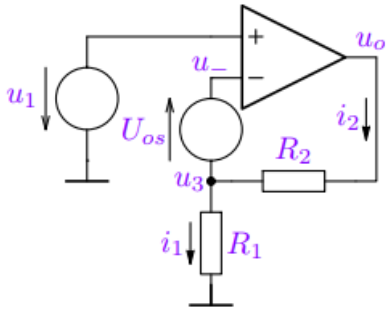
Zapojení 1



$$u_- = u_1$$

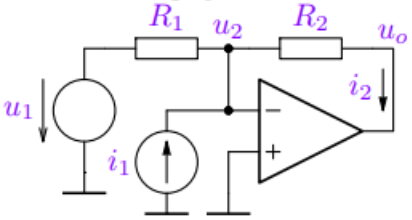
$$u_3 = u_- + U_{os} = u_1 + U_{os}$$

$$i_1 = \frac{u_3}{R_1}$$

$$i_2 = i_1 = \frac{u_3}{R_1}$$

$$u_o = u_3 + i_2 \cdot R_2 = u_3 + \frac{u_3}{R_1} \cdot R_2 = u_3 \left(1 + \frac{R_2}{R_1}\right) = (u_1 + U_{os}) \left(1 + \frac{R_2}{R_1}\right)$$

Zapojení 2



$$u_2 : \frac{u_2 - u_1}{R_1} + i_2 - i_1 = 0$$

$$i_2 = \frac{u_2 - u_o}{R_2}$$

$$\frac{u_2 - u_1}{R_1} + \frac{u_2 - u_o}{R_2} - i_1 = 0$$

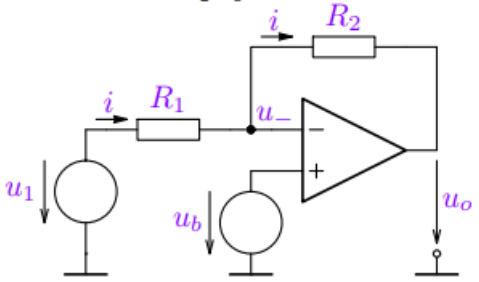
$$u_2 = 0$$

$$\frac{-u_1}{R_1} + \frac{-u_o}{R_2} - i_1 = 0$$

$$-R_2 u_1 - R_1 u_o = i_1 R_1 R_2$$

$$u_o = -\frac{R_2}{R_1} u_1 - i_1 R_2$$

Zapojení 3



$$\frac{u_- - u_1}{R_1} + \frac{u_- - u_o}{R_2} = 0$$

$$u_- = u_b$$

$$\frac{u_b - u_1}{R_1} = -\frac{u_b - u_o}{R_2}$$

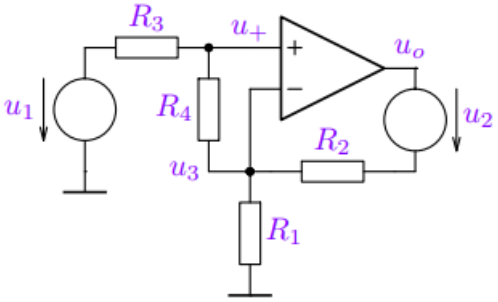
$$R_2 u_b - R_2 u_1 = -R_1 u_b + R_1 u_o$$

$$R_1 u_o = R_2 u_b - R_2 u_1 + R_1 u_b$$

$$u_o = \frac{R_2}{R_1} u_b + u_b - \frac{R_2}{R_1} u_1$$

$$u_o = u_b \left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} u_1$$

Zapojení 4



$$u_3 : \frac{u_3 - u_+}{R_4} + \frac{u_3}{R_1} + \frac{u_3 - (u_o - u_2)}{R_2} = 0$$

$$u_+ : \frac{u_+ - u_1}{R_3} + \frac{u_+ - u_3}{R_4} = 0$$

$$u_+ = u_3$$

$$u_3 : \frac{u_3}{R_1} + \frac{u_3 - u_o + u_2}{R_2} = 0$$

$$u_+ : \frac{u_3 - u_1}{R_3} = 0$$

$$u_3 = u_1$$

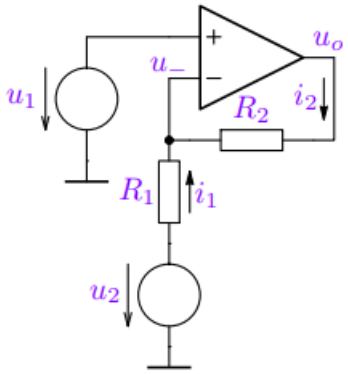
$$u_3 : \frac{u_1}{R_1} + \frac{u_1 - u_o + u_2}{R_2} = 0$$

$$R_1 u_1 - R_1 u_o + R_1 u_2 = -R_2 u_1$$

$$R_1 u_o = R_1 u_1 + R_1 u_2 + R_2 u_1$$

$$u_o = u_1 \left(1 + \frac{R_2}{R_1}\right) + u_2$$

Zapojení 5



$$u_-: -i_1 + i_2 = 0$$

$$i_1 = \frac{u_2 - u_-}{R_1}$$

$$i_2 = \frac{u_- - u_0}{R_2}$$

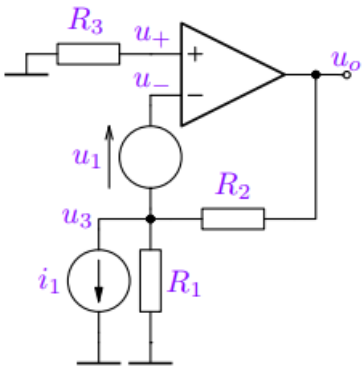
$$u_- = u_1$$

$$u_-: \frac{u_1 - u_2}{R_1} + \frac{u_1 - u_0}{R_2} = 0$$

$$R_1 u_0 = R_2 u_1 - R_2 u_2 + R_1 u_1$$

$$u_0 = u_1\left(1 + \frac{R_2}{R_1}\right) - u_2\frac{R_2}{R_1}$$

Zapojení 6



$$u_+: \frac{u_+}{R_3} = 0$$

$$u_3: i_1 + \frac{u_3}{R_1} + \frac{u_3 - u_0}{R_2} = 0$$

$$u_+ = 0$$

$$u_- = u_+ = 0$$

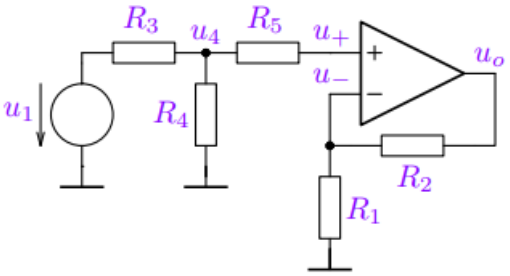
$$u_3 = u_- + u_1 = u_1$$

$$i_1 + \frac{u_1}{R_1} + \frac{u_1 - u_0}{R_2} = 0$$

$$R_1 R_2 i_1 + R_2 u_1 + R_1 u_1 - R_1 u_0 = 0$$

$$u_0 = R_2 i_1 + u_1\left(1 + \frac{R_2}{R_1}\right)$$

Zapojení 7



$$u_4: \frac{u_4 - u_1}{R_3} + \frac{u_4}{R_4} + \frac{u_4 - u_+}{R_5} = 0$$

$$u_+: \frac{u_+ - u_4}{R_5} = 0$$

$$u_+ = u_4$$

$$u_-: \frac{u_-}{R_1} + \frac{u_- - u_o}{R_2} = 0$$

$$u_- = u_+ = u_4$$

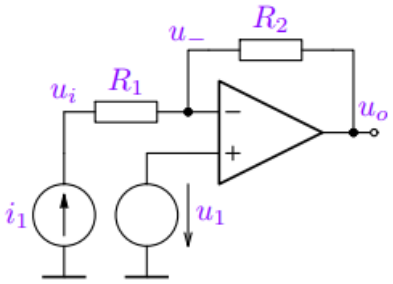
$$u_4: \frac{u_4 - u_1}{R_3} + \frac{u_4}{R_4} = 0$$

$$u_-: \frac{u_4}{R_1} + \frac{u_4 - u_o}{R_2} = 0$$

$$u_4 = \frac{R_4}{R_4 + R_3} u_1$$

$$u_o = u_4\left(1 + \frac{R_2}{R_1}\right) = \frac{R_4}{R_4 + R_3}\left(1 + \frac{R_2}{R_1}\right) u_1$$

Zapojení 8



$$u_-: -i_1 + \frac{u_- - u_o}{R_2} = 0$$

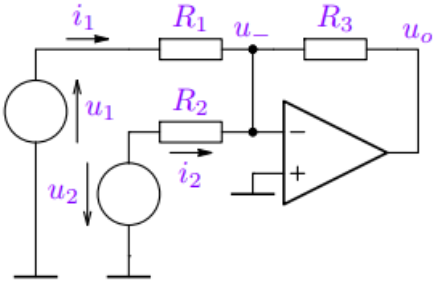
$$u_- = u_1$$

$$u_i = u_- + i_1 R_1 = u_1 + i_1 R_1$$

$$u_-: -i_1 + \frac{u_1 - u_o}{R_2} = 0$$

$$u_o = u_1 - i_1 R_2$$

Zapojení 9



$$u_-: -i_1 - i_2 + \frac{u_- - u_o}{R_3} = 0$$

$$u_- = 0$$

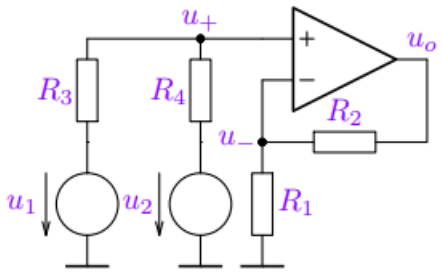
$$i_1 = \frac{-u_1 - u_-}{R_1} = \frac{-u_1}{R_1}$$

$$i_2 = \frac{u_2 - u_-}{R_2} = \frac{u_2}{R_2}$$

$$u_-: \frac{u_1}{R_1} - \frac{u_2}{R_2} + \frac{-u_o}{R_3} = 0$$

$$u_o = \frac{R_3}{R_1}u_1 - \frac{R_3}{R_2}u_2$$

Zapojení 10



$$u_+: \frac{u_+ - u_1}{R_3} + \frac{u_+ - u_2}{R_4} = 0$$

$$u_-: \frac{u_-}{R_1} + \frac{u_- - u_o}{R_2} = 0$$

$$u_- = u_+$$

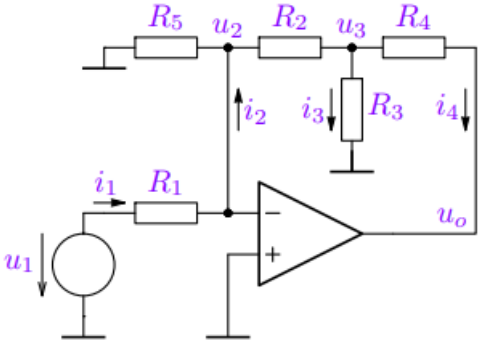
$$u_+: R_4u_+ - R_4u_1 + R_3u_+ - R_3u_2 = 0$$

$$u_-: R_2u_+ + R_1u_+ - R_1u_o = 0$$

$$u_+ = \frac{R_4}{R_4 + R_3}u_1 + \frac{R_3}{R_4 + R_3}u_2$$

$$u_o = u_+\left(1 + \frac{R_2}{R_1}\right) = \left(1 + \frac{R_2}{R_1}\right)\frac{R_4}{R_4 + R_3}u_1 + \left(1 + \frac{R_2}{R_1}\right)\frac{R_3}{R_4 + R_3}u_2$$

Zapojení 11



$$u_2 : \frac{u_2}{R_5} + \frac{u_2 - u_3}{R_2} - i_2 = 0$$

$$u_3 : \frac{u_3 - u_2}{R_2} + i_3 + i_4 = 0$$

$$u_2 = 0$$

$$i_1 = \frac{u_1 - u_2}{R_1} = \frac{u_1}{R_1}$$

$$i_2 = i_1 = \frac{u_1}{R_1}$$

$$i_3 = \frac{u_3}{R_3}$$

$$i_4 = \frac{u_3 - u_o}{R_4}$$

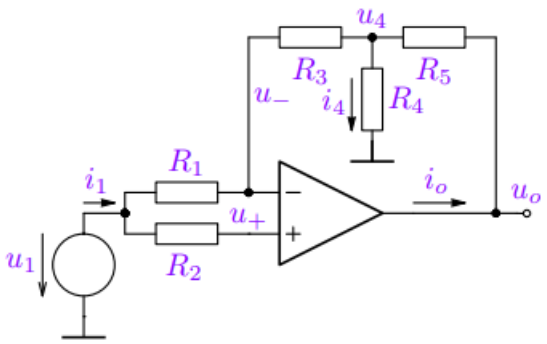
$$u_2 : -\frac{u_3}{R_2} - \frac{u_1}{R_1} = 0$$

$$u_3 : \frac{u_3}{R_2} + \frac{u_3}{R_3} + \frac{u_3 - u_o}{R_4} = 0$$

$$u_3 = -\frac{R_2}{R_1} u_1$$

$$u_o = u_3 \left(1 + \frac{R_4}{R_2} + \frac{R_4}{R_3}\right) = -\frac{R_2}{R_1} \left(1 + \frac{R_4}{R_2} + \frac{R_4}{R_3}\right) u_1$$

Zapojení 12



$$u_+ : \frac{u_+ - u_1}{R_2} = 0$$

$$u_- : -i_1 + \frac{u_- - u_4}{R_3} = 0$$

$$u_4 : \frac{u_4 - u_-}{R_3} + \frac{u_4}{R_4} - i_o = 0$$

$$u_+ = u_1$$

$$u_- = u_+ = u_1$$

$$i_1 = \frac{u_1 - u_-}{R_1} = 0$$

$$u_- : \frac{u_1 - u_4}{R_3} = 0$$

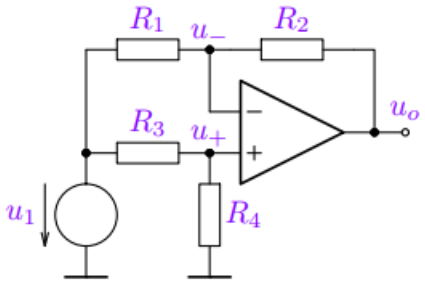
$$u_4 = u_1$$

$$i_o = \frac{u_o - u_4}{R_5} = \frac{u_o - u_1}{R_5}$$

$$u_4 : \frac{u_1}{R_4} - \frac{u_o - u_1}{R_5} = 0$$

$$u_o = u_1 \left(1 + \frac{R_5}{R_4}\right)$$

Zapojení 13



$$u_+: \frac{u_+ - u_1}{R_3} + \frac{u_+}{R_4} = 0$$

$$u_-: \frac{u_- - u_1}{R_1} + \frac{u_- - u_o}{R_2} = 0$$

$$u_- = u_+$$

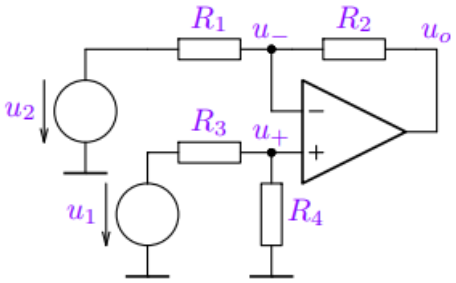
$$u_+: R_4 u_+ - R_4 u_1 + R_3 u_+ = 0$$

$$u_-: R_2 u_+ - R_2 u_1 + R_1 u_+ - R_1 u_o = 0$$

$$u_+ = \frac{R_4}{R_3 + R_4} u_1$$

$$u_o = u_+ \left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} u_1 = \left(\frac{R_4(R_1 + R_2)}{R_1(R_3 + R_4)} - \frac{R_2}{R_1}\right) u_1$$

Zapojení 14



$$u_+: \frac{u_+ - u_1}{R_3} + \frac{u_+}{R_4} = 0$$

$$u_-: \frac{u_- - u_2}{R_1} + \frac{u_- - u_o}{R_2} = 0$$

$$u_- = u_+$$

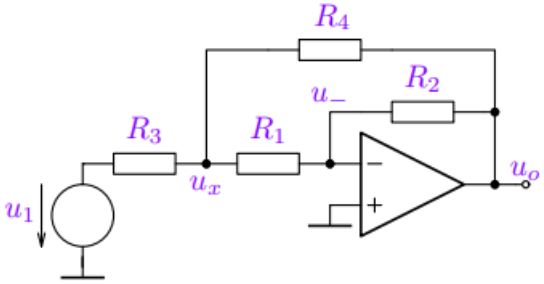
$$u_+: R_4 u_+ - R_4 u_1 + R_3 u_+ = 0$$

$$u_-: R_2 u_+ - R_2 u_2 + R_1 u_+ - R_1 u_o = 0$$

$$u_+ = \frac{R_4}{R_3 + R_4} u_1$$

$$u_o = u_+ \left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} u_2 = \frac{R_4(R_1 + R_2)}{R_1(R_3 + R_4)} u_1 - \frac{R_2}{R_1} u_2$$

Zapojení 15



$$u_x: \frac{u_x - u_1}{R_3} + \frac{u_x - u_o}{R_4} + \frac{u_x - u_-}{R_1} = 0$$

$$u_-: \frac{u_- - u_x}{R_1} + \frac{u_- - u_o}{R_2} = 0$$

$$u_- = 0$$

$$u_x: R_1R_4u_x - R_1R_4u_1 + R_1R_3u_x - R_1R_3u_o + R_3R_4u_x = 0$$

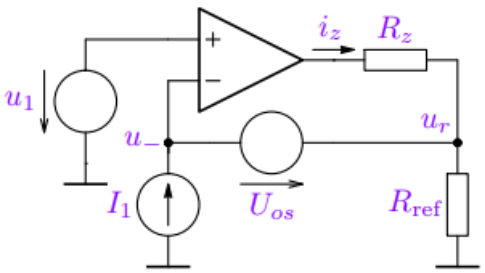
$$u_-: -R_2u_x - R_1u_o = 0$$

$$u_x = \frac{R_1R_4}{R_1R_4 + R_1R_3 + R_3R_4}u_1 + \frac{R_1R_3}{R_1R_4 + R_1R_3 + R_3R_4}u_o$$

$$u_o = -\frac{R_2}{R_1}u_x = -\frac{R_2R_4}{R_1R_4 + R_1R_3 + R_3R_4}u_1 - \frac{R_2R_3}{R_1R_4 + R_1R_3 + R_3R_4}u_o$$

$$u_o = -\frac{R_2R_4}{R_2R_3 + R_1R_4 + R_1R_3 + R_3R_4}u_1$$

Zapojení 16

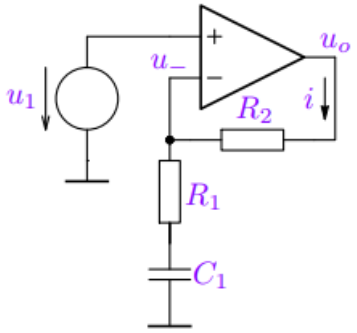


$$u_-: -I_1 - i_z + \frac{u_- - U_{os}}{R_{ref}} = 0$$

$$u_- = u_1$$

$$i_z = \frac{u_1 - U_{os}}{R_{ref}} - I_1$$

Zapojení 17



$$u_-: \frac{u_-}{R_1 + \frac{1}{j\omega C_1}} + \frac{u_- - u_o}{R_2} = 0$$

$$u_- = u_1$$

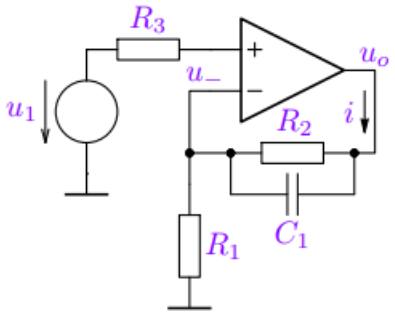
$$u_-: R_2 u_1 + u_1\left(R_1 + \frac{1}{j\omega C_1}\right) - u_o\left(R_1 + \frac{1}{j\omega C_1}\right) = 0$$

$$u_1\left(R_1 + R_2 + \frac{1}{j\omega C_1}\right) - u_o\left(R_1 + \frac{1}{j\omega C_1}\right) = 0$$

$$H(j\omega) = \frac{u_o}{u_1} = \frac{R_1 + R_2 + \frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}} = \frac{j\omega C_1}{j\omega C_1} \cdot \frac{j\omega C_1 R_1 + j\omega C_1 R_2 + 1}{j\omega C_1 R_1 + 1} = \frac{1 + j\omega C_1(R_1 + R_2)}{1 + j\omega C_1 R_1} = \frac{1 + j\frac{\omega}{\omega_1}}{1 + j\frac{\omega}{\omega_2}}$$

$$\omega_1 = \frac{1}{C_1(R_1 + R_2)};\ \omega_2 = \frac{1}{C_1 R_1}$$

Zapojení 18



$$u_-: \frac{u_-}{R_1} - i = 0$$

$$i = \frac{u_o - u_-}{\frac{R_2 \cdot \frac{1}{j\omega C_1}}{R_2 + \frac{1}{j\omega C_1}}}$$

$$u_- = u_1$$

$$u_-: \frac{u_1}{R_1} + \frac{u_1 - u_o}{\frac{R_2 \cdot \frac{1}{j\omega C_1}}{R_2 + \frac{1}{j\omega C_1}}} = 0$$

$$\left(\frac{R_2 \cdot \frac{1}{j\omega C_1}}{R_2 + \frac{1}{j\omega C_1}} + R_1 \right) u_1 - R_1 u_o = 0$$

$$H(j\omega) = \frac{u_o}{u_1} = \frac{\frac{R_2 \cdot \frac{1}{j\omega C_1}}{R_2 + \frac{1}{j\omega C_1}} + R_1}{R_1} = 1 + \frac{R_2 \cdot \frac{1}{j\omega C_1}}{R_1 R_2 + \frac{R_1}{j\omega C_1}} = \frac{R_1 R_2 + \frac{R_1}{j\omega C_1} + R_2 \cdot \frac{1}{j\omega C_1}}{R_1 R_2 + \frac{R_1}{j\omega C_1}} = \frac{j\omega C_1}{j\omega C_1} \frac{j\omega C_1 R_1 R_2 + R_1 + R_2}{j\omega C_1 R_1 R_2 + R_1}$$

$$= \left(1 + \frac{R_2}{R_1}\right) \frac{1 + j\omega \frac{C_1 R_1 R_2}{R_1 + R_2}}{1 + j\omega C_1 R_2} = \left(1 + \frac{R_2}{R_1}\right) \frac{1 + j\frac{\omega}{\omega_1}}{1 + j\frac{\omega}{\omega_2}}$$

$$\omega_1 = \frac{R_1 + R_2}{C_1 R_1 R_2} = \frac{1}{C_1 R_1} + \frac{1}{C_1 R_2};\ \omega_1 = \frac{1}{C_1 R_2}$$