Universalkompensation

$$A_D(s) = K \frac{\prod_{\mu=1}^{m}(s - s_{0\mu})}{\prod_{\nu=1}^{n}(s - s_{\infty\nu})} = K' \frac{\prod_{\mu=1}^{m}\left(1 - \frac{s}{s_{0\mu}}\right)}{\prod_{\nu=1}^{n}\left(1 - \frac{s}{s_{\infty\nu}}\right)} \quad \text{mit } K' = K(-1)^{n-m} \frac{\prod_{\mu=1}^{m} s_{0\mu}}{\prod_{\nu=1}^{n} s_{\infty\nu}}$$

$$A_D(j\omega) = K' e^{j(\sum\psi_\mu - \sum\varphi_\nu)} \frac{\prod_{\mu=1}^{m}\sqrt{1+\left(\frac{\omega}{s_{0\mu}}\right)^2}}{\prod_{\nu=1}^{n}\sqrt{1+\left(\frac{\omega}{s_{\infty\nu}}\right)^2}}, \quad \tan\psi_\mu = -\frac{\omega}{s_{0\mu}}$$

$$\tan\varphi_\nu = -\frac{\omega}{s_{\infty\nu}}$$

$\frac{\omega}{s_{0\mu}} \ll 1$ für $\mu = 1, \dots, m$

$\frac{\omega}{s_{\infty\nu}} \ll 1$ für $\nu = 2, \dots, n$

$$\Rightarrow A_D(j\omega) = K' e^{-j\varphi} \frac{1}{\sqrt{1+\left(\frac{\omega}{s_{\infty 1}}\right)^2}}$$

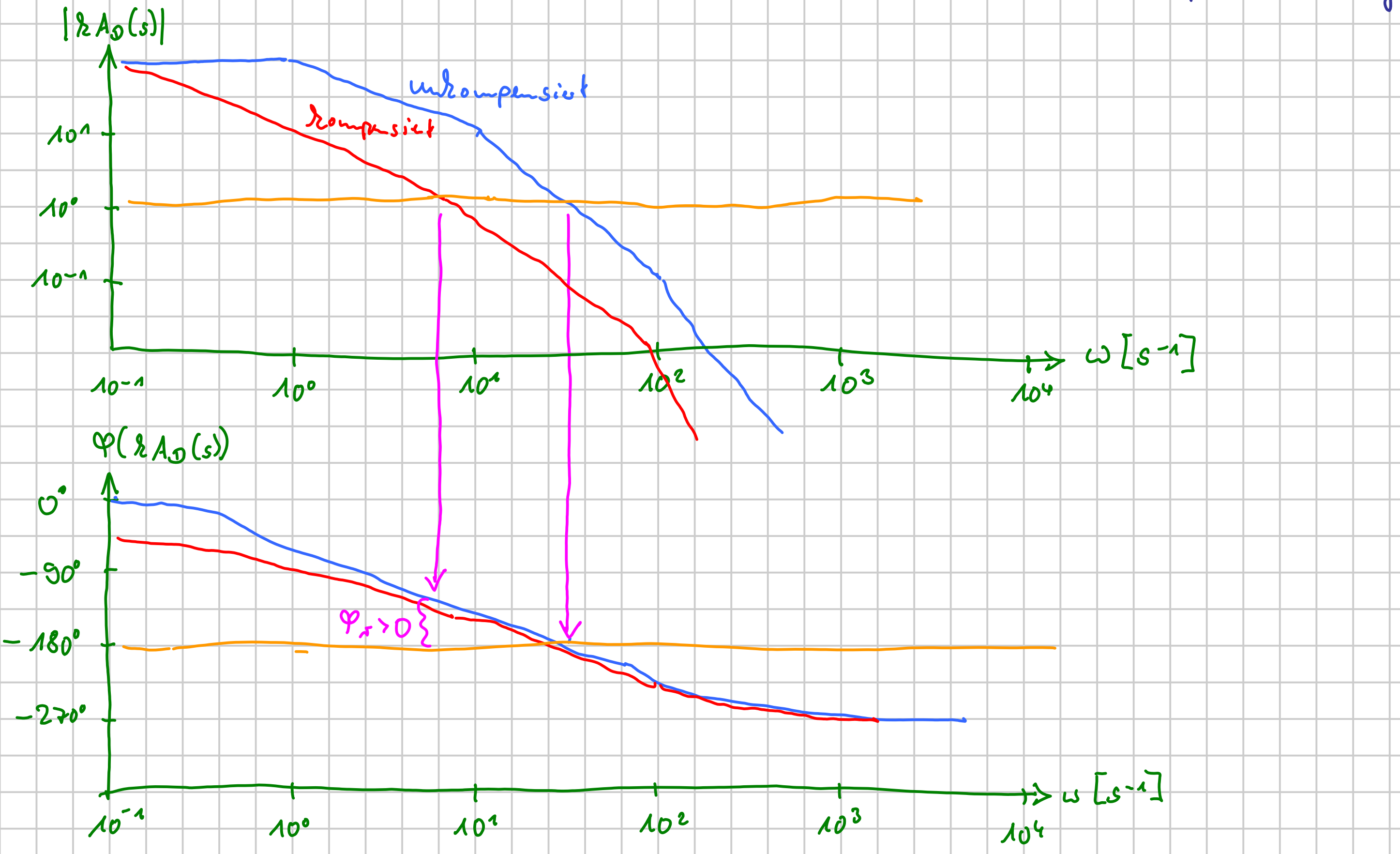
Vernachlässigung der anderen Wurzel-Terme

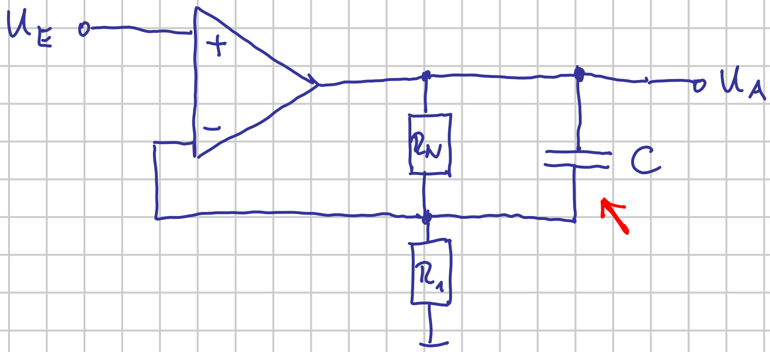
„dominanter" Pol

Kompensation: Verringerung der Frequenz des ersten Pols $s_{\infty 1}$ so, dass ein dominanter Pol entsteht $\rightarrow$ Einfügen einer Kapazität

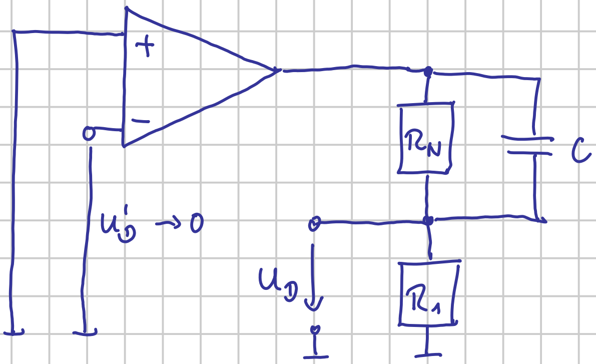
$$\Rightarrow A_D(s) \approx \frac{K'}{1 - \frac{s}{s_{\infty 1}}} \approx \frac{A_{D0}}{1 - \frac{s}{s_{\infty 1}}}, \quad A_{D0} > 0$$

$s \gg s_{\infty 1} \Rightarrow A_D(s) \propto s_{\infty 1} \Rightarrow A_D(s) \propto s^{-1}$ Näherung des OpV durch Tiefpass 1. Ordnung





$$U_D = \frac{R_1}{R_1 + R_N \| \frac{1}{sC}} U_A = -A_D(s) \frac{R_1}{R_1 + R_N \| \frac{1}{sC}} U_D' = -A_D(s)\, k(s)$$

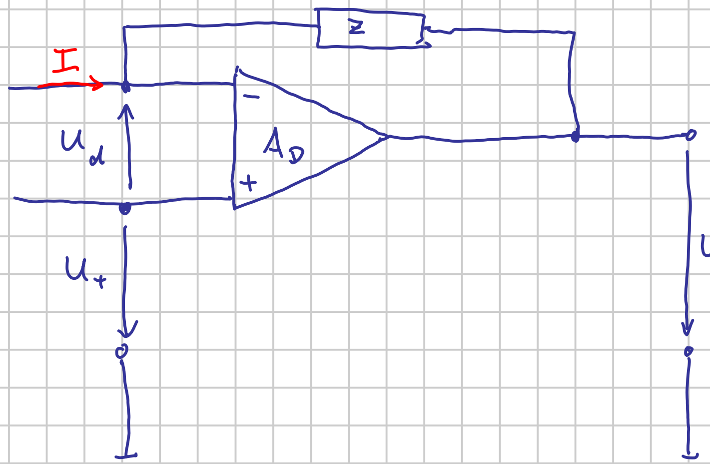


$$\frac{U_D}{U_D'} = -A_D(s) \frac{sC + \frac{1}{R_N}}{sC + \frac{1}{R_N} + \frac{1}{R_1}}$$

$$= -A_D(s) \underbrace{\frac{s + \frac{1}{CR_N}}{s + \frac{1 + R_1/R_N}{CR_1}}}_{= k(s)}$$

$$\Rightarrow k(s) A_D(s) \approx \frac{R_1}{R_1 + R_N} \frac{1 + s/\sigma_0}{1 + s/\sigma_\infty} A_D(s)$$

Operationsverstärker-Schaltungen



Leerlaufverstärkung → ∞

Stromfluss in den Eingängen → 0

$U_d \to 0$

$$I + \frac{U_A - U_+ + U_d}{Z} = 0$$

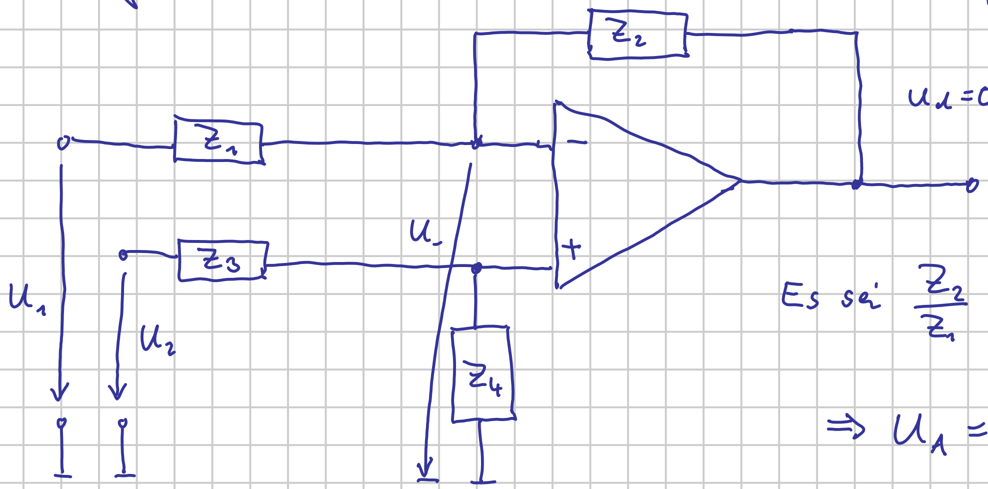
$$U_A = A_D U_d$$

$$\Rightarrow \frac{U_A}{Z} - \frac{U_+}{Z} + \frac{U_d}{Z} = -I$$

$$\Leftrightarrow U_d = \frac{U_+ - ZI}{A_D + 1}$$

$$\Rightarrow \lim_{A_D \to \infty} U_d = 0$$

Schaltung zur Subtraktion:



$$U_+ = U_2 \frac{Z_4}{Z_3+Z_4}$$

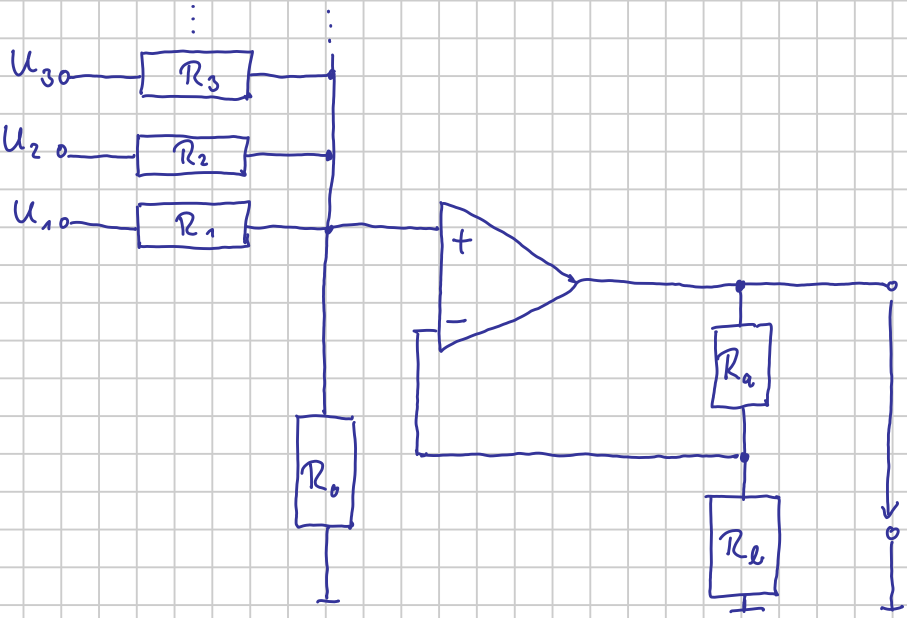
$$u_d = 0 \Rightarrow U_- = (U_A - U_1)\frac{Z_1}{Z_1+Z_2} + U_1$$

$$\Downarrow$$

Es sei $\frac{Z_2}{Z_1} = \frac{Z_4}{Z_3}$

$$\Rightarrow U_A = \frac{Z_2}{Z_1}(U_2 - U_1)$$

Schaltung zur Summation mit nichtinvertierendem OpV:



$u=0$

$$U_A = U_+\left(1+\frac{R_a}{R_b}\right)$$

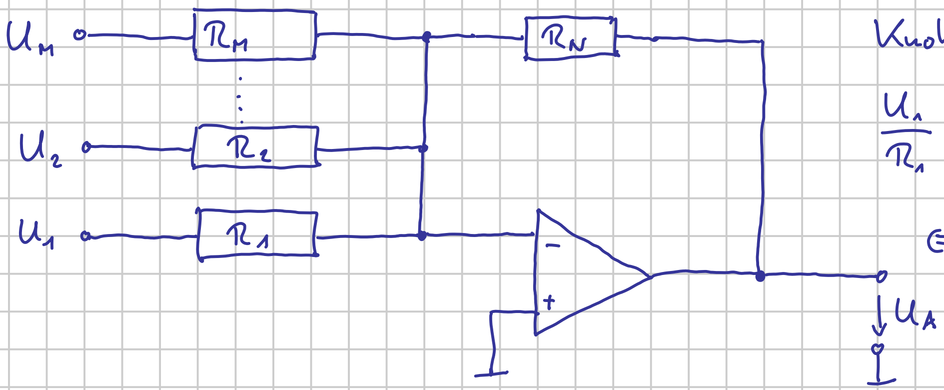
Knotenregel für Eingangsstrom $=0$:

$$\frac{U_+}{R_0} + \frac{U_+ - U_1}{R_1} + \frac{U_+ - U_2}{R_2} + \ldots = 0$$

$$\Leftrightarrow \frac{U_+}{R_0} + \frac{U_+}{R_1} - \frac{U_1}{R_1} + \frac{U_+}{R_2} - \frac{U_2}{R_2} + \ldots - \ldots = 0$$

$$\Rightarrow U_A = \left(1+\frac{R_a}{R_b}\right)\frac{\sum_{m=1}^{M} U_m \cdot \frac{1}{R_m}}{\sum^{m} \frac{1}{R_n}}$$

Schaltung zur Summation mit invertierenden OpV:



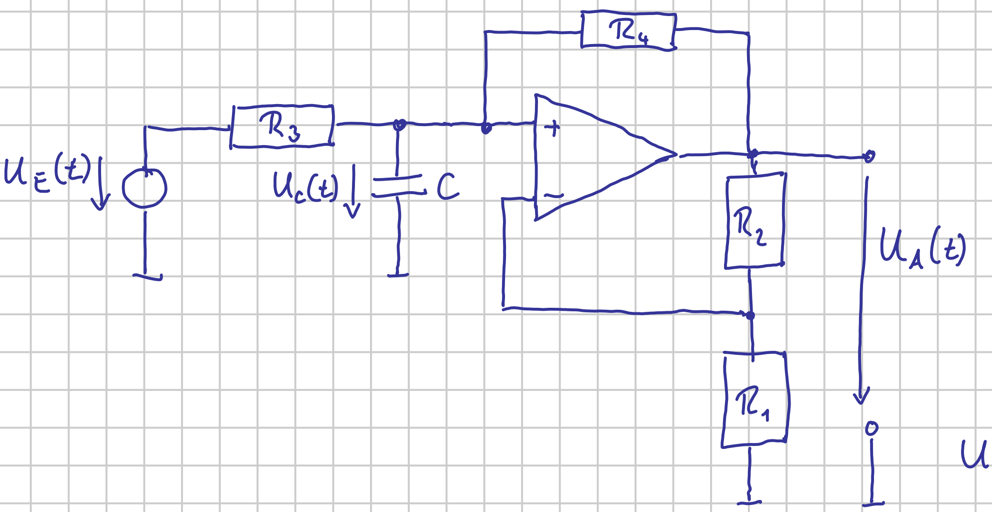
Knotenregel für Eingangsstrom $=0$:

$$\frac{U_1}{R_1} + \frac{U_2}{R_2} + \ldots + \frac{U_M}{R_M} + \frac{U_A}{R_N} = 0$$

$$\Leftrightarrow U_A = -R_N \sum_{m=1}^{M} \frac{U_m}{R_m}$$

Strom durch m-ten Zweig des Eingangs

Schaltung zur Integration mit nichtinvertierendem OpV:



$$U_- = U_A \frac{R_1}{R_1+R_N} \overset{U_d \to 0}{=} U_+ = U_c$$

Knotenregel:

$$C \frac{dU_c(t)}{dt} + \frac{U_c - U_E}{R_3} + \frac{U_c - U_A}{R_4} = 0$$

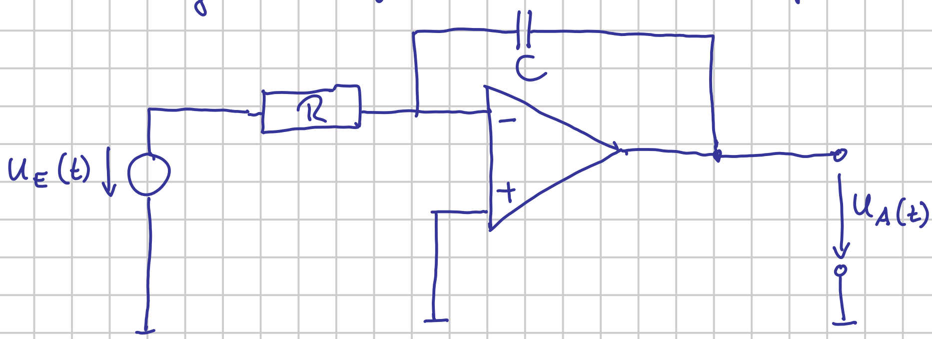
$$U_A = U_c \left(1 + \frac{R_2}{R_1}\right)$$

$$\Rightarrow R_4 C \frac{dU_c}{dt} + \cancel{\left(\frac{R_4}{R_3} - \frac{R_2}{R_1}\right)} U_c = \frac{R_4}{R_3} U_E$$

$$\frac{R_4}{R_3} = \frac{R_2}{R_1}$$

$$\Rightarrow U_A = \left(1 + \frac{R_2}{R_1}\right)\left[U_c(t_0) + \frac{1}{R_3 C} \int_{t_0}^{t} U_E(\tau)\, d\tau\right]$$

Schaltung zur Integration mit invertierendem OpV:



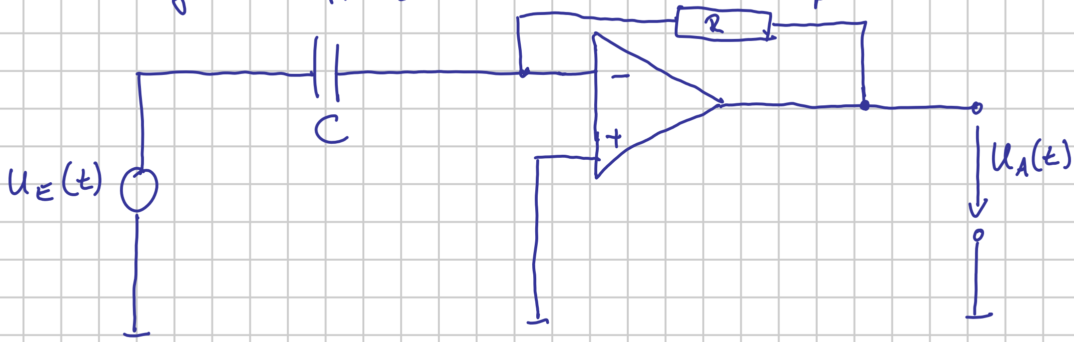
Knotenregel:

$$\frac{U_E(t)}{R} + C \frac{dU_A(t)}{dt} = 0$$

$$\Leftrightarrow \frac{dU_A(t)}{dt} = -\frac{1}{RC} U_E(t)$$

$$\Rightarrow U_A(t) = \underbrace{U_A(t_0)}_{\text{Integrationskonstante}} - \frac{1}{RC} \int_{t_0}^{t} U_E(\tau)\, d\tau$$

Schaltung zur Differenziation mit invertierendem OpV:



Knotenregel am inv. Eingang: $C \frac{dU_E(t)}{dt} + \frac{U_A(t)}{R} = 0$

$$\Leftrightarrow \quad U_A(t) = -RC \frac{dU_E(t)}{dt}$$