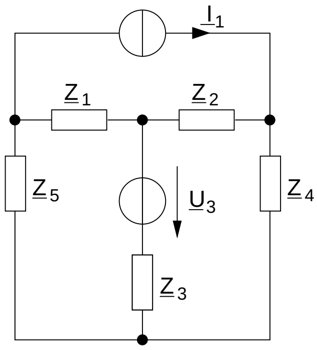
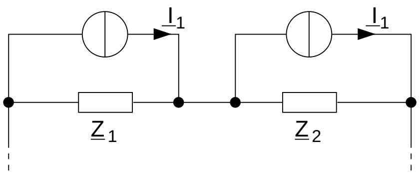
Klausur Elektronik II, SS 2006
Lösungsvorschlag

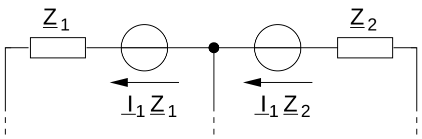
Aufgabe 1 (5 Punkte): Netzwerkberechnung



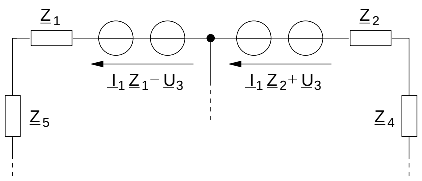
Stromquelle $\underline{I}_1$ verdoppeln



Umwandeln in Spannungsquellen

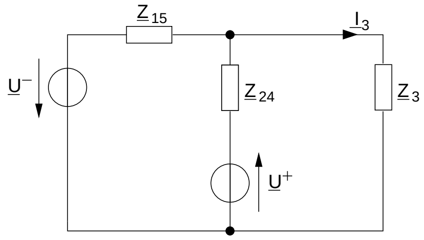


Spannungsquelle $\underline{U}_3$ über Knoten ziehen

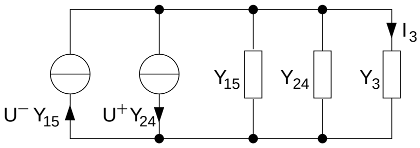


Spannungsquellen und Impedanzen in Reihe zusammenfassen

$$\underline{Z}_{15} = \underline{Z}_1 + \underline{Z}_5 \qquad \underline{U}^- = \underline{I}_1 \cdot \underline{Z}_1 - \underline{U}_3$$
$$\underline{Z}_{24} = \underline{Z}_2 + \underline{Z}_4 \qquad \underline{U}^+ = \underline{I}_1 \cdot \underline{Z}_2 + \underline{U}_3$$



Spannungsquellen in Serie zu Impedanzen in Stromquellen umwandeln

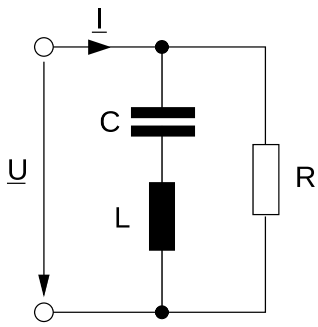


Ströme müssen sich kompensieren, damit

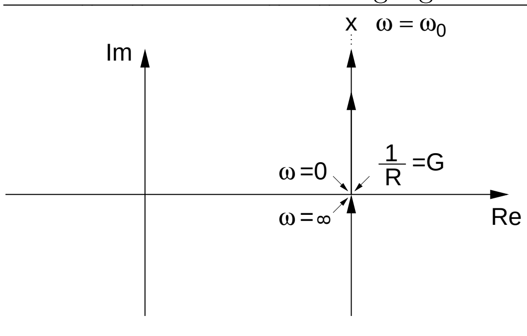
$$\Rightarrow I_3 = 0.$$

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

Aufgabe 2 (5 Punkte): Ortskurve

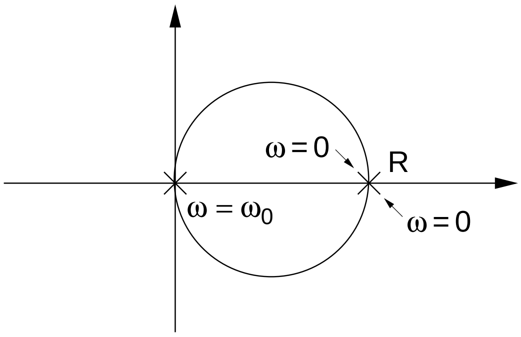


1) Skizze der Ortskurve der Eingangsadmittanz:



$$\underline{Y} = \frac{1}{\left(j\omega L + \frac{1}{j\omega C}\right)} + G$$
$$= \frac{j\omega C}{1 - \omega^2 LC} + G$$
$$\Rightarrow \quad \omega_0 = \sqrt{\frac{1}{LC}}$$

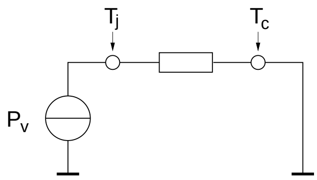
2) Skizze der Ortskurve der Eingangsimpedanz: Inversion von 1)



Aufgabe 3 (5 Punkte): Arbeitspunkt, Wärmewiderstand

1) Verlustleistung des Transistors:

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



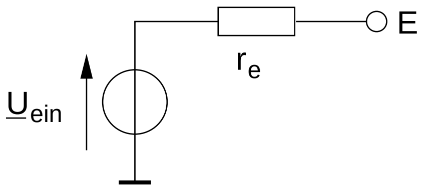
$$P_V \cdot R_{thjc} = T_j - T_c$$
$$P_V = \frac{T_j - T_c}{R_{thjc}} = \frac{(100-60)\,\mathrm{K}}{80\,\mathrm{K}} W$$
$$P_V = 0,5\,W$$

2) Kollektorwiderstand R_C:

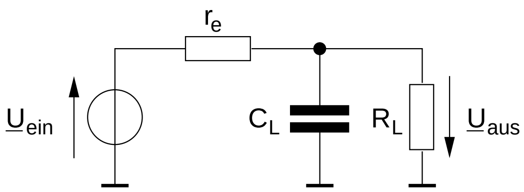
$$U_{RC} = 12\,\mathrm{V} - 1\,\mathrm{V} - 5\,\mathrm{V} = 6\,\mathrm{V}$$
$$R_C = \frac{U_{RC}}{0,1\,\mathrm{A}} = \frac{6\,\mathrm{V}}{0,1\,\mathrm{A}} = \underline{\underline{60\,\Omega}}$$

Aufgabe 4 (10 Punkte): Schaltungsberechnung, Dimensionierung, Arbeitspunkt

1) Kollektor-Grundschaltung: $r_e = \frac{1}{g_m} = \frac{U_T}{I_C}$ $\beta = \infty \Rightarrow g_{be} = 0$
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 $\frac{\underline{F}_a}{1+\underline{F}_a \cdot \underline{F}_2}$ $1 + \frac{r_e}{R_L} = \frac{R_L + r_e}{R_L}$

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

Im Ausdruck aus 1) Im(N) = 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

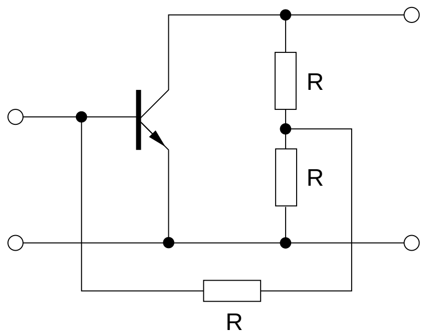
$$
\begin{aligned}
&\Rightarrow \omega_0 R_L C_L \geq 1 \quad \text{mit} \quad R_L C_L = \frac{1}{\omega_L} \\
&\Rightarrow \frac{\omega_0}{\omega_L} \geq 1 \Longleftrightarrow \omega_0 \geq \omega_L
\end{aligned}
$$

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

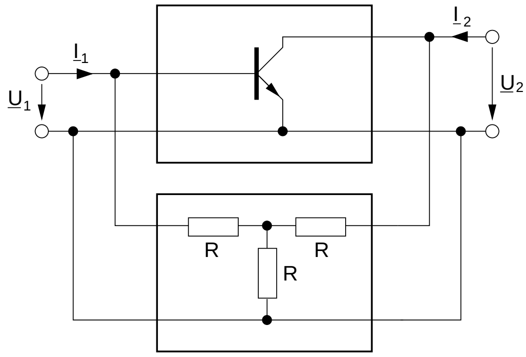
$$
\begin{aligned}
&\Rightarrow |U_{ein}| = 0 \ \text{ (streng) mit Vernachlässigung kleiner Ströme} \\
&\Rightarrow |U_{ein}| \ll U_{D,BC} \ \text{Diffussionsspannung}
\end{aligned}
$$

Aufgabe 5 (15 Punkte): Rückkopplung, Zweitor

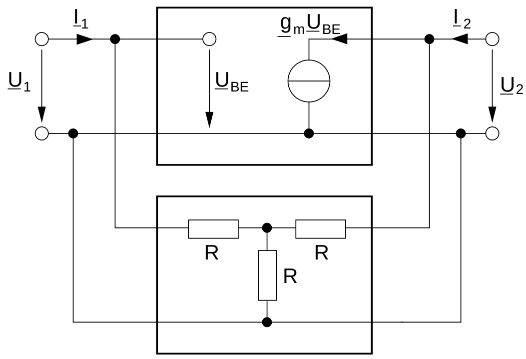
1) WS-ESB



Zerlegung in Haupt- und Rückkopplungs Zweitor:



Kleinsignal-ESB:



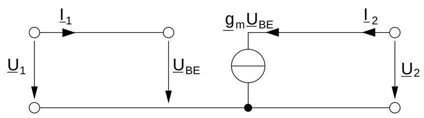
2) PPK, da Spannungen $\underline{F}_a, \underline{F}_2$ gleich sind und sich die Ströme addieren.

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) Hauptzweitor:

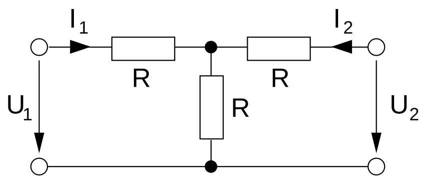
$$\underline{Y}_{11}^{(1)} = \left.\frac{\underline{I}_1}{\underline{U}_1}\right|_{\underline{U}_2=0} = 0$$
$$\underline{Y}_{12}^{(1)} = \left.\frac{\underline{I}_1}{\underline{U}_2}\right|_{\underline{U}_1=0} = 0$$
$$\underline{Y}_{21}^{(1)} = \left.\frac{\underline{I}_2}{\underline{U}_1}\right|_{\underline{U}_2=0} = g_m$$
$$\underline{Y}_{22}^{(1)} = \left.\frac{\underline{I}_2}{\underline{U}_2}\right|_{\underline{U}_1=0} = 0$$



$$\Rightarrow \left[\underline{Y}^{(1)}\right] = \begin{bmatrix} 0 & 0 \\ g_m & 0 \end{bmatrix}$$

Rückkopplungszweitor:

$$\underline{Y}_{11}^{(2)} = \left.\frac{\underline{I}_1}{\underline{U}_1}\right|_{\underline{U}_2=0} = \frac{2}{3R}$$
$$\underline{Y}_{12}^{(2)} = \left.\frac{\underline{I}_1}{\underline{U}_2}\right|_{\underline{U}_1=0} = -\frac{1}{3R}$$
$$\underline{Y}_{21}^{(2)} = \left.\frac{\underline{I}_2}{\underline{U}_1}\right|_{\underline{U}_2=0} = -\frac{1}{3R}$$
$$\underline{Y}_{22}^{(2)} = \left.\frac{\underline{I}_2}{\underline{U}_2}\right|_{\underline{U}_1=0} = \frac{2}{3R}$$



$$\Rightarrow \left[\underline{Y}^{(2)}\right] = \begin{bmatrix} \frac{2}{3R} & -\frac{1}{3R} \\ -\frac{1}{3R} & \frac{2}{3R} \end{bmatrix}$$

$$\Rightarrow \left[\underline{Y}\right] = \left[\underline{Y}^{(1)}\right] + \left[\underline{Y}^{(2)}\right] = \begin{bmatrix} \frac{2}{3R} & -\frac{1}{3R} \\ g_m - \frac{1}{3R} & \frac{2}{3R} \end{bmatrix}$$

$$[\underline{Y}_{ges}] = [\underline{Y}_1] + [\underline{Y}_2]$$
$$= \begin{bmatrix} 0 & 0 \\ g_m & 0 \end{bmatrix} + \begin{bmatrix} \frac{2}{3R} & -\frac{1}{3R} \\ -\frac{1}{3R} & \frac{2}{3R} \end{bmatrix}$$
$$[\underline{Y}_{ges}] = \begin{bmatrix} \frac{2}{3R} & -\frac{1}{3R} \\ -\frac{1}{3R} + g_m & \frac{2}{3R} \end{bmatrix}$$

5) <u>Bestimmung der Transimpedanz:</u>

$$\underline{Z}_T = \left.\frac{\underline{U}_{aus}}{\underline{I}_{ein}}\right|_{\underline{I}_{aus}=0}$$

$$\Rightarrow I_2 = \underline{I}_{aus} = 0 = \underline{U}_1\underline{Y}_{21} + \underline{U}_2\underline{Y}_{22}$$

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

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

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

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

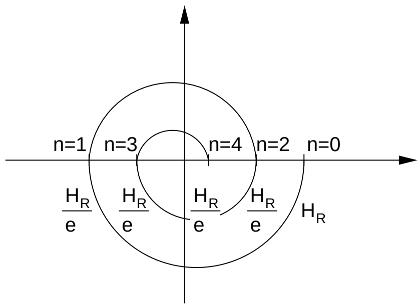
$$= \frac{-(3Rg_m - 1)}{g_m - \frac{1}{3R} + \frac{4}{3R}} = \frac{1 - 3R\,g_m}{\frac{1}{R} + g_m}$$

6) Vereinfachung des Ausdrucks für $\underline{Z}_T$:

$$R \cdot g_m \gg 1$$
$$\Rightarrow g_m \gg \frac{1}{R}$$
$$\Rightarrow \frac{U_2}{I_1} \approx \frac{-3R \cdot g_m}{g_m} = \underline{\underline{-3R}}$$

Aufgabe 6 (12 Punkte): Stabilität, Ortskurve

1) Skizze der Ortskurve von $\underline{H}(j\omega)$:



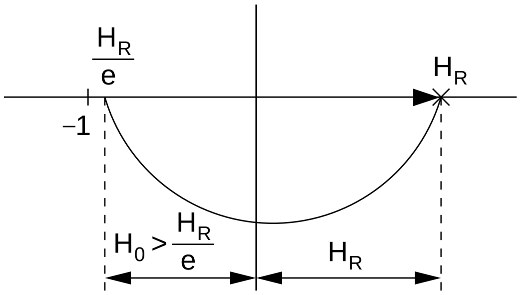
2) a) Schwarz'sches Spiegelungsprizip ist nicht erfüllt
b) für $\omega \to \infty$ würde Ampl. ∞

3) $H_0 + H_R e^{\frac{\omega}{\omega_0}} e^{j\frac{\omega}{\omega_0}\pi}$, $\omega < 0$.

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)



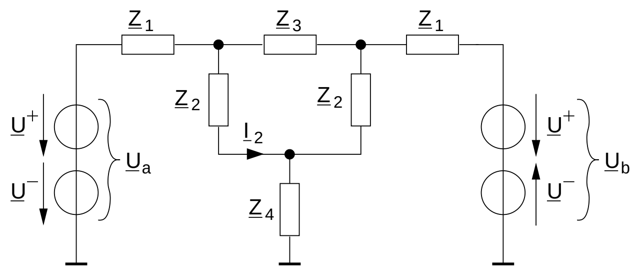
$H(0) > \left(\frac{H_R}{e} + H_R\right) = H_R\left(1 + \frac{1}{e}\right)$

Aufgabe 7 (8 Punkte): Gleichtakt-, Gegentaktzerlegung

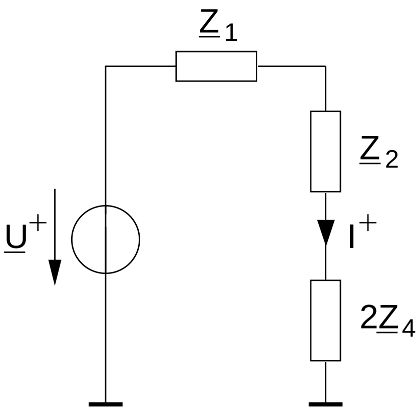
1) Ansteuerung durch Überlagerung von Gleich- und Gegentaktquellen:

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

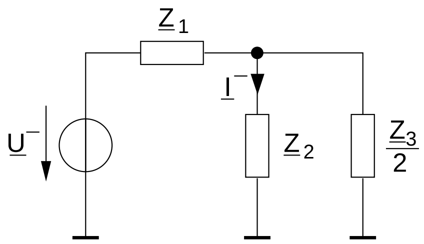
$$\underline{U}_a = \underline{U}^+ + \underline{U}^- \qquad \underline{U}_b = \underline{U}^+ - \underline{U}^-$$



2) Gleichtakt - Ersatzschaltbild:



Gleichtakt - Ersatzschaltbild:



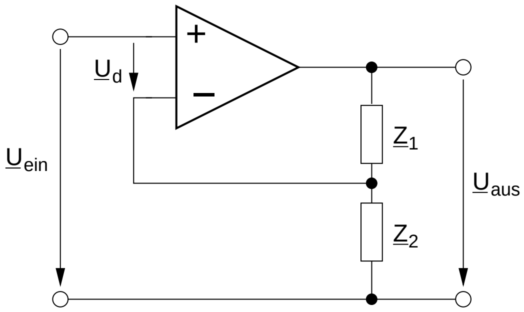
3) Strom $\underline{I}_2$ durch Überlagerung der Ergebnisse von Gleich- und Gegentakt Ersatzschaltung:

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

$$\underline{I}^- = \frac{\underline{U}^-}{\frac{3}{2}\underline{Z}} \cdot \frac{1}{2} = \frac{\underline{U}^-}{3\underline{Z}}$$

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

Aufgabe 8 (15 Punkte): Operationsverstärker, Bode-Diagramm



1) Bestimmung der allgemeinen Verstärkung:

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

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

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

$$\left(\underline{Z}_2=R_2,\quad \underline{Z}_1=j\omega L\right)$$

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)

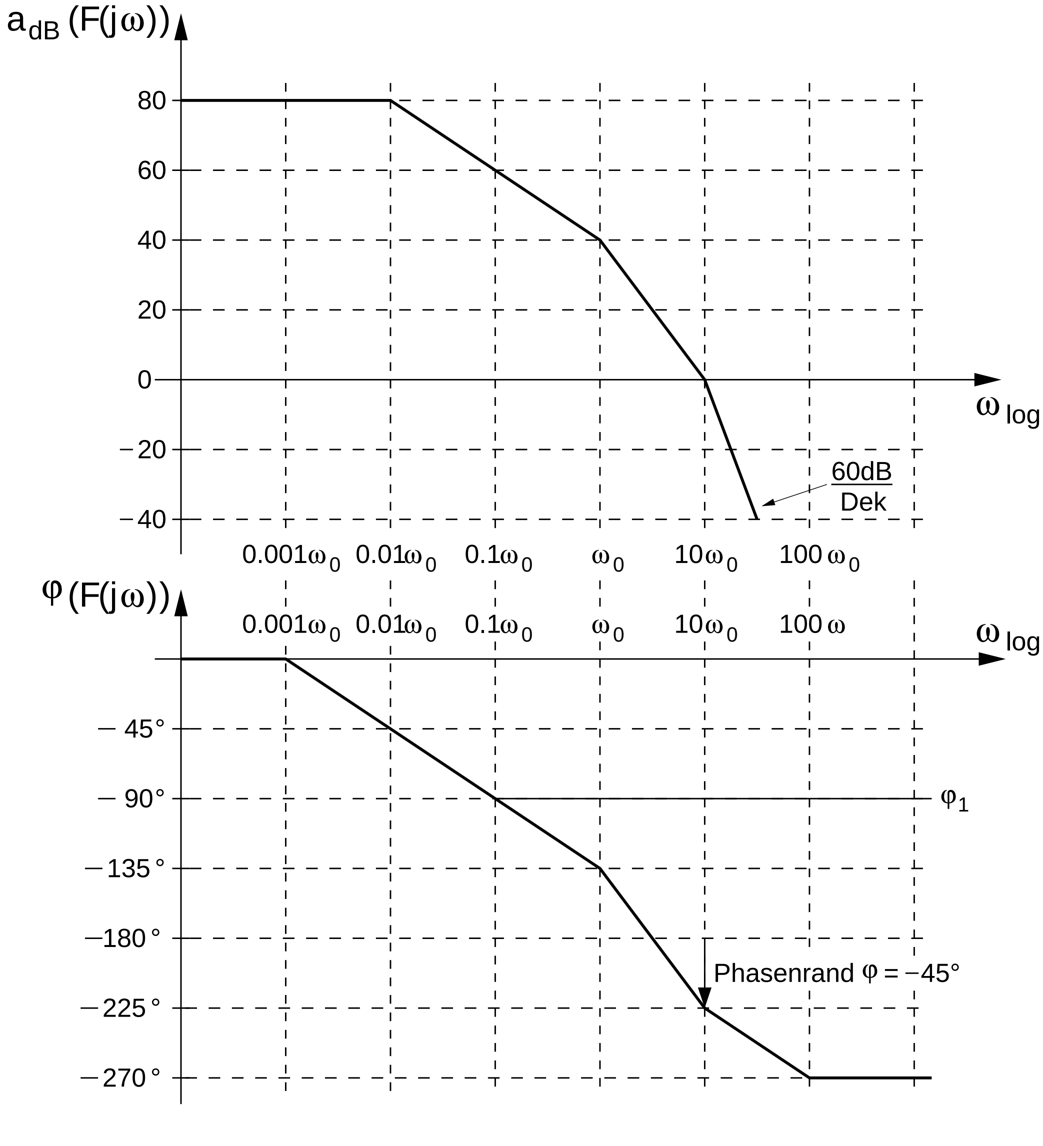
$$\underline{F}(j\omega)f\ddot{u}r\,|\underline{v}_u|\Rightarrow\infty=\frac{1}{\underline{F}_2}$$

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: siehe Bodediagramm.

6) Für $\varphi = 45°$ muss $v_0 = 10^2 = 40\text{dB}$ sein.