Aufgabe 1

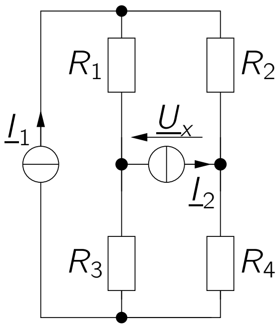
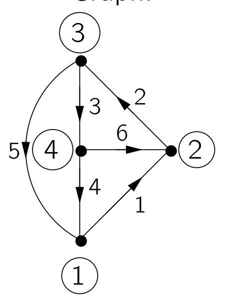


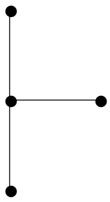
Abb. 1: Gegebenes Netzwerk.

a)

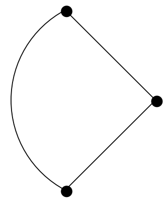
Graph:



Baum:



Co-Baum:



b)

$$A = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \end{array} \begin{array}{c} \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{pmatrix} 1 & 0 & 0 & -1 & -1 & 0 \\ -1 & 1 & 0 & 0 & 0 & -1 \\ 0 & -1 & 1 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 1 \end{pmatrix} \end{array}$$

Bezugsknoten 1 $\Rightarrow$ streiche 1. Zeile

$$A = \begin{pmatrix} -1 & 1 & 0 & 0 & 0 & -1 \\ 0 & -1 & 1 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 1 \end{pmatrix}$$

c)

$$Y = \begin{pmatrix} \frac{1}{R_4} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{R_2} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{R_1} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{R_3} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$\begin{aligned} Y_n &= AYA^T \\ &= \begin{pmatrix} -1 & 1 & 0 & 0 & 0 & -1 \\ 0 & -1 & 1 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} \frac{1}{R_4} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{R_2} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{R_1} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{R_3} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} -1 & 0 & 0 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \\ -1 & 0 & 1 \end{pmatrix} \\ &= \begin{pmatrix} -1 & 1 & 0 & 0 & 0 & -1 \\ 0 & -1 & 1 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} -\frac{1}{R_4} & 0 & 0 \\ \frac{1}{R_2} & -\frac{1}{R_2} & 0 \\ 0 & \frac{1}{R_1} & -\frac{1}{R_1} \\ 0 & 0 & \frac{1}{R_3} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \\ &= \begin{pmatrix} \frac{1}{R_4} + \frac{1}{R_2} & -\frac{1}{R_2} & 0 \\ -\frac{1}{R_2} & \frac{1}{R_2} + \frac{1}{R_1} & -\frac{1}{R_1} \\ 0 & -\frac{1}{R_1} & \frac{1}{R_1} + \frac{1}{R_3} \end{pmatrix} \end{aligned}$$

$$
\begin{aligned}
I_{qn} &= A(I_g - YU_g) \\
&= \begin{pmatrix} -1 & 1 & 0 & 0 & 0 & -1 \\ 0 & -1 & 1 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -I_1 \\ I_2 \end{pmatrix} \\
&= \begin{pmatrix} -I_2 \\ -I_1 \\ I_2 \end{pmatrix}
\end{aligned}
$$

d)

$$
\begin{pmatrix} \frac{1}{R_4} + \frac{1}{R_2} & -\frac{1}{R_2} & 0 \\ -\frac{1}{R_2} & \frac{1}{R_2} + \frac{1}{R_1} & -\frac{1}{R_1} \\ 0 & -\frac{1}{R_1} & \frac{1}{R_1} + \frac{1}{R_3} \end{pmatrix} \begin{pmatrix} U_{n2} \\ U_{n3} \\ U_{n4} \end{pmatrix} = \begin{pmatrix} -I_2 \\ -I_1 \\ I_2 \end{pmatrix}
$$

Einsetzen:
$R_1 = R_2 = R_x$
$R_3 = R_4 = R_y$

$$
\begin{pmatrix} \frac{1}{R_x} + \frac{1}{R_y} & -\frac{1}{R_x} & 0 \\ -\frac{1}{R_x} & \frac{2}{R_x} & -\frac{1}{R_x} \\ 0 & -\frac{1}{R_x} & \frac{1}{R_x} + \frac{1}{R_y} \end{pmatrix} \begin{pmatrix} U_{n2} \\ U_{n3} \\ U_{n4} \end{pmatrix} = \begin{pmatrix} -I_2 \\ -I_1 \\ I_2 \end{pmatrix}
$$

$$
\begin{aligned}
&(I) && \left(\frac{1}{R_x} + \frac{1}{R_y}\right) U_{n2} \quad -\frac{1}{R_x} U_{n3} && = -I_2 \\
&(III) && \qquad -\frac{1}{R_x} U_{n3} + \left(\frac{1}{R_x} + \frac{1}{R_y}\right) U_{n4} && = I_2
\end{aligned}
$$

$(I) - (III)$:

$$
\left(\frac{1}{R_x} + \frac{1}{R_y}\right) U_{n2} - \left(\frac{1}{R_x} + \frac{1}{R_y}\right) U_{n4} = -2\, I_2
$$

$$
U_{24} = U_{n2} - U_{n4} = \frac{-2\, I_2}{\left(\frac{1}{R_x} + \frac{1}{R_y}\right)}
$$

Aufgabe 2

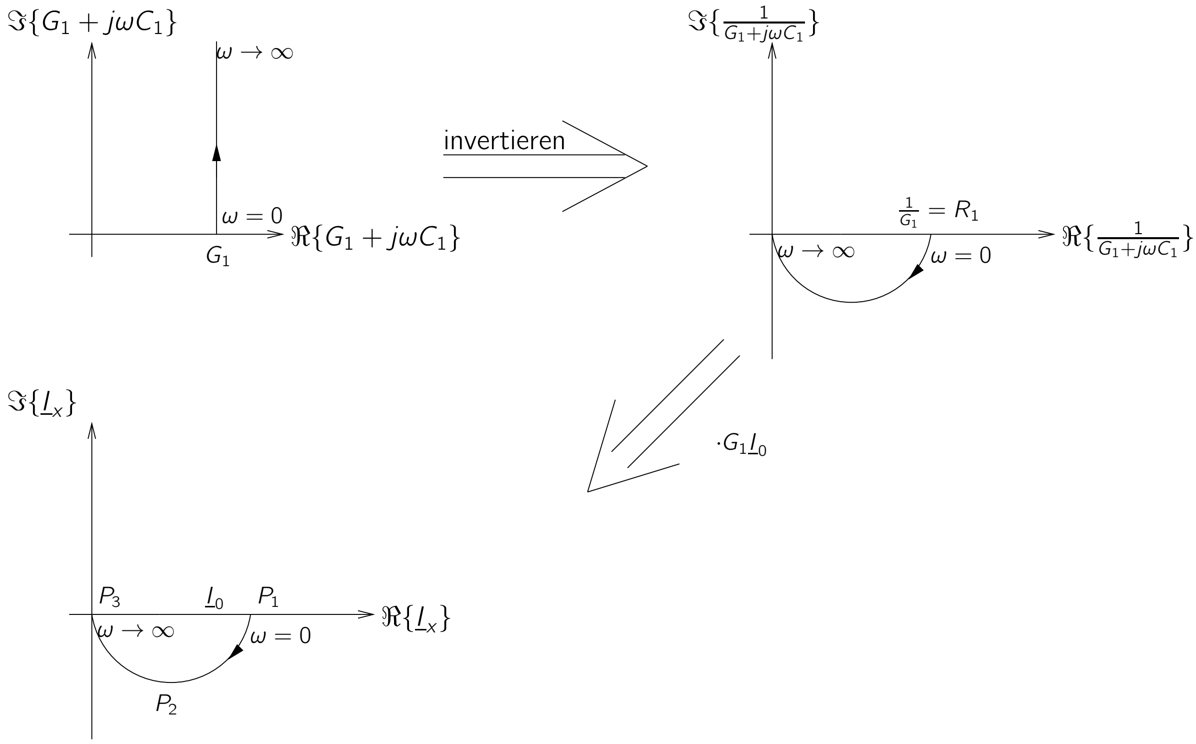
a)

$$\frac{I_x}{I_0} = \frac{\frac{1}{R_1}}{\frac{1}{R_1}+j\omega C_1} = \frac{G_1}{G_1+j\omega C_1} \qquad G_1 = \frac{1}{R_1}$$

$$\frac{I_y}{I_0} = \frac{j\omega C_2}{\frac{1}{R_2}+j\omega C_2} = \frac{j\omega C_2}{G_2+j\omega C_2} \qquad G_2 = \frac{1}{R_2}$$

b)

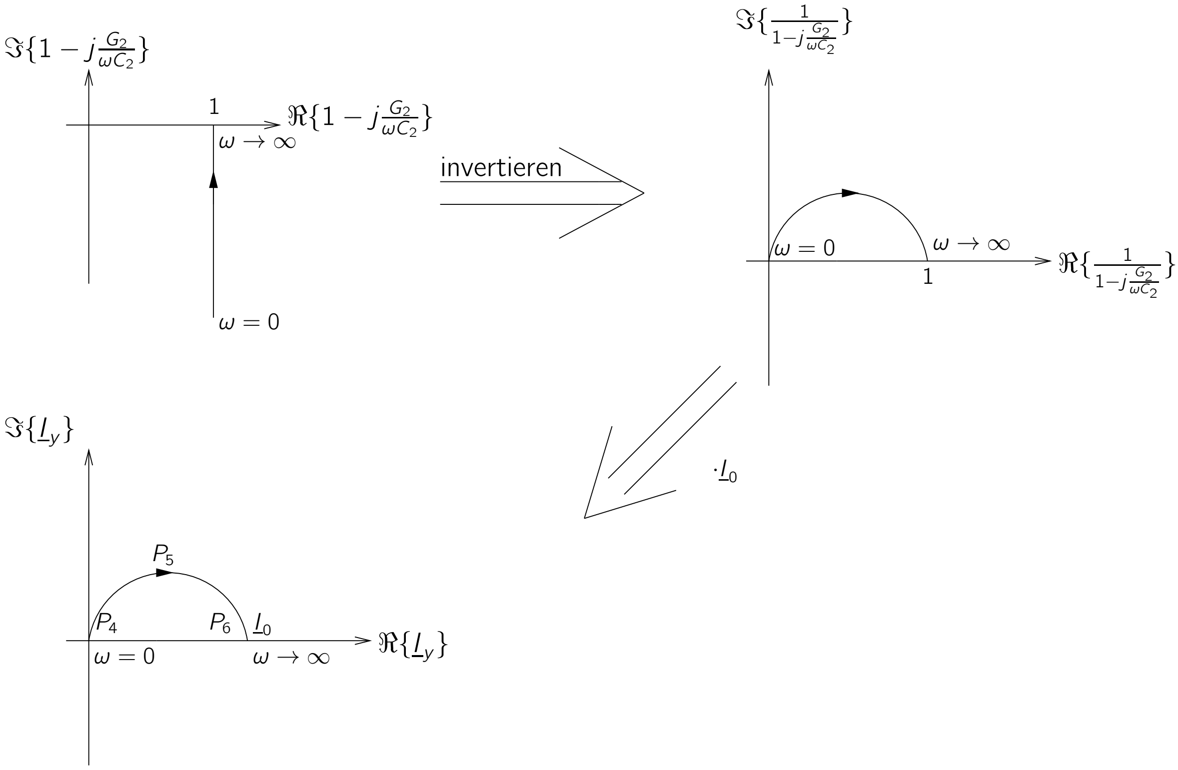
$\underline{I}_x$:



$P_1 : \underline{I}_x\,(\omega = 0) = \underline{I}_0$
$P_2 : \underline{I}_x\left(\omega = \frac{G_1}{C_1}\right) = \frac{\underline{I}_0}{2}\,(1-j)$
$P_3 : \underline{I}_x\,(\omega \to \infty) = 0$

$\underline{I}_y = \frac{1}{1-j\frac{G_2}{\omega C_2}} \underline{I}_0$

$\underline{I}_y$:

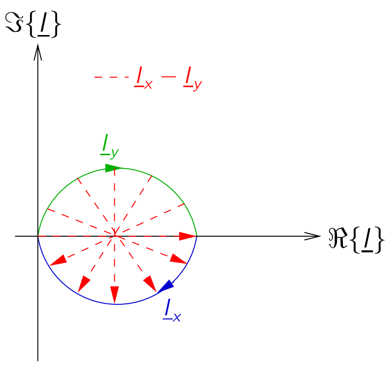


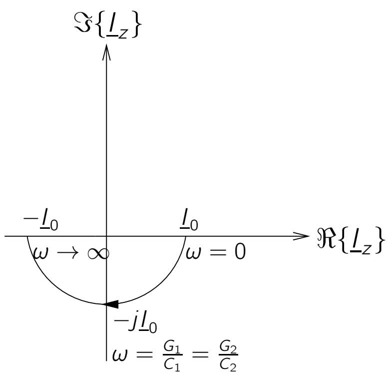
$P_4 : \underline{I}_y\,(\omega = 0) = 0$
$P_5 : \underline{I}_y\left(\omega = \frac{G_2}{C_2}\right) = \frac{\underline{I}_0}{2}\,(1 + j)$
$P_6 : \underline{I}_y\,(\omega \to \infty) = \underline{I}_0$

c)

i)

$R_1C_1 = R_2C_2 \Rightarrow \frac{G_1}{C_1} = \frac{G_2}{C_2}$
$\underline{I}_z = \underline{I}_x - \underline{I}_y$

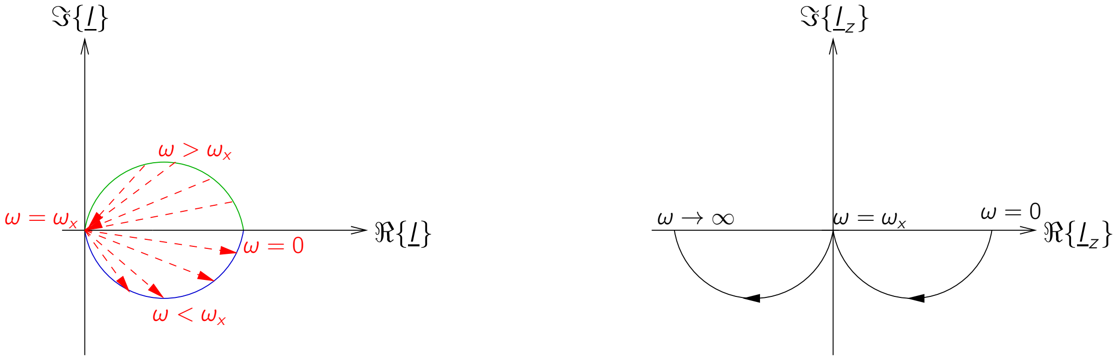




$\underline{I}_z\,(\omega = 0) = \underline{I}_0$
$\underline{I}_z\left(\omega = \frac{G_1}{C_1}\right) = -j\underline{I}_0$
$\underline{I}_z\,(\omega \rightarrow \infty) = -\underline{I}_0$

ii)

$\underline{I}_x(\omega_x) \approx 0$
$\underline{I}_y(\omega_x) \approx 0$
$\underline{I}_z(\omega_x) \approx 0$
Bei der Frequenz ω_x hat $\underline{I}_y$ den Ursprung noch nicht verlassen, $\underline{I}_x$ ist aber bereits dort angelangt.



Aufgabe 3

a)

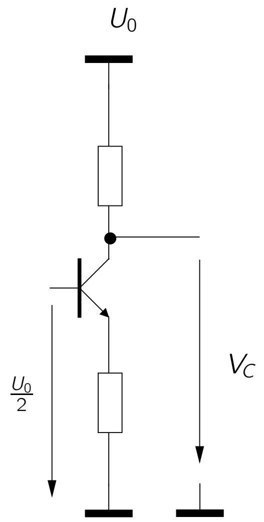
$I_E \cdot R_E + U_{BE,0} = \frac{U_0}{2}$

$I_E = \frac{\frac{U_0}{2} - U_{BE,0}}{R_E} \approx I_C$

$g_m = \frac{I_C}{U_T} = \frac{\frac{U_0}{2} - U_{BE,0}}{R_E \cdot U_T}$

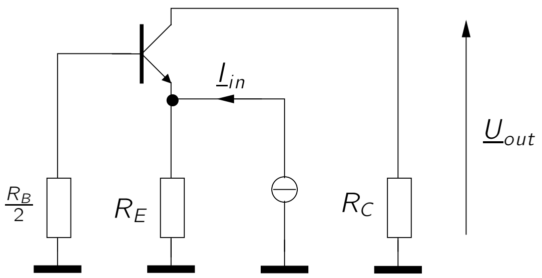
b)

$$V_{C,min} = \frac{U_0}{2}$$
$$V_{C,max} = U_0$$
$$I_C \cdot R_C \overset{!}{=} U_0 - \frac{V_{C,min} + V_{C,max}}{2}$$
$$R_C = \frac{1}{I_C} \cdot \left(U_0 - \frac{\frac{U_0}{2} + U_0}{2} \right)$$
$$= \frac{1}{I_C} \cdot \frac{U_0}{4}$$

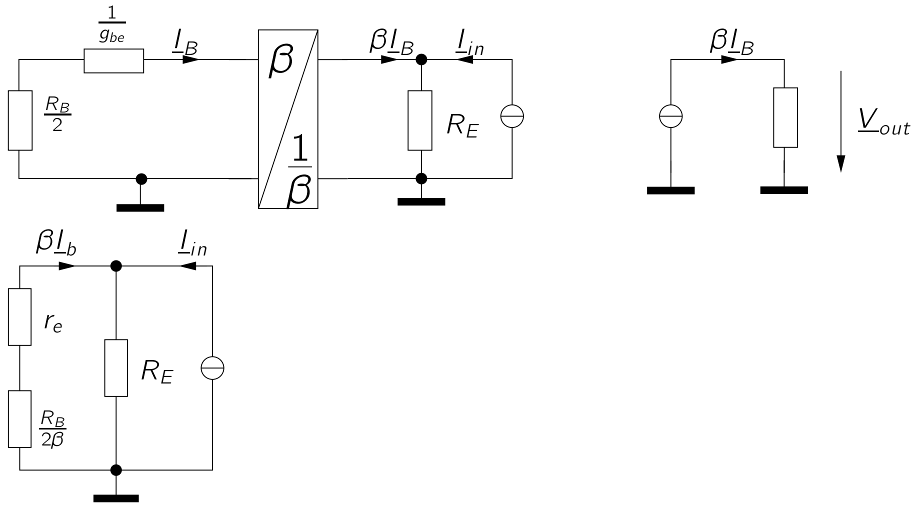


c)

Basis-Grundschaltung (BGS)



d)

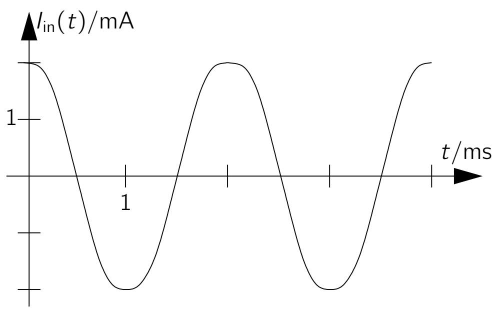


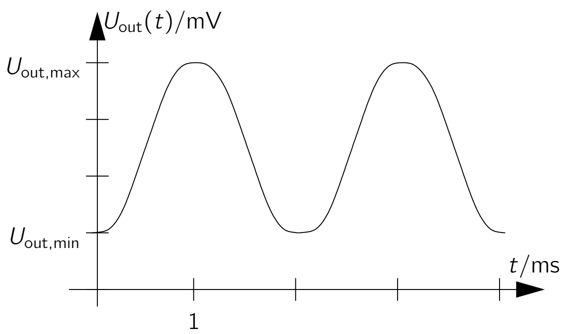
$$\underline{V}_{out} = +R_C \cdot \beta \underline{I}_b$$
$$= -R_C \cdot \underline{I}_{in} \cdot \frac{R_E}{r_e + \frac{R_B}{2\beta} + R_E}$$

$$\underline{Z}_{trans} = -R_C \cdot \frac{R_E}{r_e + \frac{R_B}{2\beta} + R_E}$$

e)

$\underline{Z}_{trans} = -R_C = -100\,\Omega$
$U_0 = 4\,\text{V}$
$U_{out}(t) = \left(U_0 - \frac{V_{C,min}+V_{C,max}}{2}\right) - 100\,\Omega \cdot I_{in}(t)$





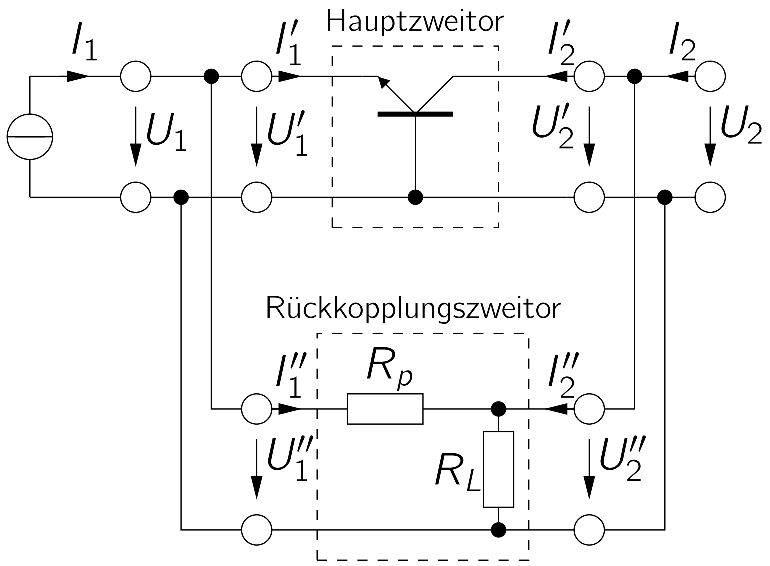
$U_{out,max} = 1{,}2\,\text{V}$
$U_{out,min} = 0{,}8\,\text{V}$

f)

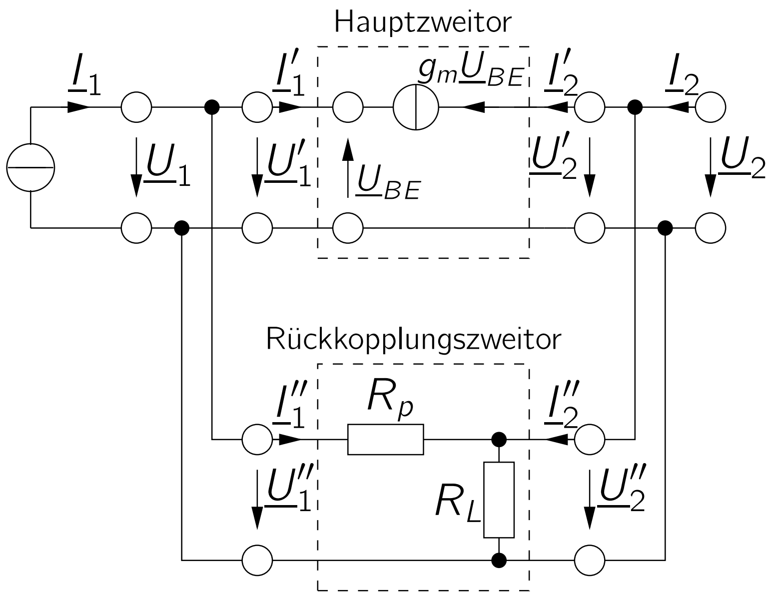
$3\,\mathrm{V} - I_{max} \cdot 100\,\Omega = \frac{U_0}{2} = 2\,\mathrm{V}$
$I_{max} < 10\,\mathrm{mA}$

Aufgabe 4

a)



b)



c)

i)

Parallel-Parallel-Kopplung (PPK)

ii)

Y-(Admittanz-)Matrix

$$\begin{aligned}
\underline{U}_1 &= \underline{U}_1' = \underline{U}_1'' \\
\underline{I}_1 &= \underline{I}_1' + \underline{I}_1'' \\
&= \underline{Y}_{11}'\underline{U}_1 + \underline{Y}_{11}''\underline{U}_1 + \underline{Y}_{12}'\underline{U}_2 + \underline{Y}_{12}''\underline{U}_2 \\
&= \left(\underline{Y}_{11}' + \underline{Y}_{11}''\right)\underline{U}_1 + \left(\underline{Y}_{12}' + \underline{Y}_{12}''\right)\underline{U}_2
\end{aligned}$$

$$\begin{aligned}
\underline{U}_2 &= \underline{U}_2' = \underline{U}_2'' \\
\underline{I}_2 &= \underline{I}_2' + \underline{I}_2'' \\
&= \underline{Y}_{21}'\underline{U}_1 + \underline{Y}_{21}''\underline{U}_1 + \underline{Y}_{22}'\underline{U}_2 + \underline{Y}_{22}''\underline{U}_2 \\
&= \left(\underline{Y}_{21}' + \underline{Y}_{21}''\right)\underline{U}_1 + \left(\underline{Y}_{22}' + \underline{Y}_{22}''\right)\underline{U}_2
\end{aligned}$$

d)

$$\begin{aligned}
\underline{Y}_{11}' &= \left.\frac{\underline{I}_1'}{\underline{U}_1'}\right|_{\underline{U}_2'=0} = g_m \\
\underline{Y}_{21}' &= \left.\frac{\underline{I}_2'}{\underline{U}_1'}\right|_{\underline{U}_2'=0} = -g_m \\
\underline{Y}_{12}' &= \left.\frac{\underline{I}_1'}{\underline{U}_2'}\right|_{\underline{U}_1'=0} = 0 \\
\underline{Y}_{22}' &= \left.\frac{\underline{I}_2'}{\underline{U}_2'}\right|_{\underline{U}_1'=0} = 0
\end{aligned}$$

$$\begin{aligned}
\underline{Y}_{11}'' &= \left.\frac{\underline{I}_1''}{\underline{U}_1''}\right|_{\underline{U}_2''=0} = \frac{1}{R_p} \\
\underline{Y}_{21}'' &= \left.\frac{\underline{I}_2''}{\underline{U}_1''}\right|_{\underline{U}_2''=0} = -\frac{1}{R_p} \\
\underline{Y}_{12}'' &= \left.\frac{\underline{I}_1''}{\underline{U}_2''}\right|_{\underline{U}_1''=0} = -\frac{1}{R_p} \\
\underline{Y}_{22}'' &= \left.\frac{\underline{I}_2''}{\underline{U}_2''}\right|_{\underline{U}_1''=0} = \frac{1}{R_p} + \frac{1}{R_L}
\end{aligned}$$

$$\begin{aligned}
\Rightarrow \underline{Y} &= \underline{Y}' + \underline{Y}'' \\
&= \begin{pmatrix} g_m + \frac{1}{R_p} & -\frac{1}{R_p} \\ -g_m - \frac{1}{R_p} & \frac{1}{R_p} + \frac{1}{R_L} \end{pmatrix}
\end{aligned}$$

e)

$\underline{I}_2 = 0 = \underline{Y}_{21}\underline{U}_1 + \underline{Y}_{22}\underline{U}_2 \Leftrightarrow \underline{U}_1 = -\frac{\underline{Y}_{22}}{\underline{Y}_{21}}\underline{U}_2$

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

$\Leftrightarrow \frac{\underline{U}_2}{\underline{I}_1} = \frac{1}{\underline{Y}_{12} - \frac{\underline{Y}_{11}\underline{Y}_{22}}{\underline{Y}_{21}}} = \frac{\underline{Y}_{21}}{\underline{Y}_{12}\underline{Y}_{21} - \underline{Y}_{11}\underline{Y}_{22}} = \underline{Z}_T$

Einsetzen:

$\underline{Z}_T = \frac{-g_m - \frac{1}{R_p}}{-\frac{1}{R_p}\left(-g_m - \frac{1}{R_p}\right) - \left(g_m + \frac{1}{R_p}\right)\left(\frac{1}{R_p} + \frac{1}{R_L}\right)} = \frac{1}{-\frac{1}{R_p} + \frac{1}{R_p} + \frac{1}{R_L}} = R_L$

$\Rightarrow \underline{Z}_T$ ist nur abhängig von R_L.

Aufgabe 5

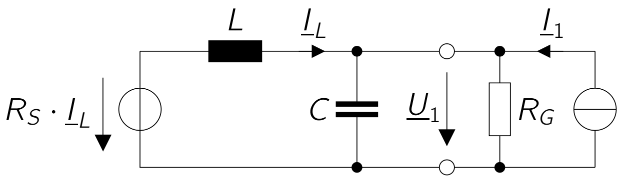


Abb. 5: Zu untersuchende Schaltung.

a)

$\underline{U}_1 = \frac{\underline{I}_L + \underline{I}_1}{\frac{1}{R_G} + sC}$

$\underline{I}_L = \frac{R_S \cdot \underline{I}_L - \underline{U}_1}{sL}$

$\underline{I}_L \left(1 - \frac{R_S}{sL}\right) = -\frac{\underline{U}_1}{sL}$

$\underline{U}_1 = -sL\underline{I}_L \left(1 - \frac{R_S}{sL}\right) = R_S \underline{I}_L - sL\underline{I}_L$

$R_S \underline{I}_L - sL\underline{I}_L = \frac{\underline{I}_L}{\frac{1}{R_G} + sC} + \frac{\underline{I}_1}{\frac{1}{R_G} + sC}$

$\underline{I}_L \left(\frac{R_S}{R_G} + sCR_S - \frac{sL}{R_G} - s^2LC - 1\right) = \underline{I}_1$

$\frac{\underline{I}_L}{\underline{I}_1} = \frac{1}{\frac{R_S}{R_G} + sCR_S - \frac{sL}{R_G} - s^2LC - 1}$

b)

Verantwortlich für Stabilität: Pole der Wirkungsfunktion
Alle Wirkungsfunktionen mit gleicher Ursache haben die gleichen Pole (Determinante der Knotenadmittanzmatrix). ⇒ Untersuchung der Stabilität mit jeder Wirkungsfunktion des Netzwerkes möglich.

c)

$$\frac{R_S}{R_G} - 1 + s\left(R_S C - \frac{L}{R_G}\right) - s^2LC = 0$$

$$\underbrace{\frac{-\frac{R_S}{R_G} + 1}{LC}}_{q} + s\underbrace{\left(-\frac{R_S}{L} + \frac{1}{R_G C}\right)}_{p} + s^2 = 0$$

$$\Rightarrow s_{12} = -\frac{p}{2} \pm \sqrt{\left(\frac{p}{2}\right)^2 - q}$$

mit

$$p = \frac{1}{R_G C} - \frac{R_S}{L} = \frac{L - R_G R_S C}{L R_G C}$$
$$q = \frac{1 - \frac{R_S}{R_G}}{LC} = \frac{R_G - R_S}{L R_G C}$$

d)

aufklingend, sinusförmig $\Rightarrow s = \sigma + j\omega$, mit $\sigma > 0$
$\Rightarrow -\frac{p}{2} > 0$
$\left(\frac{p}{2}\right)^2 - q < 0$

$$-(L - R_G R_S C) > 0 \Leftrightarrow R_S > \frac{L}{R_G C}$$

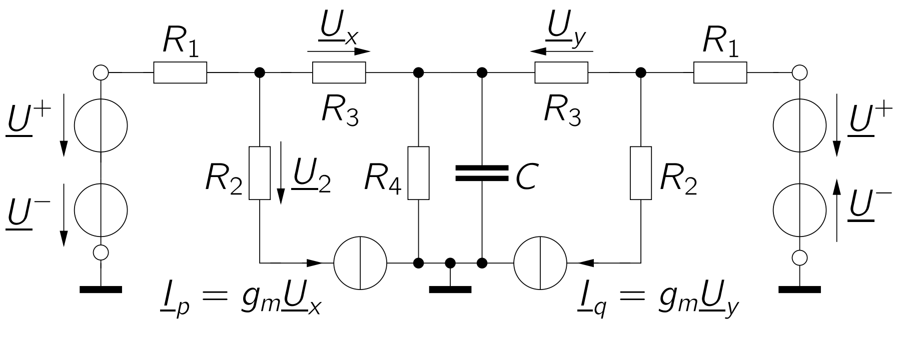
$$\frac{L^2 - 2R_G R_S CL + R_G^2 R_S^2 C^2}{4L^2 R_G^2 C^2} - \frac{R_G - R_S}{L R_G C} < 0$$
$$L^2 - 2R_G R_S CL + R_G^2 R_S^2 C^2 - 4L R_G^2 C + 4L R_G R_S C < 0$$
$$L^2 + 2R_G R_S CL + R_G^2 R_S^2 C^2 - 4L R_G^2 C < 0$$
$$(L + R_G R_S C)^2 - 4L R_G^2 C < 0$$
$$L + R_G R_S C < \pm 2R_G \sqrt{LC}$$
$$R_S < \frac{\pm 2R_G \sqrt{LC} - L}{R_G C}$$
$$R_S > 0 \Rightarrow R_S < \frac{2R_G \sqrt{LC} - L}{R_G C}$$
$$R_S > \frac{L}{R_G C}$$
$$\frac{L}{R_G C} < R_S < \frac{2R_G \sqrt{LC} - L}{R_G C}$$

e)

$$\frac{L}{R_G C} < \frac{2R_G \sqrt{LC} - L}{R_G C}$$
$$\not{2}L < \not{2}R_G \sqrt{LC}$$
$$R_G > \sqrt{\frac{L}{C}}$$

Aufgabe 6

a)



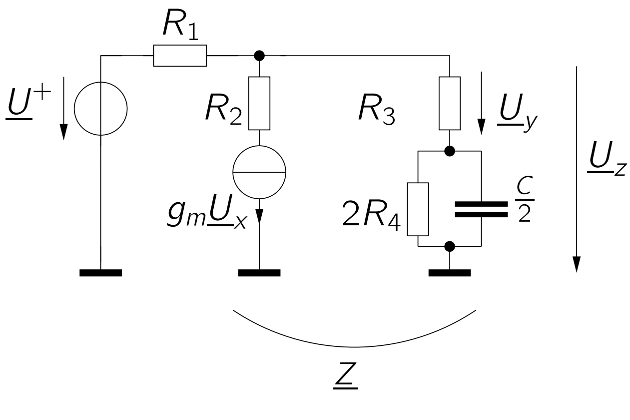
Phasoren:

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

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

b)

Gleichtakt:



$\underline{Z} = R_3 + \left(2R_4 \,||\, \frac{C}{2}\right)$

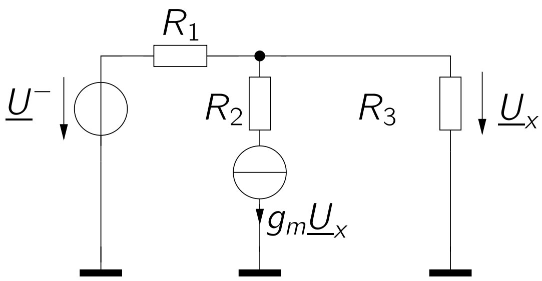
$\underline{U}_z = \frac{\underline{Z}}{R_3} \underline{U}_x$

$\frac{\underline{U}^+ - \underline{U}_z}{R_1} - g_m \underline{U}_x - \frac{\underline{U}_x}{R_3} = 0$
$\Leftrightarrow \frac{\underline{U}^+}{R_1} - \left(\frac{\underline{Z}}{R_3 R_1} + g_m + \frac{1}{R_3}\right) \underline{U}_x = 0$

$$\underline{U}_x = \underbrace{\frac{1}{R_1\left(\frac{\underline{Z}}{R_3 R_1} + g_m + \frac{1}{R_3}\right)}}_{\underline{X}} \underline{U}^+$$

$$\underline{U}_2^+ = R_2\, g_m\, \underline{X}\, \underline{U}^+$$

Gegentakt:



$$\frac{\underline{U}^- - \underline{U}_x}{R_1} - g_m \underline{U}_x - \frac{\underline{U}_x}{R_3} = 0$$
$$\frac{\underline{U}^-}{R_1} - \left(\frac{1}{R_1} + g_m + \frac{1}{R_3}\right)\underline{U}_x = 0$$
$$\underline{U}_x = \underbrace{\frac{1}{R_1\left(\frac{1}{R_1} + g_m + \frac{1}{R_3}\right)}}_{\underline{Y}} \underline{U}^-$$
$$\underline{U}_2^- = \frac{g_m R_2}{R_1\left(\frac{1}{R_1} + g_m + \frac{1}{R_3}\right)} \underline{U}^- = R_2\, g_m\, \underline{Y}\, \underline{U}^-$$

c)

$$\begin{aligned} \underline{U}_2 &= \underline{U}_2^+ + \underline{U}_2^- \\ &= R_2\, g_m\, \underline{X}\, \underline{U}^+ \; + \; R_2\, g_m\, \underline{Y}\, \underline{U}^- \\ &= R_2\, g_m\, \underline{X}\, \frac{\underline{U}_a + \underline{U}_b}{2} \; + \; R_2\, g_m\, \underline{Y}\, \frac{\underline{U}_a - \underline{U}_b}{2} \\ &= (\underline{X} + \underline{Y})\, \frac{R_2 g_m}{2} \underline{U}_a + (\underline{X} - \underline{Y})\, \frac{R_2 g_m}{2} \underline{U}_b \end{aligned}$$

d)

Vorzeichenänderung im Gegentakt bei g_m.

Aufgabe 7

a)

$$\frac{\underline{U}_1 + \underline{U}_d}{R_1} = \underline{I}_1$$

$\frac{\underline{U}_2+\underline{U}_d}{R_2} = \underline{I}_2$

$\underline{U}_d = \frac{\underline{U}_2}{\underline{V}_u}$

$\underline{I}_1 + \underline{I}_2 = -j\,\omega\,C\,\underline{U}_d$

$\Rightarrow \underline{U}_d \left(\frac{1}{R_1} + \frac{1}{R_2} + j\,\omega\,C\right) + \frac{\underline{U}_1}{R_1} + \frac{\underline{U}_2}{R_2} = 0$

$\Leftrightarrow \underline{U}_2 \left[\frac{1}{\underline{V}_u}\left(\frac{1}{R_1} + \frac{1}{R_2} + j\,\omega\,C\right) + \frac{1}{R_2}\right] = -\frac{1}{R_1}\underline{U}_1$

$\Leftrightarrow \frac{\underline{U}_2}{\underline{U}_1} = -\frac{1}{\frac{R_1}{R_2} + \frac{1}{\underline{V}_u}\left(1+\frac{R_1}{R_2}+j\,\omega\,C\,R_1\right)} = \underline{F}(j\omega)$

b)

$|\underline{V}_u| \rightarrow \infty$

$\Rightarrow \underline{F}(j\omega) = -\frac{R_2}{R_1} = \frac{1}{\underline{F}_2}$

c)

$$\underline{F}(j\omega) = \frac{-\frac{\underline{V}_u}{1+\frac{R_1}{R_2}+j\,\omega\,R_1\,C}}{1+\underbrace{\left(-\frac{R_1}{R_2}\right)\left(-\frac{\underline{V}_u}{1\,+\,\frac{R_1}{R_2}\,+j\,\omega\,R_1\,C}\right)}_{\underline{F}_0\text{ (Schleifenverstärkung)}}}$$

$\underline{F}_2 = -\frac{R_1}{R_2}$

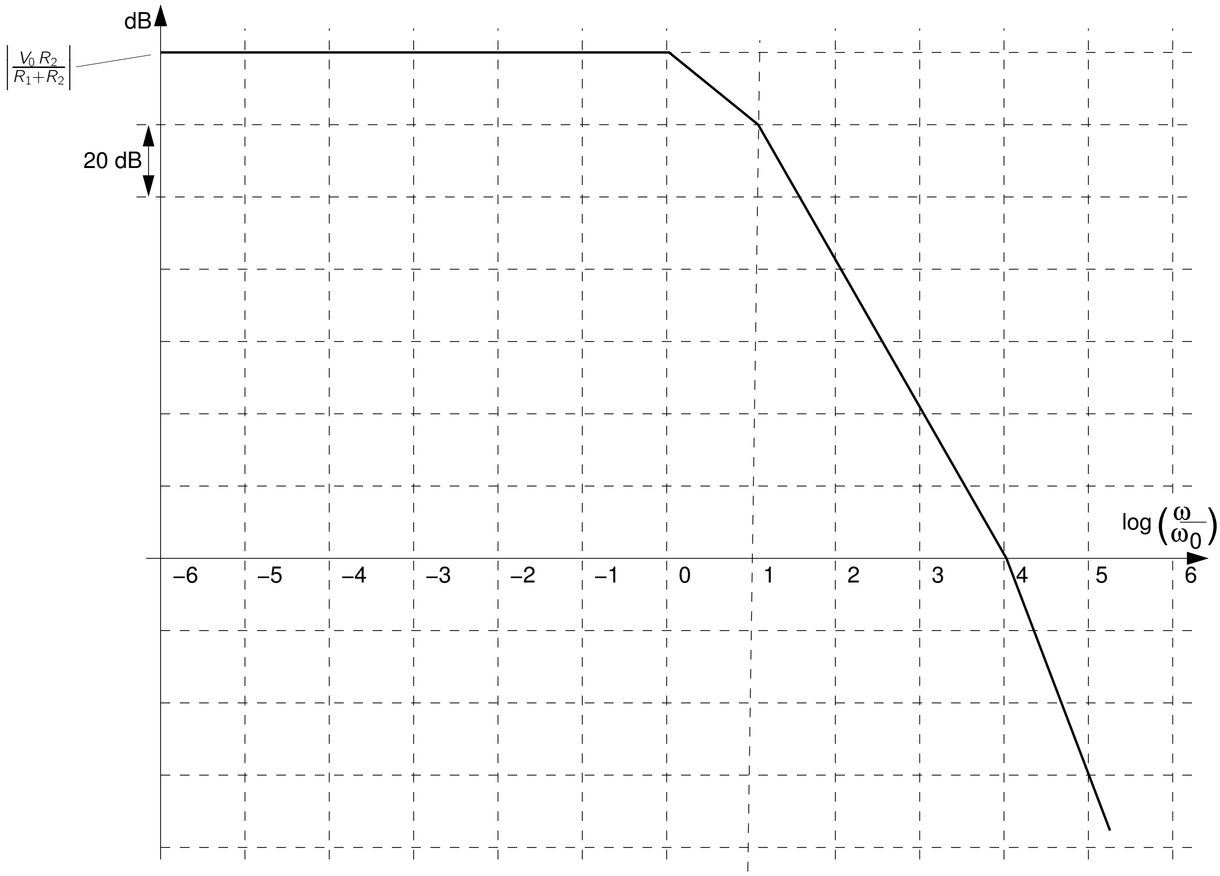
$\underline{F}_a = -\frac{\underline{V}_u}{1+\frac{R_1}{R_2}+j\,\omega\,R_1\,C} = -\frac{\underline{V}_u}{\left(1+\frac{R_1}{R_2}\right)\left(1+j\,\omega\,\frac{R_1\,R_2}{R_1+R_2}\,C\right)}$

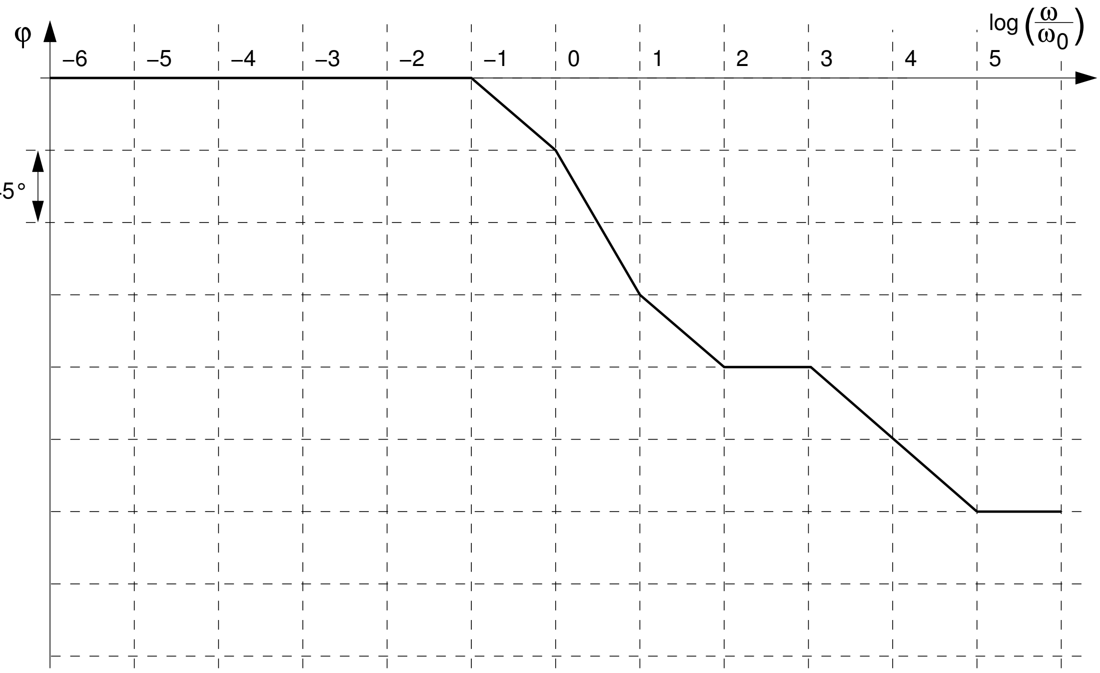
d)

$\underline{V}_u = \frac{V_0}{\left(1+\frac{j\omega}{10\omega_0}\right)\left(1+\frac{j\omega}{10000\omega_0}\right)}$

$C = \frac{R_1+R_2}{\omega_0\,R_1\,R_2}$

$\Rightarrow \underline{F}_a = -\frac{\frac{V_0\,R_2}{R_1+R_2}}{\left(1+\frac{j\omega}{\omega_0}\right)\left(1+\frac{j\omega}{10\omega_0}\right)\left(1+\frac{j\omega}{10000\omega_0}\right)}$


dB
$\left|\frac{V_0 R_2}{R_1+R_2}\right|$
20 dB
log $\left(\frac{\omega}{\omega_0}\right)$
–6
–5
–4
–3
–2
–1
0
1
2
3
4
5
6


φ
log $\left(\frac{\omega}{\omega_0}\right)$
–6
–5
–4
–3
–2
–1
0
1
2
3
4
5
45°