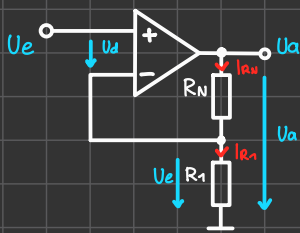


> Nicht Invertierender Verstärker <



Bei Rückkopplung: $U_d = 0$

$$U_{RN} = U_d + U_e \rightarrow \underline{U_{RN} = U_e}$$

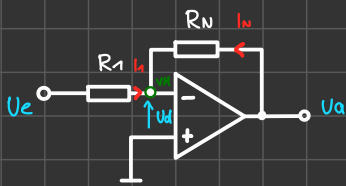
$$I_{RN} = I_{R1} = I$$

$$I = \frac{U_e}{R_1} = \frac{U_a}{R_N + R_1}$$

$$\underline{U_a = U_e \left(\frac{R_N + R_1}{R_1} \right) = U_e \left(\frac{R_N}{R_1} + 1 \right)}$$

$$\underline{V_u = \left(\frac{R_N}{R_1} + 1 \right)}$$

> Invertierender Verstärker <



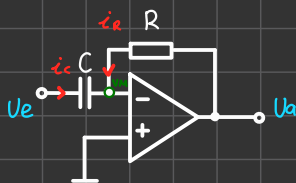
$$I_1 = -I_N$$

$$\frac{U_e}{R_1} = -\frac{U_a}{R_N}$$

$$\underline{U_a = -U_e \frac{R_N}{R_1}}$$

$$\underline{V_u = \frac{R_N}{R_1}}$$

> Differenzierer <



$$i_C = C \cdot \frac{dU_e}{dt}$$

$$i_R = \frac{U_a}{R}$$

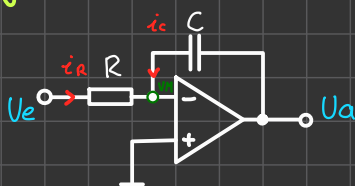
$$i_C = -i_R$$

$$-C \cdot \frac{dU_e}{dt} = \frac{U_a}{R}$$

$$\underline{U_a = -RC \cdot \frac{dU_e}{dt}}$$

$$\underline{V_u = -R \cdot C}$$

> Integrierer <



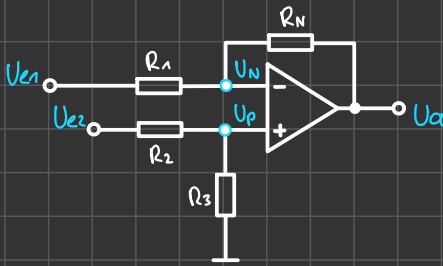
$$i_R = \frac{U_e}{R} \quad i_C = C \cdot \frac{dU_a}{dt}$$

$$i_R = -i_C \quad -C \cdot \frac{dU_a}{dt} = \frac{U_e}{R} \quad | : -C \int dt$$

$$\underline{U_a = -\frac{1}{RC} \cdot \int U_e dt}$$

$$\underline{V_u = -\frac{1}{RC}}$$

> Subtrahierer <



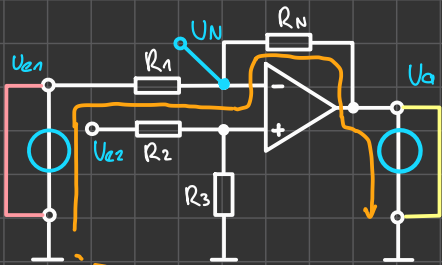
3 Lösungswege



$$V_{U_1} = - \frac{R_N}{R_1}$$

$$V_{U_2} = \frac{R_3}{R_2 + R_3} \cdot \frac{R_N + R_1}{R_1}$$

> 1. Lösungsweg <



o Helmholtz für U_N

I) U_a Kurzgeschlossen

$$U_{N1} = U_{e1} \frac{R_N}{R_N + R_1}$$

II) U_{e1} Kurzgeschlossen

$$U_{N2} = U_a \frac{R_1}{R_N + R_1}$$

$$U_N = U_{N1} + U_{N2}$$

$$U_N = U_{e1} \frac{R_N}{R_N + R_1} + U_a \frac{R_1}{R_N + R_1}$$

$$U_p = U_{e2} \frac{R_3}{R_2 + R_3}$$

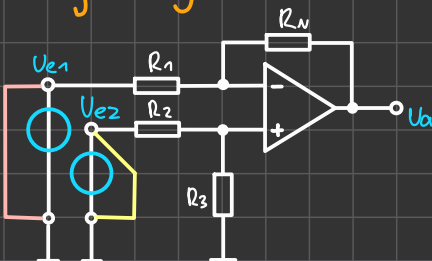
$$U_N = U_p \frac{R_3}{R_2 + R_3}$$

$$U_{e2} \cdot \frac{R_3}{R_2 + R_3} = U_{e1} \frac{R_N}{R_N + R_1} + U_a \frac{R_1}{R_N + R_1} \quad \left| - U_{e1} \frac{R_N}{R_N + R_1} \right| \cdot \frac{R_N + R_1}{R_1}$$

$$U_a = U_{e2} \frac{R_3}{R_2 + R_3} \cdot \frac{R_N + R_1}{R_1} - U_{e1} \frac{R_N}{R_N + R_1} \cdot \frac{R_N + R_1}{R_1}$$

$$U_a = - U_{e1} \frac{R_N}{R_1} + U_{e2} \frac{R_3}{R_2 + R_3} \cdot \frac{R_N + R_1}{R_1}$$

> 2. Lösungsweg <



o Helmholtz für U_a

I) U_{e2} Kurzgeschlossen

$$U_{a'} = - U_{e1} \frac{R_N}{R_1}$$

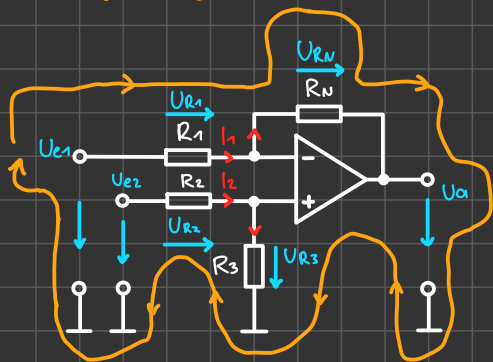
II) U_{e1} Kurzschließen

$$U_{a''} = U_{e2} \frac{R_3}{R_2 + R_3} \cdot \frac{R_N + R_1}{R_1}$$

$$U_a = U_{a'} + U_{a''}$$

$$U_a = - U_{e1} \frac{R_N}{R_1} + U_{e2} \frac{R_3}{R_2 + R_3} \cdot \frac{R_N + R_1}{R_1}$$

> 3. Lösungsweg <



Schaltungskriterien:

- o Masche
- o $U_p = U_N = U_{st}$
- o $I_{st} = 0$

$$\hookrightarrow I_1 = I_N \text{ \& } I_2 = I_3$$

KIRCHHOFF:

$$U_{e1} + U_{R2} + U_{R3} = U_{R1} + U_{RN} + U_a + U_{e2}$$

$$U_{e1} + I_2 \cdot R_2 + I_2 \cdot R_3 = I_1 \cdot R_1 + I_1 \cdot R_N + U_a + U_{e2}$$

$$U_{e1} + I_2 (R_2 + R_3) = I_1 (R_1 + R_N) + U_a + U_{e2}$$

$$U_{e1} + \frac{U_{e2} - U_{st}}{R_2} (R_2 + R_3) = \frac{U_{e1} - U_{st}}{R_1} (R_1 + R_N) + U_a + U_{e2}$$

$$U_{e1} + \frac{U_{e2} - U_{e2} \left(\frac{R_3}{R_2 + R_3} \right)}{R_2} (R_2 + R_3) = \frac{U_{e1} - U_{e2} \left(\frac{R_3}{R_2 + R_3} \right)}{R_1} (R_1 + R_N) + U_a + U_{e2}$$

$$U_{e1} + \frac{U_{e2} (R_2 + R_3) - U_{e2} \cdot R_3}{R_2} = \left(U_{e1} - U_{e2} \frac{R_3}{R_2 + R_3} \right) \cdot \frac{R_1 + R_N}{R_1} + U_a + U_{e2}$$

$$\frac{U_{e1} \cdot R_1 \cdot R_2 - U_{e2} \cdot R_1 \cdot R_2 + U_{e2} \cdot R_2 \cdot R_1 - R_2 \cdot \left(U_{e1} - U_{e2} \frac{R_3}{R_2 + R_3} \right) \cdot (R_1 + R_N)}{R_1 \cdot R_2} = U_a$$

$$\frac{U_{e1} \cdot R_1 \cdot \cancel{R_2} - U_{e1} \cdot \cancel{R_2} (R_1 + R_N) + U_{e2} \cdot \cancel{R_2} \cdot \frac{R_3}{R_2 + R_3} (R_1 + R_N)}{R_1 \cdot \cancel{R_2}} = U_a$$

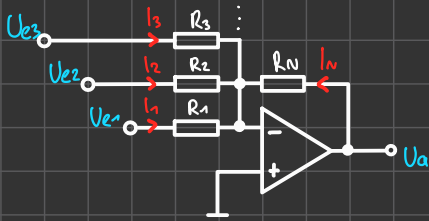
$$\frac{U_{e1} \cdot R_1}{R_1} - \frac{U_{e1} \cdot (R_1 + R_N)}{R_1} + U_{e2} \cdot \frac{R_3}{R_1} \cdot \frac{R_1 + R_N}{R_2 + R_3} = U_a$$

$$U_{e1} - U_{e1} \left(1 + \frac{R_N}{R_1} \right) + U_{e2} \cdot \frac{R_3}{R_1} \cdot \frac{R_1 + R_N}{R_2 + R_3} = U_a$$

$$\cancel{U_{e1}} - \cancel{U_{e1}} - U_{e1} \frac{R_N}{R_1} + U_{e2} \cdot \frac{R_3}{R_2 + R_3} \cdot \frac{R_1 + R_N}{R_1} = U_a$$

$$U_a = -U_{e1} \frac{R_N}{R_1} + U_{e2} \frac{R_3}{R_2 + R_3} \cdot \frac{R_1 + R_N}{R_1}$$

> Umkehrsummierer / Addierer <



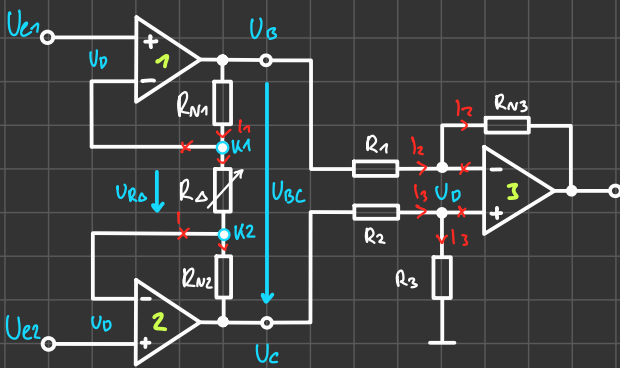
$$-I_N = I_1 + I_2 + I_3$$

$$-\frac{U_0}{R_N} = \frac{U_{e1}}{R_1} + \frac{U_{e2}}{R_2} + \frac{U_{e3}}{R_3}$$

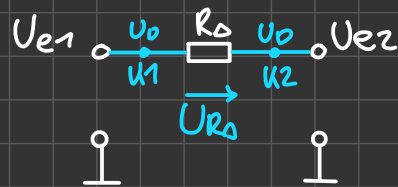
$$U_a = - \left[U_{e1} \cdot \frac{R_N}{R_1} + U_{e2} \cdot \frac{R_N}{R_2} + U_{e3} \cdot \frac{R_N}{R_3} \dots \right]$$

$$V_i = - \frac{R_N}{R_i}$$

> Instrumentenverstärker <



OPV 1,2: $U_0 = 0$



$$U_{RD} = U_{e1} - U_{e2}$$

$$I_1 = \frac{U_{RD}}{R_D}$$

$$U_{BC} = I_1 \cdot (R_{N1} + R_{N2} + R_D)$$

$$U_{BC} = U_B - U_C$$

$$U_{e1} - U_C = U_{e2} \cdot \left(\frac{R_{N2} + R_D}{R_D} \right)$$

$$U_B - U_{e2} = U_{e1} \cdot \left(\frac{R_{N1} + R_D}{R_D} \right)$$

U_{N1} ... Virtuelles U_{e1}
 U_{N2} ... Virtuelles U_{e2}

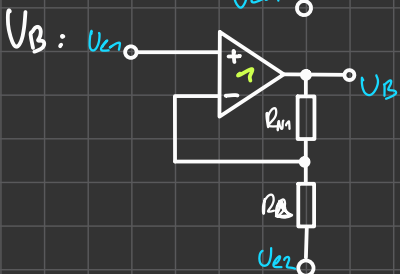
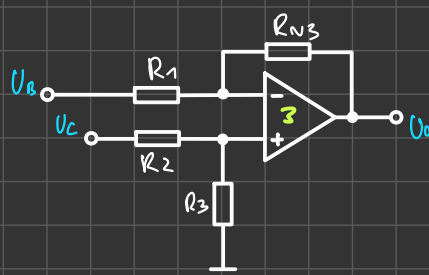
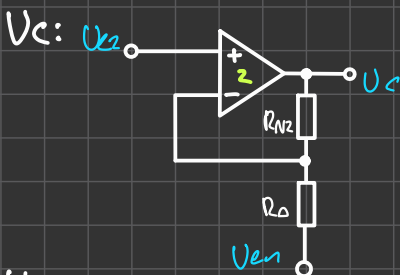
o Schaltungskriterien

> $U_0 = 0$

> $\times \rightarrow$ Kein Stromfluss

> $I_1 = I_3$

> $U_a = f(U_{e1}, U_{e2})$



$$U_a = -U_B \frac{R_N}{R_1} + U_C \frac{R_3}{R_2 + R_3} \cdot \frac{R_1 + R_N}{R_1}$$

Todo:

- Impedanzwandler
- Einweggleichrichter
- Vollweggleichrichter
- Schleifenverstärkung / Rückkopplung
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