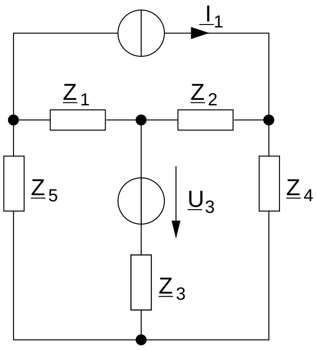
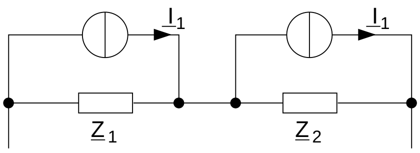
Klausur Elektronik II, SS 2006

Lösungsvorschlag

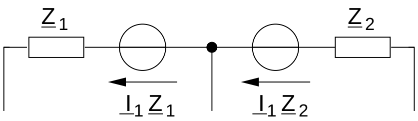
Aufgabe 1: Netzwerkberechnung



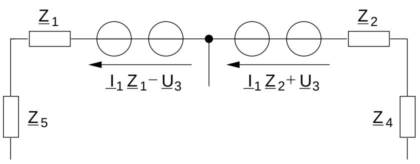
Stromquelle $\underline{I}_1$ verdoppeln



Umwandeln in Spannungsquellen



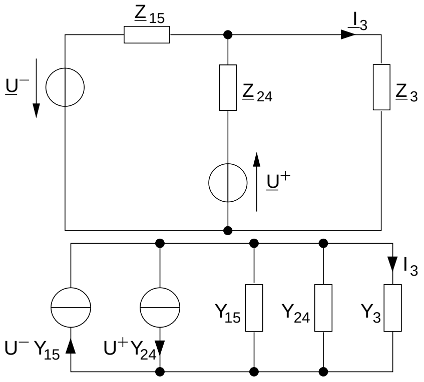
Spannungsquelle $\underline{U}_3$ über Knoten ziehen



Spannungsquellen und Impedanzen in Reihe zusammenfassen

$\underline{Z}_{15} = \underline{Z}_1 + \underline{Z}_5 \qquad \underline{U}^- = \underline{I}_1 \cdot \underline{Z}_1 - \underline{U}_3$

$\underline{Z}_{24} = \underline{Z}_2 + \underline{Z}_4 \qquad \underline{U}^+ = \underline{I}_1 \cdot \underline{Z}_2 + \underline{U}_3$

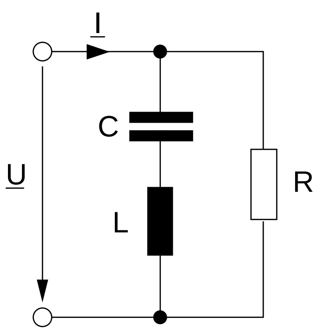


Spannungsquellen in Serie zu Impedanzen in Stromquellen umwandeln

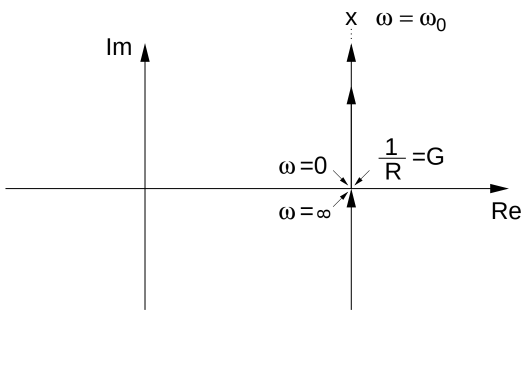
Ströme müssen sich kompensieren
$\Rightarrow I_3 = 0$

$$\underline{U}^-\underline{Y}_{15} = \underline{U}^+\underline{Y}_{24}$$
$$(\underline{I}_1\underline{Z}_1 - \underline{U}_3)\underline{Y}_{15} = (\underline{I}_1\underline{Z}_2 + \underline{U}_3)\underline{Y}_{24}$$
$$\underline{I}_1\left(\frac{\underline{Z}_1}{\underline{Z}_{15}} - \frac{\underline{Z}_2}{\underline{Z}_{24}}\right) = \frac{\underline{U}_3}{\underline{Z}_{24}} + \frac{\underline{U}_3}{\underline{Z}_{15}}$$
$$\frac{\underline{U}_3}{\underline{I}_1} = \frac{\frac{\underline{Z}_1}{\underline{Z}_{15}} - \frac{\underline{Z}_2}{\underline{Z}_{24}}}{\frac{1}{\underline{Z}_{24}} + \frac{1}{\underline{Z}_{15}}} = \frac{\underline{Z}_1\underline{Z}_{24} - \underline{Z}_2\underline{Z}_{15}}{\underline{Z}_{15} + \underline{Z}_{24}}$$

Aufgabe 2: Ortskurve

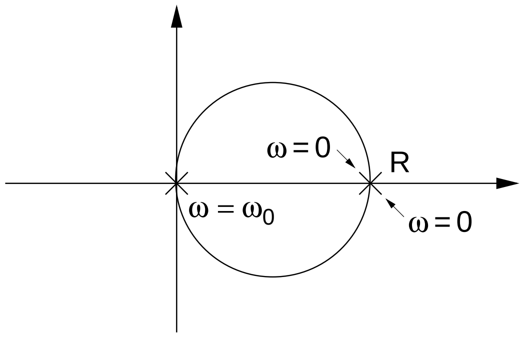


1.



$\underline{Y} = \frac{j\omega C}{1-\omega^2 LC} + G$
$\omega_0 = \sqrt{\frac{1}{LC}}$

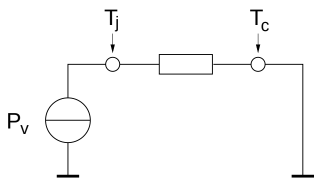
2. Inversion von 1.):



Aufgabe 3: Arbeitspunkt, Wärmewiderstand

1.

$$P_V = I_B \cdot U_{BE} + I_C \cdot U_{CE} \approx I_C \cdot U_{CE}$$
$$P_V = I_C \cdot U_{CE} \Rightarrow U_{CE} = \frac{P_V}{I_C} = \frac{0,5W}{0,1A} = \underline{\underline{5V}}$$



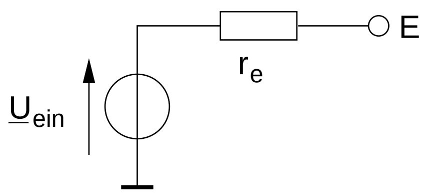
$$P_V \cdot R_{thjc} = T_j - T_c$$
$$P_V = \frac{T_j - T_c}{R_{thjc}} = \frac{(100-60)k}{80k} W$$
$$P_V = 0,5W$$

2.

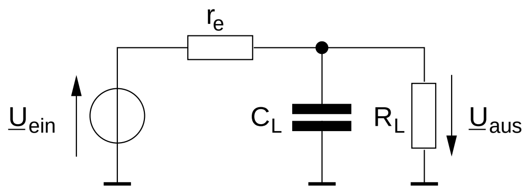
$$U_{RC} = 12V - 1V - 5V = 6V$$
$$R_C = \frac{U_{RC}}{0,1A} = \frac{6V}{0,1A} = \underline{\underline{60\Omega}}$$

Aufgabe 4: Schaltungsberechnung, Dimensionierung, Arbeitspunkt

1. R_{aus} Kollektor-Grundschaltung: $r_e = \frac{1}{g_m} = \frac{U_T}{I_C}$ $\quad \beta = \infty \Rightarrow g_{be} = 0$
   Spannungsverstärkung $v_u \approx 0$
   $\Rightarrow$ ESB der KGS (Emitterfolger)



WS-ESB



$$\underline{F}(j\omega) = \frac{\underline{U}_{aus}}{\underline{U}_{ein}} = \frac{-R_L||C_L}{r_e + R_L||C_L} = \frac{-1}{1 + \frac{r_e}{R_L||C_L}}$$
$$= \frac{-1}{1 + \frac{r_e(R_L + \frac{1}{j\omega C_L})j\omega C_L}{R_L}} = \frac{-1}{1 + j\omega C_L r_e + \frac{r_e}{R_L}}$$

2. Ausdruck aus 1) umformen zu $\frac{\underline{F}_a}{1+\underline{F}_a \cdot \underline{F}_2}$ $\qquad 1 + \frac{r_e}{R_L} = \frac{R_L + r_e}{R_L}$

$$\underline{F}(j\omega) = \frac{-1}{1 + \frac{r_e}{R_L}} \cdot \frac{1}{1 + j\omega C_L r_e \cdot \frac{R_L}{r_e + R_L}}$$
$$\Rightarrow \underline{F}(j\omega) = \frac{-v_0}{1 + \frac{j\omega}{\omega_0}} \qquad \omega_0 = \frac{r_e + R_L}{r_e R_L C_L}, \quad v_0 = \frac{R_L}{R_L + r_e}$$

Im Ausdruck aus 1) $\mathrm{Im}(N) = \mathrm{Re}(N)$ ausrechnen, Nenner-Term auf $1 + ...$ bringen:

$$\begin{aligned} v_0 &= \frac{1}{1+\frac{r_e}{R_L}} = \frac{R_L}{R_L + r_e} \\ \mathrm{Img}(N) &= \mathrm{Re}(N) \\ \frac{r_e}{R_L} + 1 &= \omega_0 C_L r_e \\ g_m + \frac{1}{R_L} &= \omega_0 C_L \\ \frac{1 + g_m R_L}{C'_L R_L} &= \omega_0 = \frac{R_L + r_e}{r_e (C_L R_L)} \end{aligned}$$

3.

$$\begin{aligned} \omega_0 &= \frac{r_e + R_L}{r_e C_L R_L} = \frac{\frac{U_T}{I_C} + R_L}{\frac{U_T}{I_C} R_L C_L} = \frac{U_T + R_L I_C}{U_T R_L C_L} \\ \omega_0 U_T R_L C_L &= U_T + R_L I_C \\ U_T(\omega_0 R_L C_L - 1) &= R_L I_C \\ I_C &= \frac{U_T}{R_L}(\omega_0 R_L C_L - 1) \end{aligned}$$

4. I_C muss ≥ 0 sein, d.h. in Richtung Kollektor fließen

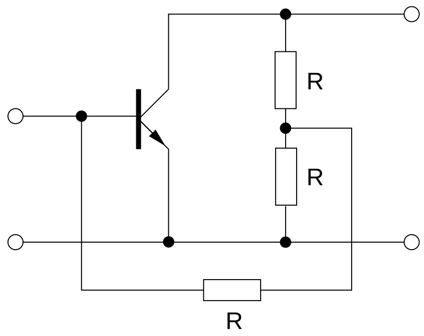
$$\Rightarrow \omega_0 R_L C_L \geq 1 \quad \text{mit} \quad R_L C_L = \frac{1}{\omega_L}$$
$$\Rightarrow \frac{\omega_0}{\omega_L} \geq 1 \Longleftrightarrow \omega_0 \geq \omega_L$$

5. Transistor muss im normal-aktiven Betrieb sein (durch U_{BC} gesteuerter Beitrag im Kollektorstrom ≈ 0)

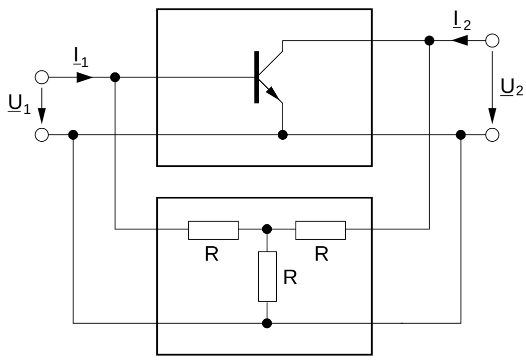
$$\Rightarrow |U_{ein}| = 0 \quad \text{(streng) mit Vernachlässigung kleiner Ströme}$$
$$\Rightarrow |U_{ein}| \ll U_{D,BC} \text{Diffussionsspannung}$$

Aufgabe 5: Rückkopplung, Zweitor

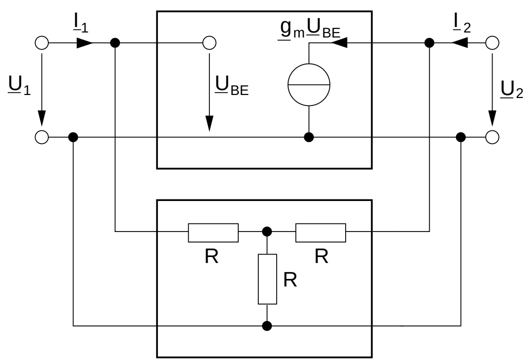
1. WS-ESB



Zerlegung in Haupt-Rückkopplungs Zweitor:



Kleinsignal-ESB:



2. PPK, da Spannungen $\underline{F}_a, \underline{F}_2$ gleich sind und sich die Ströme addieren. Torbed. ist erfüllt, da einfließende = ausfließende Ströme.

3. $\underline{I}_1 = \underline{U}_1\underline{Y}_{11} + \underline{U}_2\underline{Y}_{12}$ Admittanz-Matrizen, da $\underline{I}_2 = \underline{U}_1\underline{Y}_{21} + \underline{U}_2\underline{Y}_{22}$

4.

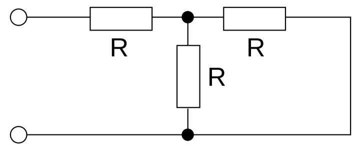
$\underline{F}_a$:

$$\underline{Y}_{11} = \left.\frac{I_1}{U_1}\right|_{U_2=0} = 0$$

$$\underline{Y}_{12} = \left.\frac{I_1}{U_2}\right|_{U_1=0} = 0 \qquad [\underline{\mathrm{Y}}] = \begin{bmatrix} 0 & 0 \\ g_m & 0 \end{bmatrix}$$

$$\underline{Y}_{21} = \left.\frac{I_2}{U_1}\right|_{U_2=0} = g_m$$

$$\underline{Y}_{22} = \left.\frac{I_2}{U_2}\right|_{U_1=0} = 0$$



$\underline{F}_2$:

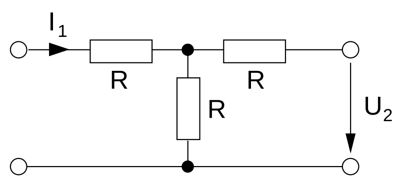
$$\underline{Y}_{11} = \frac{1}{R + \frac{R}{2}} = \frac{2}{3R}$$

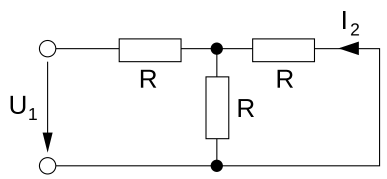
$$\underline{Y}_{12} = -\frac{1}{3R}$$

$$\underline{Y}_{21} = -\frac{1}{3R} = \underline{Y}_{12}$$

$$\underline{Y}_{22} = \underline{Y}_{11} = \frac{2}{3R}$$

$$-\underline{I}_1 = \frac{\underline{U}_2}{R + \frac{R}{2}} \cdot \frac{1}{2}$$





$$[\underline{Y}_{ges}] = [\underline{Y}_1] + [\underline{Y}_2]$$

$$= \begin{bmatrix} 0 & 0 \\ g_m & 0 \end{bmatrix} + \begin{bmatrix} \frac{2}{3R} & -\frac{1}{3R} \\ -\frac{1}{3R} & \frac{2}{3R} \end{bmatrix}$$

$$[\underline{Y}_{ges}] = \begin{bmatrix} \frac{2}{3R} & -\frac{1}{3R} \\ -\frac{1}{3R} + g_m & \frac{2}{3R} \end{bmatrix}$$

5.

$$\left.\frac{\underline{U}_{aus}}{\underline{I}_{ein}}\right|_{\underline{I}_{aus}=0} \Rightarrow I_2 = \underline{I}_{aus} = 0 = \underline{U}_1\underline{Y}_{21} + \underline{U}_2\underline{Y}_{22}$$

$$\underline{U}_1 = \frac{-\underline{U}_2\underline{Y}_{22}}{\underline{Y}_{21}}$$

$$\underline{I}_1 = -\underline{U}_2\,\frac{\underline{Y}_{22}}{\underline{Y}_{21}}\,\underline{Y}_{11} + \underline{U}_2\underline{Y}_{12}$$

$$\underline{I}_1 = \underline{U}_2\left(\underline{Y}_{12} - \frac{\underline{Y}_{22}\underline{Y}_{11}}{\underline{Y}_{21}}\right) = \underline{U}_2\,\frac{\underline{Y}_{12}\underline{Y}_{21} - \underline{Y}_{11}\underline{Y}_{22}}{\underline{Y}_{21}}$$

$$\frac{\underline{U}_2}{\underline{I}_1} = \frac{\underline{Y}_{21}}{\underline{Y}_{12}\underline{Y}_{21} - \underline{Y}_{11}\underline{Y}_{12}} = \frac{g_m - \frac{1}{3R}}{-\frac{1}{3R}(g_m - \frac{1}{3R}) - (\frac{2}{3R})^2)}$$

$$= \frac{-(3Rg_m - 1)}{g_m - \frac{1}{3R} + \frac{4}{3R}} = \frac{1 - 3R\,g_m}{\frac{1}{R} + g_m}$$

6.

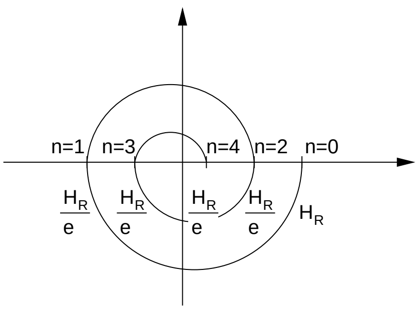
$$R \cdot g_m \gg 1$$

$$\Rightarrow g_m \gg \frac{1}{R}$$

$$\Rightarrow \frac{U_2}{I_1} \approx \frac{-3Rg_m}{g_m} = \underline{\underline{-3R}}$$

Aufgabe 6: Stabilität, Ortskurve

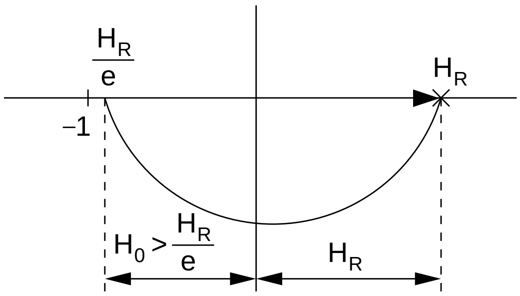
1.



2. a) Schwarzsches Spiegelungsprizip ist nicht erfüllt
   b) für $\omega \to \infty$ würde Ampl. ∞

3. $H_0 + H_R e^{\frac{\omega}{\omega_0}} e^{j\frac{\omega}{\omega_0}\pi}$

4. Für $\varphi = -\pi$ (Punkt -1) muss $Q = P$ sein (keine Nullstelle für $\underline{H}(j\omega)$)
   $\Rightarrow \frac{H_R}{e} < H_0$ (nach 1) darf -1 nicht umschlossen werden)

5. 

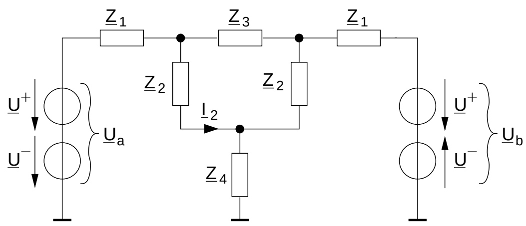
   $H(0) > \left(\frac{H_R}{e} + H_R\right) = H_R\left(1 + \frac{1}{e}\right)$

Aufgabe 7: Gleichtakt- Gegentaktzerlegung

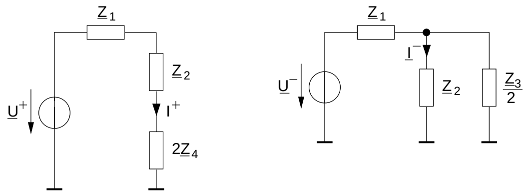
1.

$$\underline{U}^+ = \frac{\underline{U}_a + \underline{U}_b}{2} \qquad \underline{U}^- = \frac{\underline{U}_a - \underline{U}_b}{2}$$

$$\underline{U}_a = \underline{U}^+ + \underline{U}^- \qquad \underline{U}_b = \underline{U}^+ - \underline{U}^-$$



2.

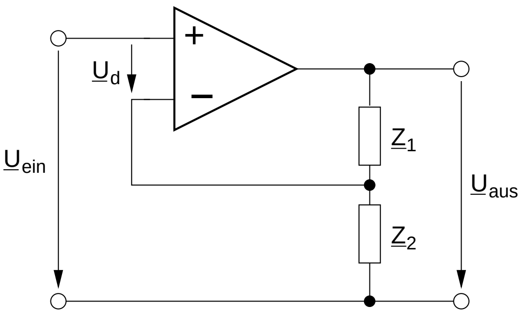


3.

$$\underline{I}^+ = \frac{\underline{U}^+}{\underline{Z}_1 + \underline{Z}_2 + 2\underline{Z}_4} = \frac{\underline{U}^+}{3\underline{Z}} \qquad \underline{I}^- = \frac{\underline{U}^-}{\frac{3}{2}\underline{Z}} \cdot \frac{1}{2} = \frac{\underline{U}^-}{3\underline{Z}}$$

$$\begin{aligned} \underline{I}_2 &= \underline{I}^+ + \underline{I}^- = \frac{\underline{U}^-}{3\underline{Z}} + \frac{\underline{U}^+}{3\underline{Z}} \\ &= \frac{\underline{U}_a - \underline{U}_b}{2}\frac{1}{3\underline{Z}} + \frac{\underline{U}_a + \underline{U}_b}{2}\frac{1}{3\underline{Z}} \\ &= \frac{2\underline{U}_a}{6\underline{Z}} \end{aligned}$$

Aufgabe 8: Operationsverstärker, Bode-Diagramm, Frequenzgangskompensation



1.

$$\underline{U}_{aus}\frac{\underline{Z}_2}{\underline{Z}_1+\underline{Z}_2}+\underline{U}_d=\underline{U}_{ein}$$

$$\underline{U}_{aus}\left(\frac{\underline{Z}_2}{\underline{Z}_1+\underline{Z}_2+\frac{1}{\underline{v}_U}}\right)=\underline{U}_{ein}$$

$$\frac{\underline{U}_{aus}}{\underline{U}_{ein}}=\frac{1}{\frac{1}{\underline{v}_U}+\frac{\underline{Z}_2}{\underline{Z}_1+\underline{Z}_2}}=\frac{\underline{v}_U}{1+\underline{v}_U\frac{\underline{Z}_2}{\underline{Z}_1+\underline{Z}_2}}$$

$$\underline{Z}_2=R_2,\quad \underline{Z}_1=j\omega L$$

2.

$$\underline{v}_U=F_a, \underline{F}_2(j\omega)=\frac{\underline{Z}_2}{\underline{Z}_1+\underline{Z}_2}$$

$$F_0=F_aF_2=\underline{v}_U\frac{R_2}{j\omega L+R_2}=\underline{v}_U\frac{1}{1+j\omega\frac{L}{R_2}}=\underline{v}_U\frac{1}{1+\frac{j\omega}{\omega L}}$$

3.

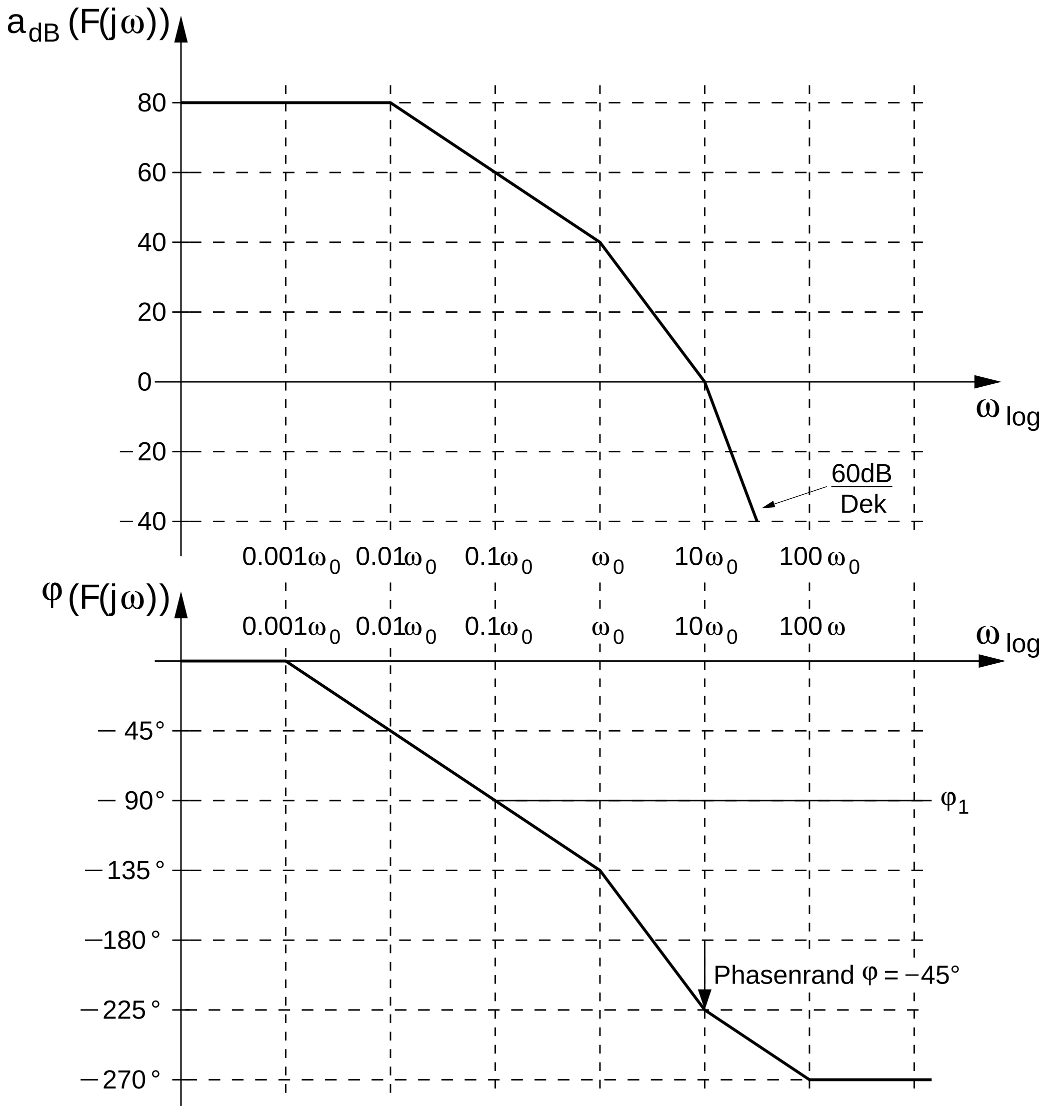
$$\underline{F}(j\omega) für\ |\underline{v}_U|\Rightarrow\infty=\frac{1}{\underline{F}_2}$$

4.

$$\underline{V}_U(j\omega)=\frac{V_0}{\left(1+\frac{j\omega}{\omega_0}\right)\left(1+\frac{j\omega}{10\omega_0}\right)}\qquad V_0=10^4\ \widehat{=}\ 80dB$$

$$\underline{F}_0(j\omega)=\frac{v_0}{\left(1+\frac{j\omega}{\omega_0}\right)\left(1+\frac{j\omega}{10\omega_0}\right)\left(1+\frac{j\omega}{0{,}01\omega_0}\right)}$$

$$\frac{L}{R}=\frac{100}{\omega_0}\rightarrow\frac{R}{L}=\frac{\omega_0}{100}$$



5. Phasenrand

6. für $\varphi = 45^\circ$ müsste $v_0 = 10^2 = 40\text{dB}$ sein