kolo na slici izračunati izlazni napon. Poznato je $\frac{R_1}{R_3} = \frac{R_2}{R_4}$, R_5, R_6, V_{in1}, $V_{in2.}$ Pretpostaviti da su operacioni pojačavači idealni.



Rješenje:

$V^+ = V^-$

$\frac{V_{in1} - V^-}{R_1} = \frac{V^-}{R_3}$ (1) -> $V^- = \frac{R_3}{R_1 + R_3} V_{in1}$ (2) -> $V^+ = \frac{R_3}{R_1 + R_3} V_{in1}$ (3)

Dalje imamo da je $\frac{V_{in2} - V^+}{R_2} = \frac{V^+ - V_X}{R_4}$ (4) pri čemu ako u izraz (4) uvrstimo (3) dobijamo:

$\frac{V_{in2} - \frac{R_3}{R_1 + R_3} V_{in1}}{R_2} = \frac{\frac{R_3}{R_1 + R_3} V_{in1} - V_X}{R_4}$ (5) . Sređivanjem dobijamo:

$V_X = \frac{R_3}{R_1 + R_3} V_{in1} - R_4 \left(\frac{V_{in2} - \frac{R_3}{R_1 + R_3} V_{in1}}{R_2} \right) = \frac{R_3}{R_1 + R_3} V_{in1} - \frac{R_4}{R_2} V_{in2} + \frac{R_4}{R_2} \frac{R_3}{R_1 + R_3} V_{in1}$ ->

$V_X = \frac{R_3}{R_1 + R_3} V_{in1} \left(1 + \frac{R_4}{R_2}\right) - \frac{R_4}{R_2} V_{in2}$ (6)

Dalje sa slike vidimo da je $\frac{V_{out}}{R_6} = \frac{-V_X}{R_5}$ -> $V_{out} = \frac{-R_6 V_X}{R_5}$ (7) pa uvrštavanjem (6) u (7)

dobijamo: $V_{out} = \frac{-R_6}{R_5}(\frac{R_3}{R_1+R_3}V_{in1}(1+\frac{R_4}{R_2}) - \frac{R_4}{R_2}V_{in2}) =$

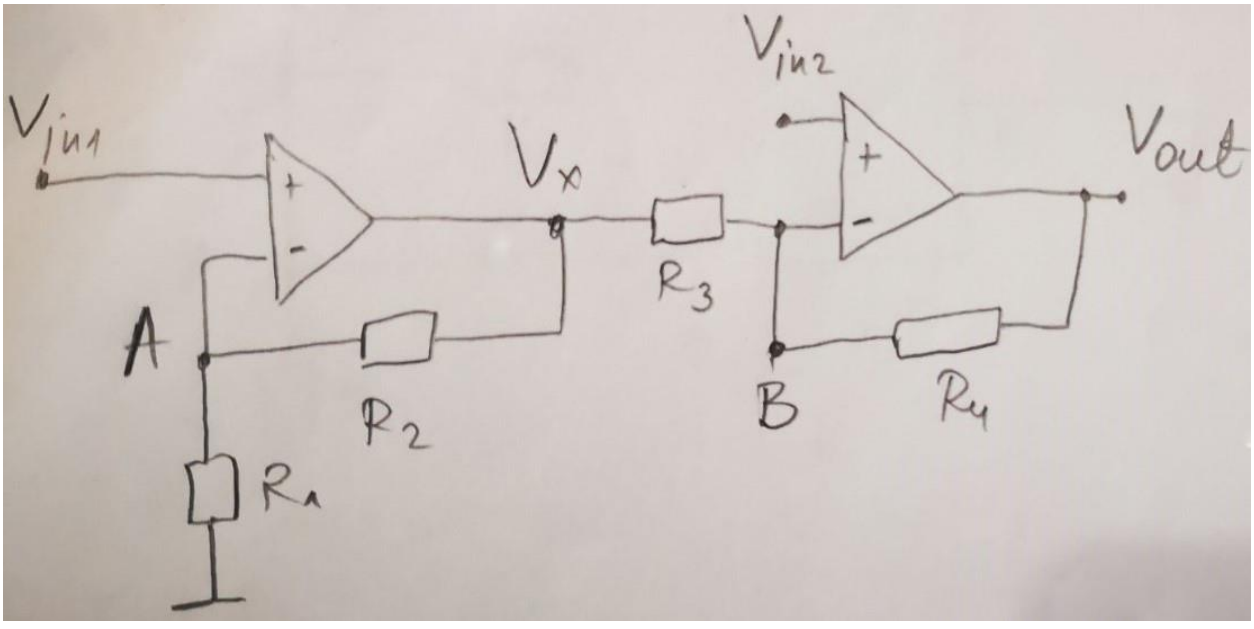
$$V_{out} = \frac{R_6}{R_5}(\frac{1}{\frac{R_2}{R_4}}V_{in2} - \frac{1}{\frac{R_1}{R_3}+1}V_{in1}(1+\frac{1}{\frac{R_2}{R_4}})) \quad (8)$$

Uvrštavanjem $\frac{R_1}{R_3} = \frac{R_2}{R_4}$ u (8) dobijamo:

$$V_{out} = \frac{R_6}{R_5}(\frac{1}{\frac{R_2}{R_4}}V_{in2} - \frac{1}{\frac{R_2}{R_4}+1}V_{in1}(1+\frac{1}{\frac{R_2}{R_4}})) = \frac{R_6}{R_5}(\frac{1}{\frac{R_2}{R_4}}V_{in2} - V_{in1}\frac{1}{\frac{R_2}{R_4}+1}(\frac{\frac{R_2}{R_4}+1}{\frac{R_2}{R_4}}))$$

$$V_{out} = \frac{R_6}{R_5}(\frac{1}{\frac{R_2}{R_4}}V_{in2} - V_{in1}\frac{1}{\frac{R_2}{R_4}}) = \frac{R_6}{R_5}\frac{R_4}{R_2}(V_{in2} - V_{in1})$$

4. a) Odrediti kakav odnos treba da bude između otpornosti R_1, R_2, R_3 i R_4 da bi kolo radilo kao instrumentacioni pojačavač.
   b) Ako se između tačaka A i B priključi otpornik R_5 odrediti Vout pri $R_1=R_2=R_3=R_4$.



Rješenje:

a) Za prvi operacioni pojačavač važi $V_1^+ = V_1^- = V_{in1}$ (1)

$\frac{-V_1^-}{R_1} = \frac{V_1^- - V_X}{R_2}$ (2) -> $V_X = (1+\frac{R_2}{R_1})V_1^-$ -> $V_X = (1+\frac{R_2}{R_1})V_{in1}$ (3)

Za drugi operacioni pojačavač važi $V_2^+ = V_2^- = V_{in2}$ (4)

$\frac{V_X - V_2^-}{R_3} = \frac{V_2^- - V_{out}}{R_4}$ (5)

Uvrštanjem (4) i (3) u (5) dobijamo: -> $\frac{(1+\frac{R_2}{R_1})V_{in1} - V_{in2}}{R_3} = \frac{V_{in2} - V_{out}}{R_4}$ (6) ->

$V_{out} = V_{in2} - R_4 \frac{(1+\frac{R_2}{R_1})V_{in1} - V_{in2}}{R_3} = V_{in2}(1+\frac{R_4}{R_3}) - \frac{R_4}{R_3}(1+\frac{R_2}{R_1})V_{in1}$ (7)

Da bi kolo radilo kao instrumentacioni pojačavač izlazni napon mora biti jednak:

$V_{out} = k(V_{in2} - V_{in1})$ (8)

Primjenljujući uslov (8) u jednačini (7) dobijamo da je:

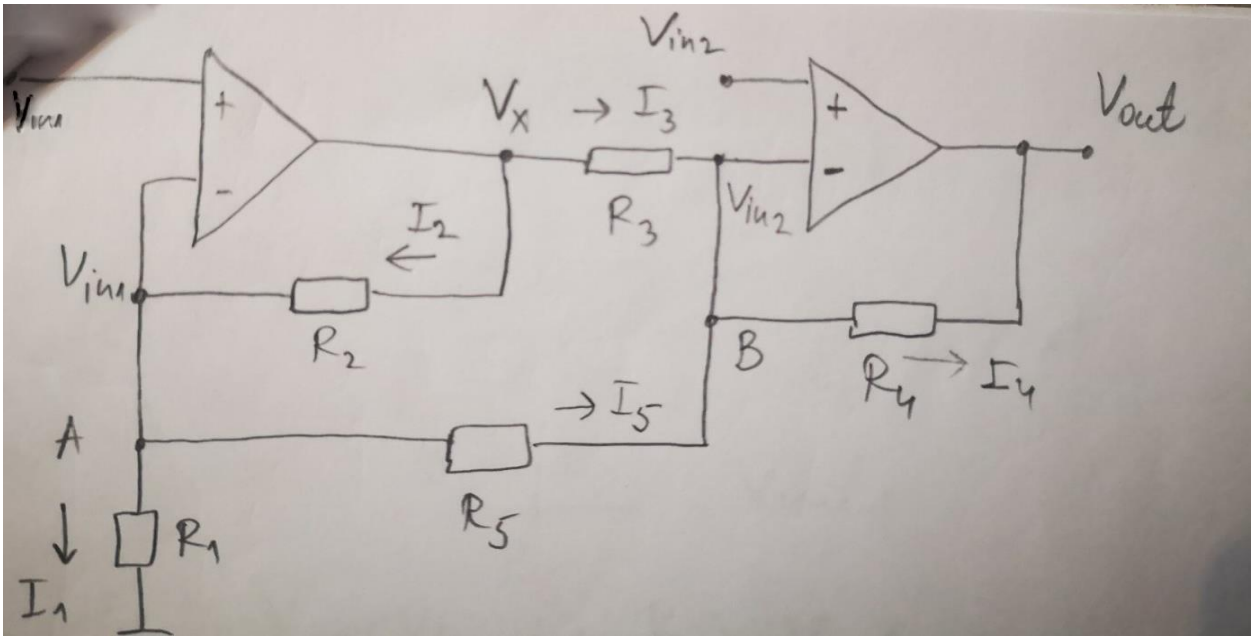
$(1+\frac{R_4}{R_3}) = k$ (9)

$\frac{R_4}{R_3}(1+\frac{R_2}{R_1}) = k$ (10)

Izjednačavajući izraze (9) i (10) dobijamo:

$(1+\frac{R_4}{R_3}) = \frac{R_4}{R_3}(1+\frac{R_2}{R_1})$ -> $\frac{R_4}{R_3}\frac{R_2}{R_1} = 1$ -> $\frac{R_4}{R_3} = \frac{R_1}{R_2}$

b) Ako se doda otpornik između tačaka A i B kolo postaje:



Za čvor A važi da je $I_2 = I_1 + I_5$ (1)

$$\frac{V_X - V_{in1}}{R_2} = \frac{V_{in1}}{R_1} + \frac{V_{in1} - V_{in2}}{R_5} \quad (2) \rightarrow$$

$$V_X = V_{in1} + \frac{R_2 V_{in1}}{R_1} + \frac{R_2 (V_{in1} - V_{in2})}{R_5} = V_{in1} \frac{R_1 R_5 + R_2 R_5 + R_1 R_2}{R_1 R_5} - \frac{R_2}{R_5} V_{in2} \quad (3)$$

Za čvor B važi da je $I_3 + I_5 = I_4$ (4)

$$\frac{V_X - V_{in2}}{R_3} + \frac{V_{in1} - V_{in2}}{R_5} = \frac{V_{in2} - V_{out}}{R_4} \quad (5) \rightarrow \quad V_{out} = V_{in2} - R_4 \left(\frac{V_X - V_{in2}}{R_3} + \frac{V_{in1} - V_{in2}}{R_5}\right) \rightarrow$$

$$V_{out} = -\frac{R_4}{R_3} V_X + V_{in2} \left(1 + \frac{R_4}{R_3} + \frac{R_4}{R_5}\right) - \frac{R_4}{R_5} V_{in1} \quad (6)$$

Uvrštavanjem (3) u (6) dobijamo:

$$V_{out} = -\frac{R_4}{R_3} \left(V_{in1} \frac{R_1 R_5 + R_2 R_5 + R_1 R_2}{R_1 R_5} - \frac{R_2}{R_5} V_{in2}\right) + V_{in2} \left(1 + \frac{R_4}{R_3} + \frac{R_4}{R_5}\right) - \frac{R_4}{R_5} V_{in1}$$

$$V_{out} = \frac{R_4}{R_3} \left(\frac{R_2}{R_5} V_{in2} - V_{in1} \frac{R_1 R_5 + R_2 R_5 + R_1 R_2}{R_1 R_5}\right) + V_{in2} \left(1 + \frac{R_4}{R_3} + \frac{R_4}{R_5}\right) - \frac{R_4}{R_5} V_{in1}$$

$$V_{out} = V_{in2} \left(\frac{R_4}{R_3} \frac{R_2}{R_5} + 1 + \frac{R_4}{R_3} + \frac{R_4}{R_5}\right) - V_{in1} \left(\frac{R_4}{R_3} \frac{R_1 R_5 + R_2 R_5 + R_1 R_2}{R_1 R_5} + \frac{R_4}{R_5}\right) \quad (7)$$

Primjernom uslova zadatka da je $R_1=R_2=R_3=R_4$, u izraz (7) dobijamo:

$$V_{out} = 2V_{in2} \left(\frac{R_1}{R_5} + 1\right) - 2V_{in1} \left(1 + \frac{R_1}{R_5}\right) = 2\left(1 + \frac{R_1}{R_5}\right)(V_{in2} - V_{in1})$$