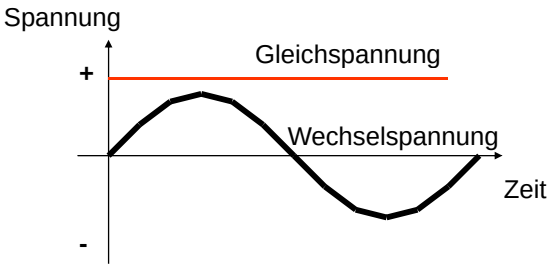
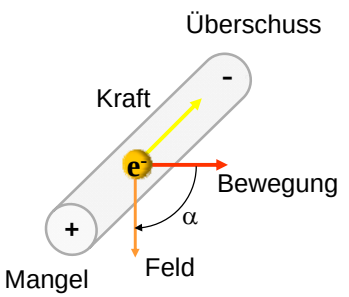
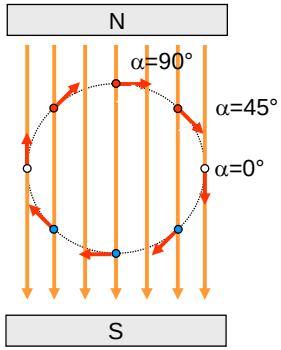
Kapitel 3:

Wechselspannungsnetz

- Kenngrößen
- Wechselstromwiderstand
- Rechnen mit komplexen Zahlen
- Grundschaltungen und Zeigerdiagramme
- CR-Glieder als Hochpassfilter
- RC-Glieder als Tiefpassfilter
- CR-Glieder als Differenzierglieder
- RC-Glieder als Integrierglieder

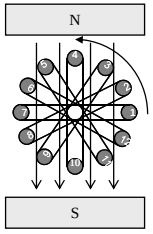


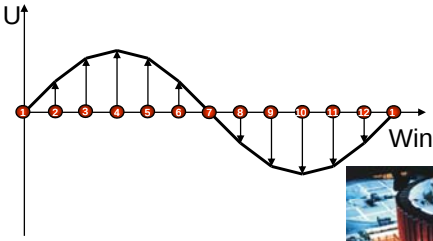


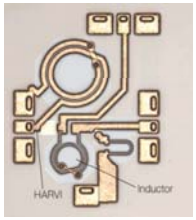


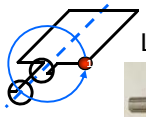
$$F = B \cdot Q \cdot v \cdot \sin\alpha$$

$$F = Q[vB]$$





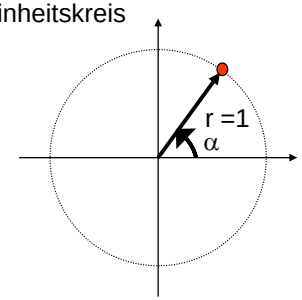




Leiterschleife

Kreisfrequenz

Einheitskreis



Bei einer Umdrehung legt der Punkt auf dem Umfang des Kreises einen Weg von:

$$U = 2 \cdot \pi \cdot r$$

zurückgelegt.
Bei r = 1 ist der Weg gleich 2π.
Der Vollkreis entspricht 360°
oder in Bogenmaß 2π.

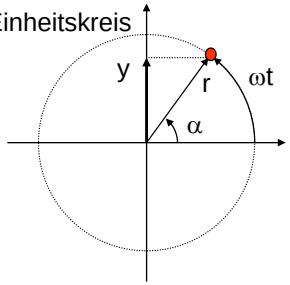
$$f = \frac{1}{T}$$

$$\omega = 2 \cdot \pi \cdot f$$

f - Frequenz
T - Zeit für einen Umlauf
oder auch Periodendauer
ω - Kreisfrequenz

Kreisfrequenz

Einheitskreis



$$\omega = 2 \cdot \pi \cdot f = 2 \cdot \pi \cdot \frac{1}{T}$$

$$\omega \cdot t = 2 \cdot \pi \cdot \frac{1}{T} \cdot t$$

$$\omega \cdot t = 2 \cdot \pi \cdot \frac{t}{T}$$

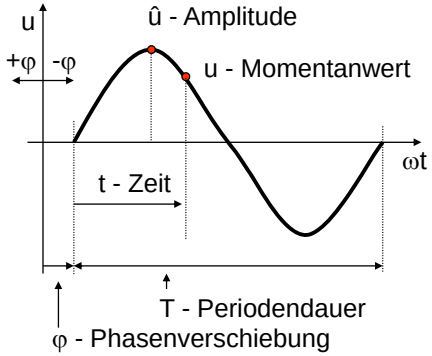
$$x = \frac{t}{T}$$

$$y = r \cdot \sin(\alpha)$$

$$y = r \cdot \sin(\omega \cdot t)$$

$$\sin(\alpha) = \sin(\omega \cdot t)$$

Kenngrößen der Wechselspannung



Frequenz

$$f = \frac{1}{T}$$

$$\omega = 2 \cdot \pi \cdot f$$

Augenblicks- oder Momentanwert

$$u = \hat{u} \cdot \sin(\omega \cdot t + \varphi)$$

Effektivwert

$$R = \frac{U}{I}$$

$$P = U \cdot I$$

$$P = R \cdot I^2$$

$$W = P \cdot t$$

$$W = R \cdot I^2 \cdot T$$

$$R \cdot I^2 \cdot T = R \cdot \int_0^T i^2 \cdot dt$$

$$I = \sqrt{\frac{1}{T} \cdot \int_0^T i^2 \cdot dt}$$

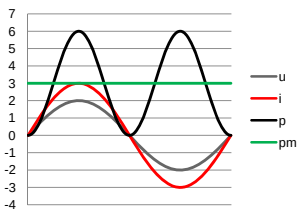
$$I = \sqrt{\frac{1}{T} \cdot \int_0^T \hat{i}^2 \cdot \sin^2(\omega t) dt}$$

$$I = \hat{i} \cdot \sqrt{\frac{1}{T} \int_0^T \sin^2(\omega t) dt}$$

$$I_{eff} = \frac{\hat{i}}{\sqrt{2}} = 0{,}707 \cdot \hat{i}$$

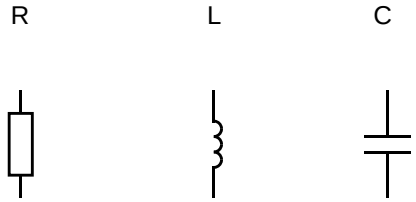
$$W = R \cdot \int_0^T i^2 \cdot dt$$

Effektivwert



Der Effektivwert eines Wechselstroms, ist der Wert eines Gleichstroms, der innerhalb einer Periode die gleiche Arbeit wie der Wechselstrom leistet.

Wechselstromwiderstand
Grundelemente

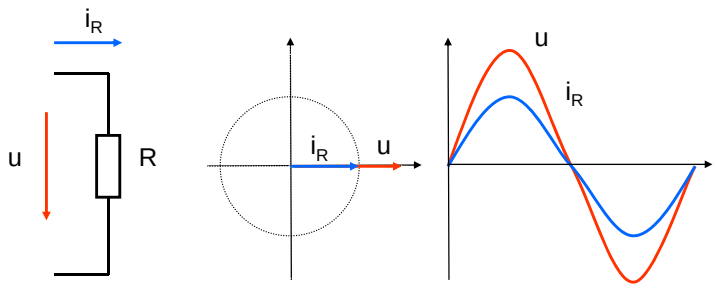


In Wechselstromnetzwerken gelten ebenfalls das Ohmsche Gesetz und die Kirchhoffschen Gesetze. Alle Berechnungen werden auf Basis der Komplexen Zahlen durchgeführt.

Wechselstromwiderstand
Ohmscher Widerstand

$$u_R = R \cdot i = R \cdot \hat{i} \cdot \sin(\omega \cdot t)$$

Wechselstromwiderstand
Ohmscher Widerstand

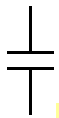


Phasenverschiebung $\varphi = 0$

Ohmscher Widerstand

$$R = \frac{U}{I}$$

Wechselstromwiderstand
Kapazitiver Widerstand



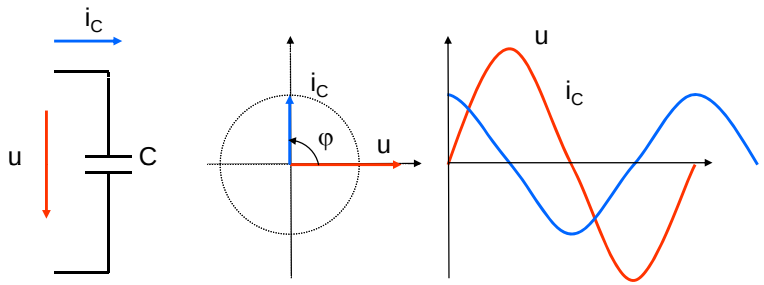
$$u_C = \hat{u}_C \cdot \sin(\omega \cdot t)$$

$$\cos(\omega \cdot t) = \sin\left(\omega \cdot t + \frac{\pi}{2}\right)$$

$$i_C = C \cdot \frac{du_C}{dt} = C \cdot \frac{d(\hat{u}_C \cdot \sin(\omega \cdot t))}{dt} = C \cdot \omega \cdot \hat{u}_C \cdot \cos(\omega \cdot t) = B_C \cdot \hat{u}_C \cdot \sin\left(\omega \cdot t + \frac{\pi}{2}\right)$$

$$\omega \cdot C = B_C = \frac{1}{X_C}$$

Wechselstromwiderstand
Kapazitiver Widerstand



Phasenverschiebung $\varphi = +90°$

Kapazitiver Blindwiderstand

$$X_C = \frac{U_C}{I_C} \qquad X_C = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

Wechselstromwiderstand
Induktiver Widerstand

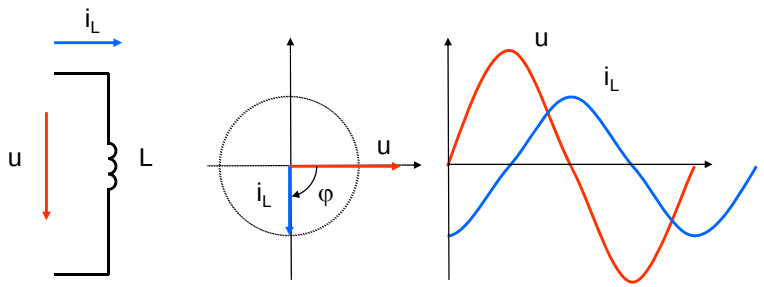
$$i_L = \hat{i}_L \cdot \sin(\omega \cdot t)$$

$$X_L = \omega \cdot L \longleftrightarrow B_L = \frac{1}{X_L} = \frac{1}{\omega \cdot L}$$

$$u_L = L \cdot \frac{di_L}{dt} = \omega \cdot L \cdot \hat{i}_L \cdot \cos(\omega \cdot t) = X_L \cdot \hat{i}_L \cdot \sin\left(\omega \cdot t + \frac{\pi}{2}\right)$$

$$\cos(\omega \cdot t) = \sin\left(\omega \cdot t + \frac{\pi}{2}\right)$$

Wechselstromwiderstand
Induktiver Widerstand

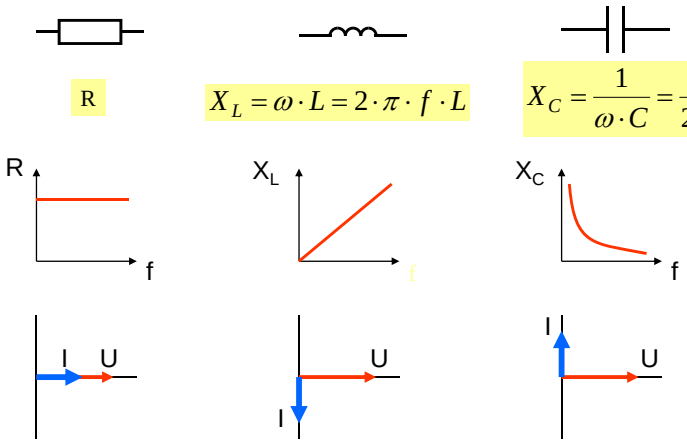


Phasenverschiebung $\varphi = -90°$

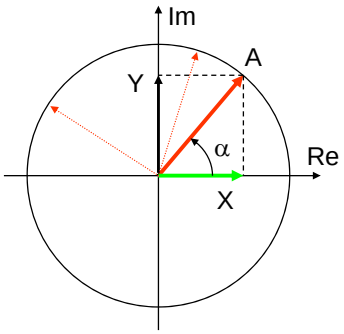
Induktiver Blindwiderstand

$$X_L = \frac{U_L}{I_L} \qquad X_L = \omega \cdot L = 2 \cdot \pi \cdot f \cdot L$$

Wechselstromwiderstand
Übersicht



Komplexer Zeiger



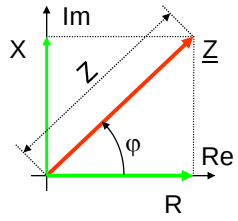
Gaußsche Zahlenebene

$$|A| = 1$$
$$\underline{A} = \cos\alpha + j \cdot \sin\alpha$$
$$X = \cos\alpha$$
$$Y = \sin\alpha$$

Eulersche Identität beschreibt
Die Eulersche Formel

$$e^{j\alpha} = \cos\alpha + j \cdot \sin\alpha$$

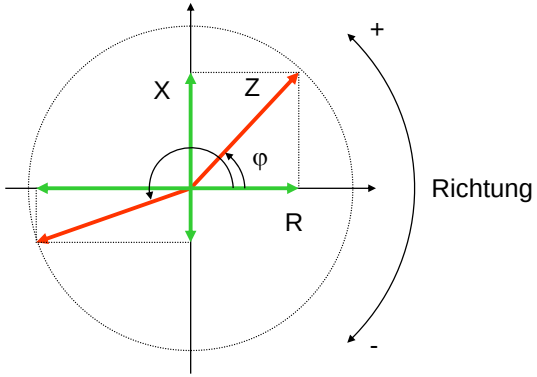
Komplexe Zahl



$\underline{Z} = Z \cdot e^{j\varphi}$	Expotential Form
$\underline{Z} = Z \cdot \cos(\varphi) + j \cdot Z \cdot \sin(\varphi)$	Trigonometrische Form
$X = Z \cdot \sin(\varphi)$	Imaginärteil von $\underline{Z}$
$R = Z \cdot \cos(\varphi)$	Realteil von $\underline{Z}$
$\underline{Z} = R + j \cdot X$	Algebraische Form
$\varphi = \arctan\frac{X}{R}$	Phasenwinkel
$Z = \sqrt{R^2 + X^2}$	Betrag von $\underline{Z}$

Komplexe Zahlen setzen sich aus einer
reellen Zahl und einer rein imaginären Zahl zusammen,
beispielsweise $\underline{Z}$=R+jX,
R heißt Realteil von $\underline{Z}$ (Re $\underline{Z}$ = R) und
X heißt Imaginärteil von $\underline{Z}$ (IM $\underline{Z}$ = X).

Zeigerdiagramm



Rechnen mit Komplexen Zahlen
Addition

$$\underline{Z} = \underline{Z}_1 + \underline{Z}_2$$
$$\underline{Z}_1 = Z_1 \cdot e^{j\varphi_1} = Z_1 \cdot \cos(\varphi_1) + j \cdot Z_1 \cdot \sin(\varphi_1) = R_1 + j \cdot X_1$$
$$\underline{Z}_2 = Z_2 \cdot e^{j\varphi_2} = Z_2 \cdot \cos(\varphi_2) + j \cdot Z_2 \cdot \sin(\varphi_2) = R_2 + jX_2$$
$$\underline{Z} = (R_1 + R_2) + j(X_1 + X_2)$$
$$\varphi = \arctan\frac{(X_1 + X_2)}{(R_1 + R_2)}$$
$$Z = \sqrt{(R_1 + R_2)^2 + (X_1 + X_2)^2}$$
$$\underline{Z} = Z \cdot e^{j\varphi}$$

Rechnen mit Komplexen Zahlen
Subtraktion

$$\underline{Z} = \underline{Z}_1 - \underline{Z}_2$$

$$\underline{Z}_1 = Z_1 \cdot e^{j\varphi_1} = Z_1 \cdot \cos(\varphi_1) + j \cdot Z_1 \cdot \sin(\varphi_1) = R_1 + j \cdot X_1$$

$$\underline{Z}_2 = Z_2 \cdot e^{j\varphi_2} = Z_2 \cdot \cos(\varphi_2) + j \cdot Z_2 \cdot \sin(\varphi_2) = R_2 + jX_2$$

$$\underline{Z} = (R_1 - R_2) + j(X_1 - X_2)$$

$$\varphi = \arctan \frac{(X_1 - X_2)}{(R_1 - R_2)}$$

$$Z = \sqrt{(R_1 - R_2)^2 + (X_1 - X_2)^2}$$

$$\underline{Z} = Z \cdot e^{j\varphi}$$

Rechnen mit Komplexen Zahlen
Multiplikation

$$\underline{Z} = \underline{Z}_1 \cdot \underline{Z}_2$$

$$\underline{Z}_1 = Z_1 \cdot e^{j\varphi_1} = Z_1 \cdot \cos(\varphi_1) + j \cdot Z_1 \cdot \sin(\varphi_1) = R_1 + j \cdot X_1$$

$$\underline{Z}_2 = Z_2 \cdot e^{j\varphi_2} = Z_2 \cdot \cos(\varphi_2) + j \cdot Z_2 \cdot \sin(\varphi_2) = R_2 + jX_2$$

$$Z = Z_1 \cdot Z_2$$

$$\varphi = \varphi_1 + \varphi_2$$

$$\underline{Z} = Z \cdot e^{j\varphi} = Z_1 \cdot Z_2 \cdot e^{j(\varphi_1 + \varphi_2)}$$

Rechnen mit Komplexen Zahlen
Division

$$\underline{Z} = \frac{\underline{Z}_1}{\underline{Z}_2}$$

$$\underline{Z}_1 = Z_1 \cdot e^{j\varphi_1} = Z_1 \cdot \cos(\varphi_1) + j \cdot Z_1 \cdot \sin(\varphi_1) = R_1 + j \cdot X_1$$

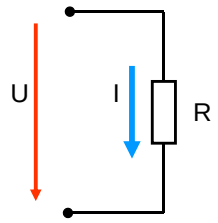
$$\underline{Z}_2 = Z_2 \cdot e^{j\varphi_2} = Z_2 \cdot \cos(\varphi_2) + j \cdot Z_2 \cdot \sin(\varphi_2) = R_2 + jX_2$$

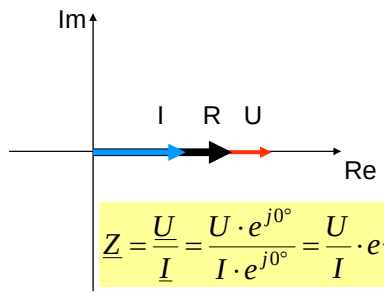
$$Z = \frac{Z_1}{Z_2}$$

$$\varphi = \varphi_1 - \varphi_2$$

$$\underline{Z} = Z \cdot e^{j\varphi} = \frac{Z_1}{Z_2} \cdot e^{j(\varphi_1 - \varphi_2)}$$

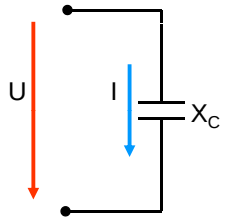
Komplexe Zeiger bei R

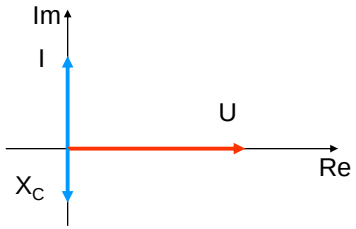




$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{U \cdot e^{j0°}}{I \cdot e^{j0°}} = \frac{U}{I} \cdot e^{j0°} = R \cdot e^{j0°}$$

Komplexe Zeiger bei C



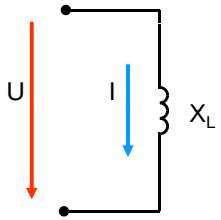


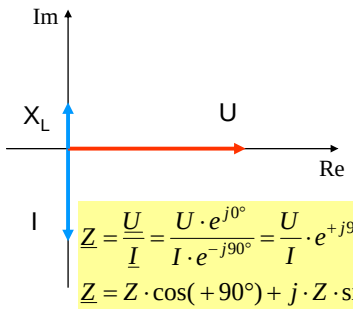
$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{U \cdot e^{j0°}}{I \cdot e^{+j90°}} = \frac{U}{I} \cdot e^{-j90°} = Z \cdot e^{-j90°}$$

$$\underline{Z} = Z \cdot \cos(-90°) + j \cdot Z \cdot \sin(-90°)$$

$$\underline{Z} = 0 - j \cdot X_C = X_C \cdot e^{-j90°}$$

Komplexe Zeiger bei L



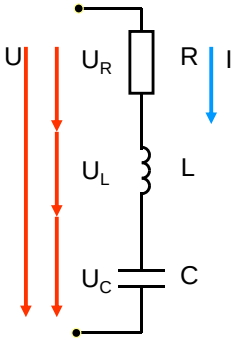


$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{U \cdot e^{j0°}}{I \cdot e^{-j90°}} = \frac{U}{I} \cdot e^{+j90°} = Z \cdot e^{+j90°}$$

$$\underline{Z} = Z \cdot \cos(+90°) + j \cdot Z \cdot \sin(+90°)$$

$$\underline{Z} = 0 + j \cdot X_L = X_L \cdot e^{+j90°}$$

Reihenschaltung



$$\underline{Z} = R + jX_L - jX_C$$

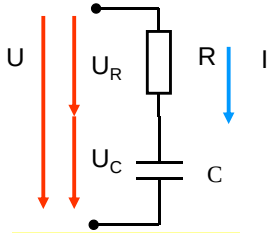
$$\underline{Z} = R + j \cdot (X_L - X_C)$$

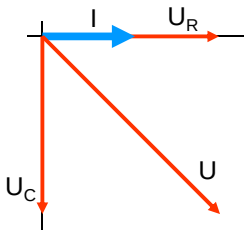
$$\varphi = \arctan \frac{X_L - X_C}{R}$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Der Strom über alle Elemente ist gleich.
Der Gesamtspannung ergibt sich aus der Summe der Teilspannungen.

RC Schaltung





$$U = \sqrt{U_R^2 + U_C^2}$$

$$U = \sqrt{I^2 \cdot R^2 + I^2 \cdot X_C^2}$$

$$U = I \cdot \sqrt{R^2 + X_C^2}$$

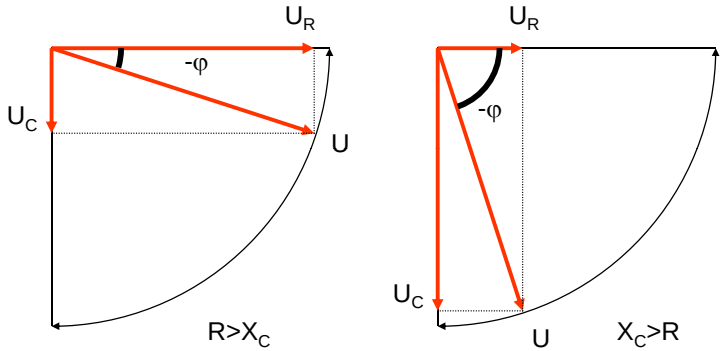
$$U = I \cdot Z$$

$$Z = \sqrt{R^2 + X_C^2}$$

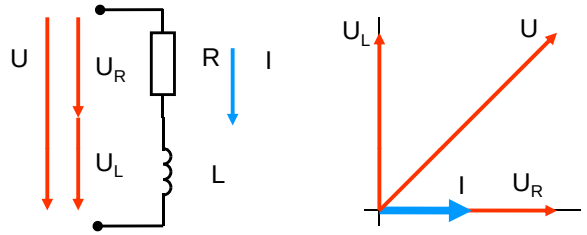
$$\varphi = \arctan \frac{-X_C}{R}$$

$$\underline{Z} = Z \cdot e^{j\varphi}$$

RC Schaltung



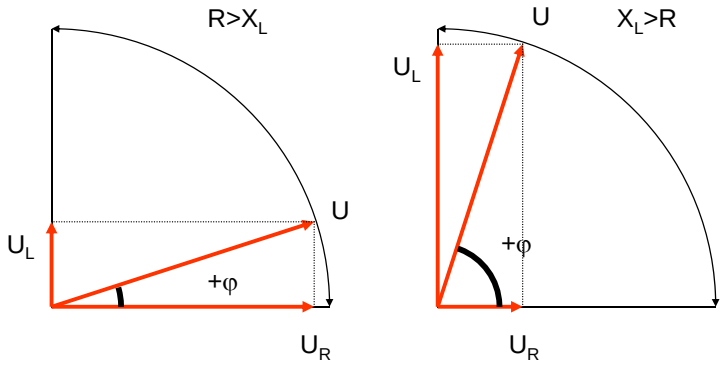
RL Schaltung



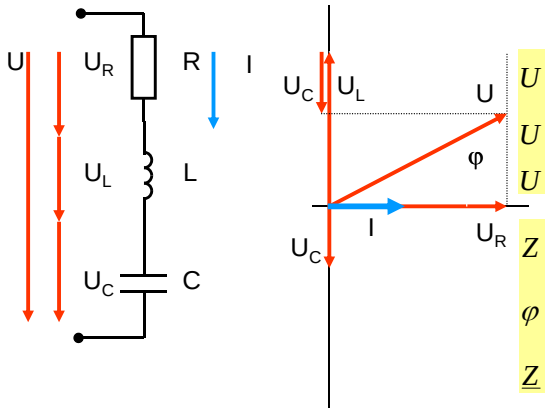
$$U = \sqrt{U_R^2 + U_L^2}$$
$$U = \sqrt{I^2 \cdot R^2 + I^2 \cdot X_L^2}$$
$$U = I \cdot \sqrt{R^2 + X_L^2}$$
$$U = I \cdot Z$$

$$Z = \sqrt{R^2 + X_L^2}$$
$$\varphi = \arctan \frac{X_L}{R}$$
$$\underline{Z} = Z \cdot e^{j\varphi}$$

RL Schaltung



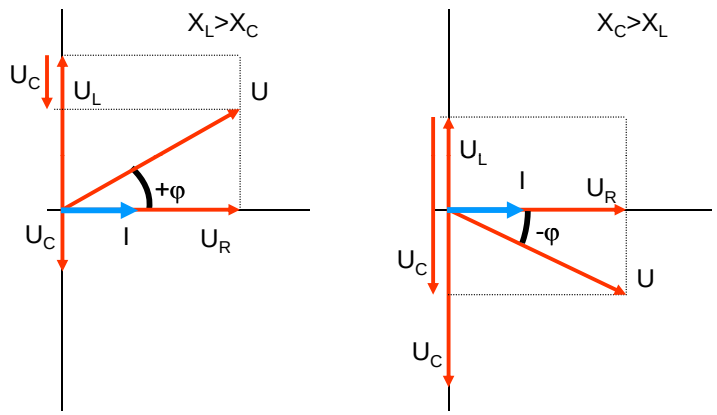
RLC Schaltung



$$U = \sqrt{U_R^2 + (U_L - U_C)^2}$$
$$U = I \cdot \sqrt{R^2 + (X_L - X_C)^2}$$
$$U = I \cdot Z$$

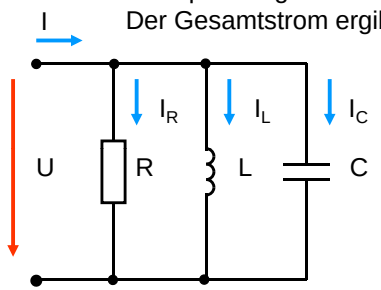
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$\varphi = \arctan \frac{X_L - X_C}{R}$$
$$\underline{Z} = Z \cdot e^{j\varphi}$$

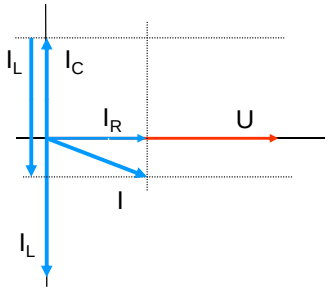
RLC Schaltung



Parallelschaltung

Die Spannung über allen Elementen ist gleich.
Der Gesamtstrom ergibt sich aus der Summe der Teilströme.





$$\underline{U} = \underline{U}_R = \underline{U}_L = \underline{U}_C$$
$$\underline{I} = \underline{I}_R + \underline{I}_L + \underline{I}_C$$

$$I = \sqrt{I_R^2 + (I_C - I_L)^2}$$

Parallelschaltung

$$I = \sqrt{I_R^2 + (I_C - I_L)^2} \qquad I = \frac{U}{R}$$

$$\frac{U}{Z} = \sqrt{\left(\frac{U_R}{R}\right)^2 + \left(\frac{U_C}{X_C} - \frac{U_L}{X_L}\right)^2} \qquad U = U_R = U_L = U_C$$

$$\frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^2} \qquad Y = \frac{1}{Z} \qquad G = \frac{1}{R}$$

$$Y = \sqrt{G^2 + (B_C - B_L)^2} \qquad B_C = \frac{1}{X_C} \qquad B_L = \frac{1}{X_L}$$

Parallelschaltung

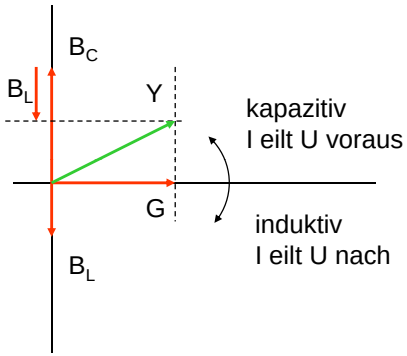
$$\tan\varphi = \frac{I_C - I_L}{I_R} = \frac{U \cdot (B_C - B_L)}{U \cdot G} = \frac{(B_C - B_L)}{G}$$

$$\varphi = \arctan\frac{(B_C - B_L)}{G}$$

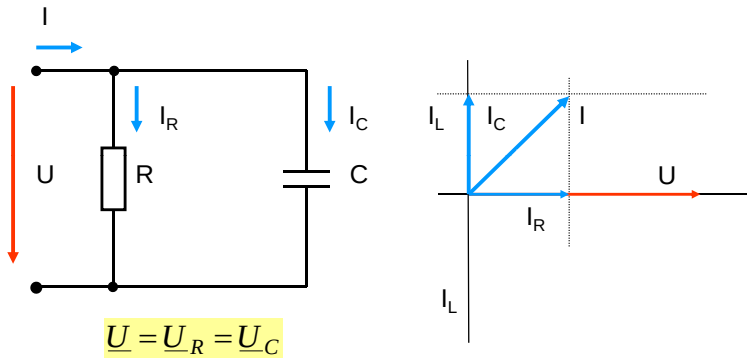
$$\underline{Y} = Y \cdot e^{j\varphi}$$

$$\underline{Z} = \frac{1}{\underline{Y}} = \frac{1}{Y \cdot e^{j\varphi}} = \frac{1}{Y} \cdot e^{-j\varphi}$$

Parallelschaltung



RC Schaltung



$$\underline{U} = \underline{U}_R = \underline{U}_C$$
$$\underline{I} = \underline{I}_R + \underline{I}_C$$

RC Schaltung

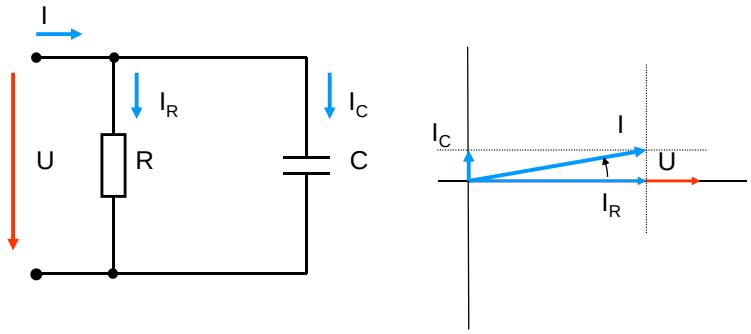
$$I = \sqrt{I_R^2 + I_C^{\,2}} \qquad \frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C}\right)^2}$$

$$Y = \sqrt{G^2 + B_C^{\,2}}$$

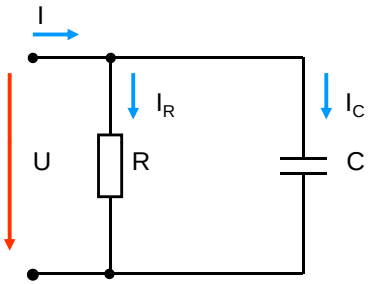
$$\tan\varphi = \frac{I_C}{I_R} = \frac{U \cdot B_C}{U \cdot G} = \frac{B_C}{G}$$

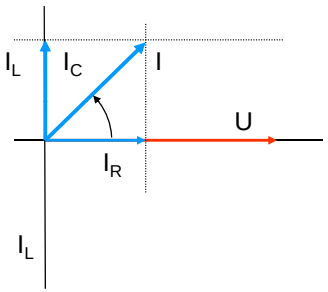
$$\underline{Y} = Y \cdot e^{j\varphi} \qquad \underline{Z} = \frac{1}{\underline{Y}} = \frac{1}{Y \cdot e^{j\varphi}} = \frac{1}{Y} \cdot e^{-j\varphi}$$

RC Schaltung

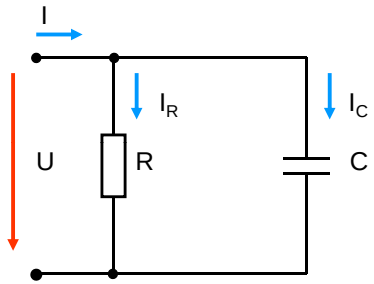


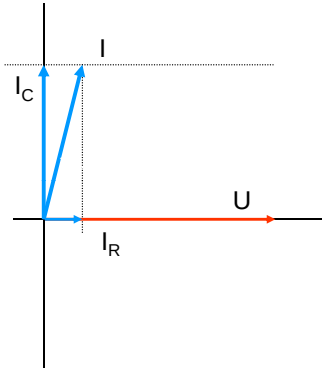
RC Schaltung



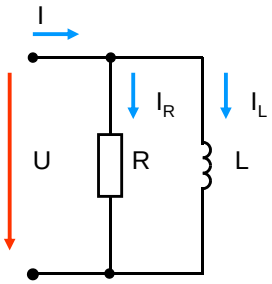


RC Schaltung

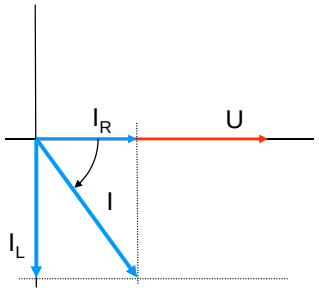




RL Schaltung



$$\underline{U} = \underline{U}_R = \underline{U}_L$$
$$\underline{I} = \underline{I}_R + \underline{I}_L$$



RL Schaltung

$$I = \sqrt{I_R^2 + (-I_L)^2} \qquad \frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(-\frac{1}{X_L}\right)^2}$$

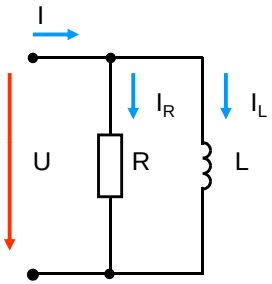
$$Y = \sqrt{G^2 + (-B_L)^2}$$

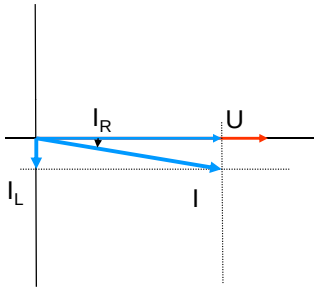
$$\tan\varphi = \frac{-I_L}{I_R} = \frac{U \cdot (-B_L)}{U \cdot G} = \frac{-B_L}{G}$$

$$\varphi = \arctan\frac{-B_L}{G}$$

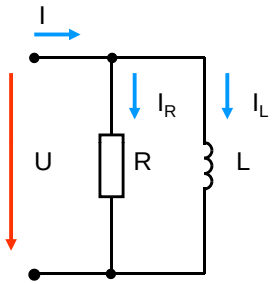
$$\underline{Y} = Y \cdot e^{j\varphi} \qquad \underline{Z} = \frac{1}{\underline{Y}} = \frac{1}{Y \cdot e^{j\varphi}} = \frac{1}{Y} \cdot e^{-j\varphi}$$

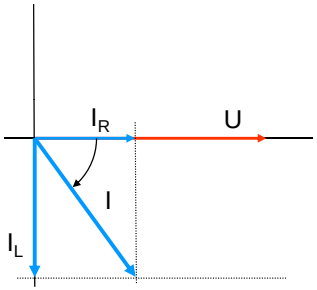
RL Schaltung



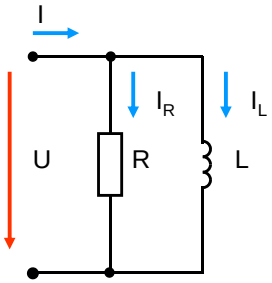


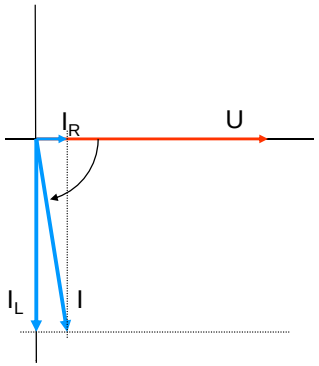
RL Schaltung



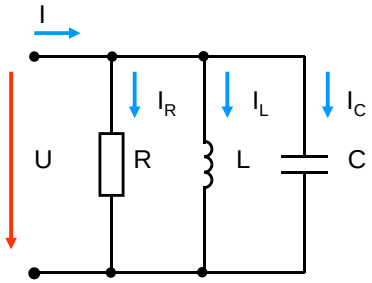


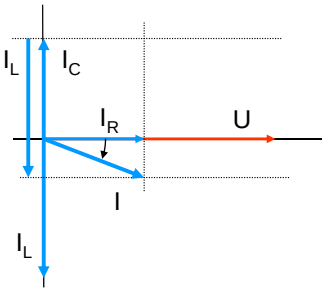
RL Schaltung





RLC Schaltung





$$\underline{U} = \underline{U}_R = \underline{U}_L = \underline{U}_C$$
$$\underline{I} = \underline{I}_R + \underline{I}_L + \underline{I}_C$$

RLC Schaltung

$$I = \sqrt{I_R^2 + (I_C - I_L)^2} \qquad \frac{1}{Z} = \sqrt{\left(\frac{1}{R}\right)^2 + \left(\frac{1}{X_C} - \frac{1}{X_L}\right)^2}$$

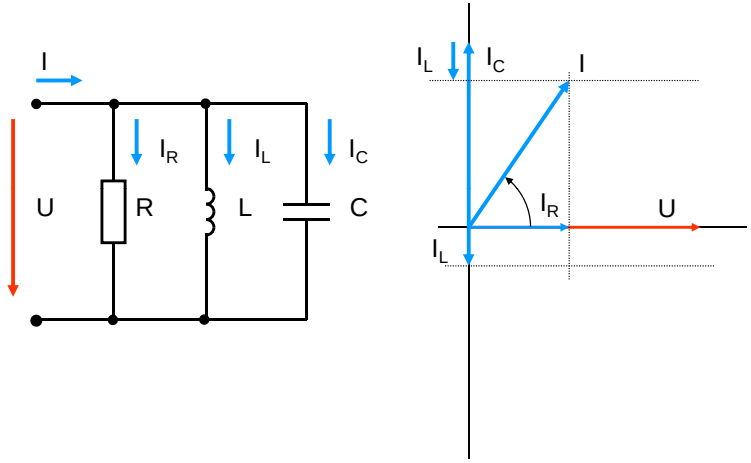
$$Y = \sqrt{G^2 + (B_C - B_L)^2}$$

$$\tan\varphi = \frac{I_C - I_L}{I_R} = \frac{U \cdot (B_C - B_L)}{U \cdot G} = \frac{(B_C - B_L)}{G}$$

$$\varphi = \arctan\frac{(B_C - B_L)}{G}$$

$$\underline{Y} = Y \cdot e^{j\varphi} \qquad \underline{Z} = \frac{1}{\underline{Y}} = \frac{1}{Y \cdot e^{j\varphi}} = \frac{1}{Y} \cdot e^{-j\varphi}$$

RLC Schaltung



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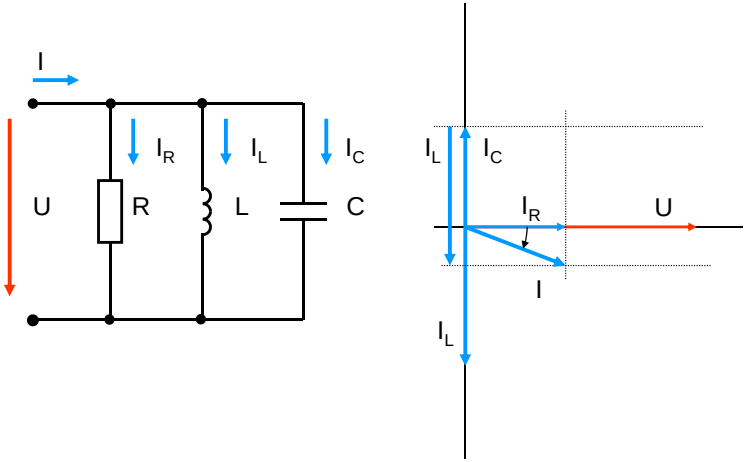

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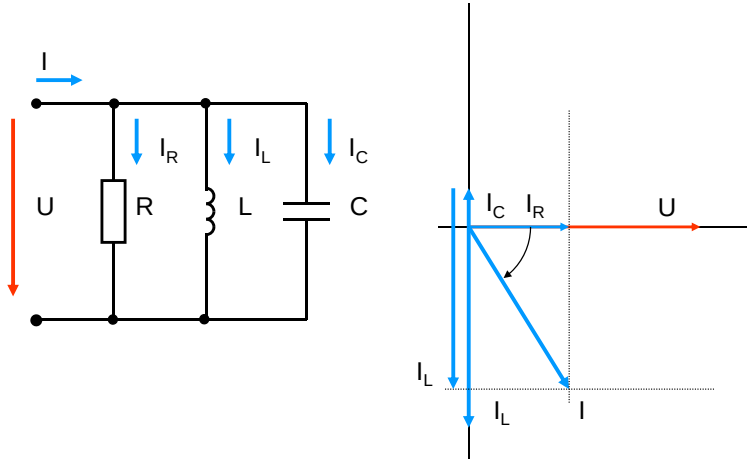
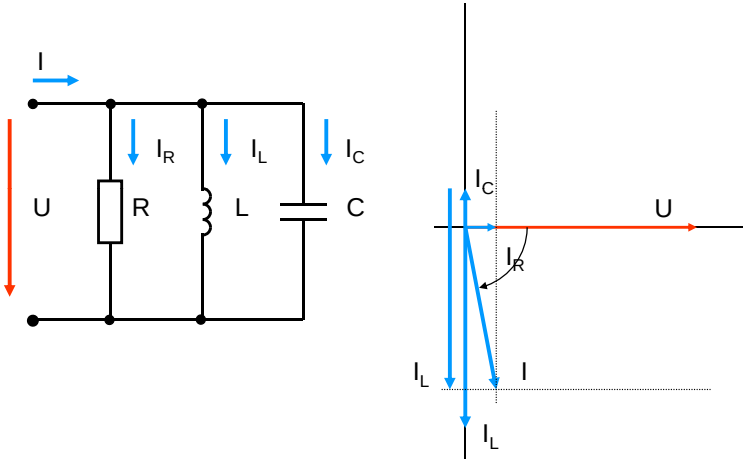


RLC Schaltung



Transformation
Parallelschaltung in Reihenschaltung

$$\underline{Z} = R_R + jX_R = \frac{1}{\underline{Y}} = \frac{1}{G_P - jB_P} \quad \text{mit } G_P + jB_P \text{ erweitern}$$

$$R_R + jX_R = \frac{G_P + jB_P}{G_P^{\,2} + B_P^{\,2}} = \frac{G_P}{G_P^{\,2} + B_P^{\,2}} + j\frac{B_P}{G_P^{\,2} + B_P^{\,2}}$$

$$R_R = \frac{G_P}{Y^2}$$

$$X_R = \frac{B_P}{Y^2}$$

$j^0 = +1$
$j^1 = j$
$j^2 = -1$
$j^3 = -j$
$j^4 = +1$
$\frac{1}{j} = j^{-1} = -j$
$-j \cdot j = 1$

Transformation
Reihenschaltung in Parallelschaltung

$$\underline{Y} = G_P - jB_P = \frac{1}{\underline{Z}} = \frac{1}{R_R + jX_R} \quad \text{mit } R_R - jX_R \text{ erweitern}$$

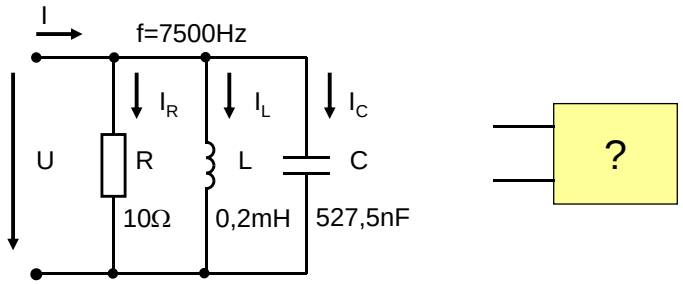
$$G_P - jB_P = \frac{R_R - jX_R}{R_R^{\,2} + X_R^{\,2}} = \frac{R_R}{Z^2} - j\frac{X_R}{Z^2}$$

$$G_P = \frac{R_R}{Z^2}$$

$$B_P = \frac{X_R}{Z^2}$$

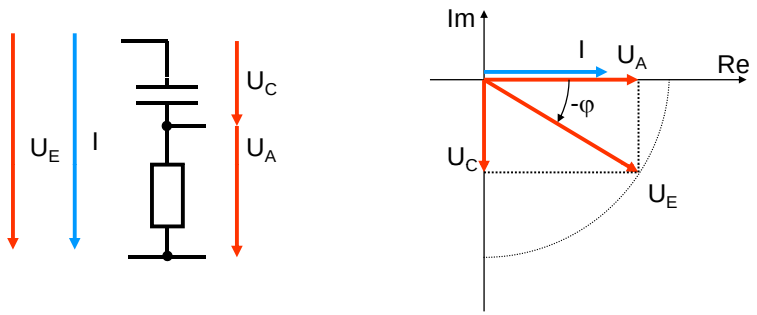
$j^0 = +1$
$j^1 = j$
$j^2 = -1$
$j^3 = -j$
$j^4 = +1$
$\frac{1}{j} = j^{-1} = -j$
$-j \cdot j = 1$

Berechnung von Netzwerken



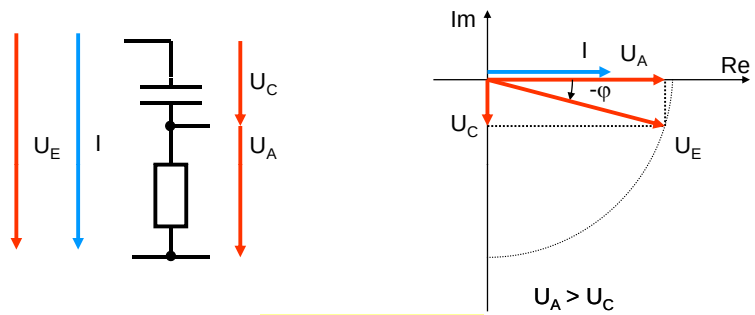
Welche Phasenverschiebung ruft die Schaltung bei einer Frequenz von f=7500Hz zwischen dem Gesamtstrom und der Spannung hervor, und durch welches Blindschaltelement (Kondensator oder Spule) und dem ohmschen Widerstand lässt sich für die angegebene Frequenz die Schaltung ersetzen.

CR - Glied
Zeiger am CR - Glied



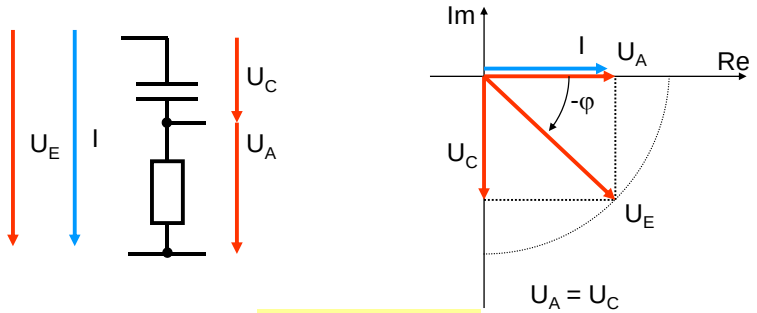
$$X_C = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

CR - Glied
Zeiger am CR - Glied bei R > X_C



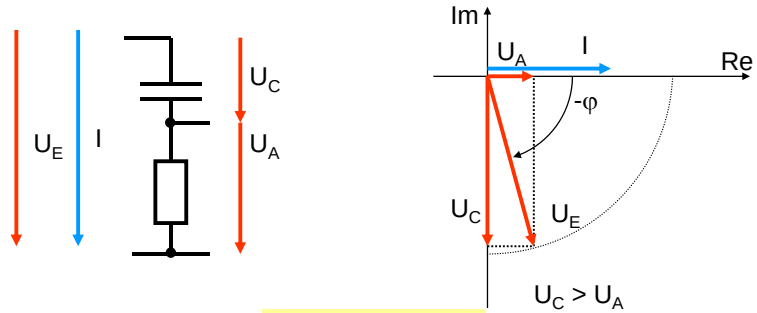
$$X_C = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

CR - Glied
Zeiger am CR - Glied bei R = X_C



$$X_C = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

CR - Glied
Zeiger am CR - Glied bei R < X_C



$$X_C = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

CR - Glied
Zeiger und Berechnungsgleichungen

$$Z = \sqrt{R^2 + (-X_C)^2}$$

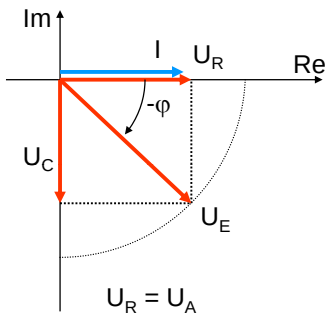
$$\varphi = \arctan \frac{-X_C}{R}$$

$$\underline{Z} = Z \cdot e^{j\varphi} \qquad X_C = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

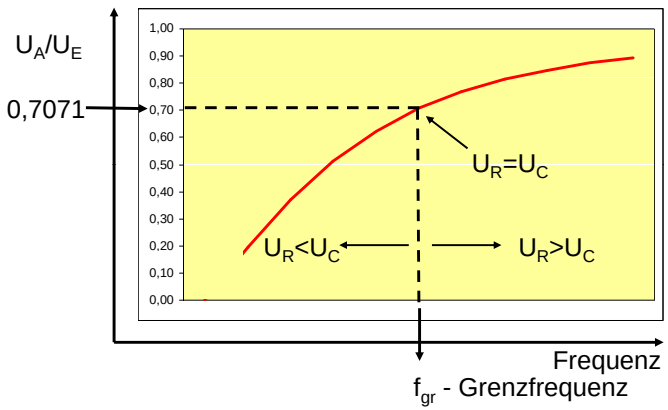
$$\underline{U}_R = \frac{\underline{Z}_R}{\underline{Z}} \cdot \underline{U}_E$$

$$\underline{U}_R = \frac{R \cdot e^{j0^\circ}}{Z \cdot e^{-j\varphi}} \cdot U_E \cdot e^{j\varphi_u} = \frac{R}{Z} \cdot U_E \cdot e^{j(\varphi + \varphi_u)}$$

$$\underline{U}_R = \frac{R \cdot U_E}{\sqrt{R^2 + (-X_C)^2}} \cdot e^{j(\varphi + \varphi_u)}$$



CR - Glied
CR - Glied als Hochpassfilter



CR - Glied
Grenzfrequenzberechnung für das Hochpassfilter

$$U_C = U_R$$

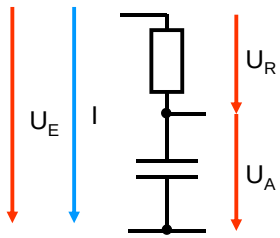
$$I \cdot X_C = I \cdot R$$

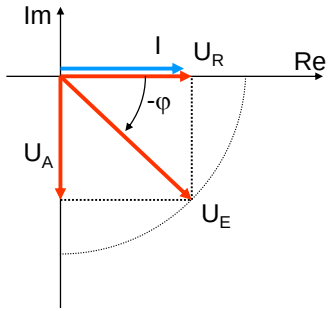
$$X_C = R$$

$$\frac{1}{\omega \cdot C} = R$$

$$f_{gr} = \frac{1}{2 \cdot \pi \cdot C \cdot R}$$

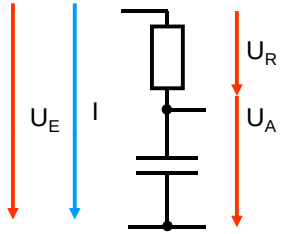
RC - Glied
Zeiger am RC - Glied

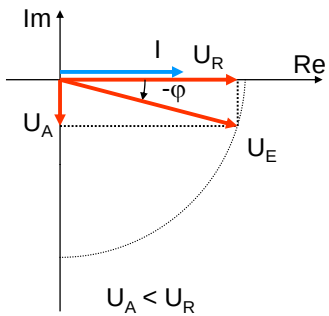




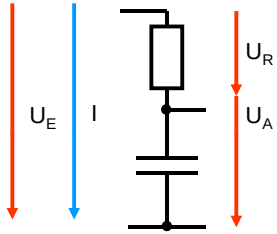
$U_C = U_R$

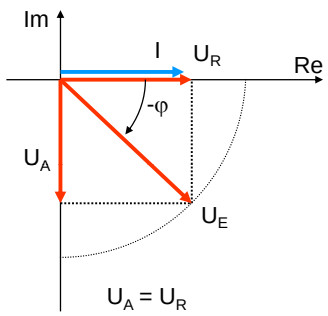
RC - Glied
Zeiger am RC - Glied bei R > X_C



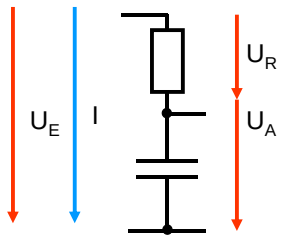


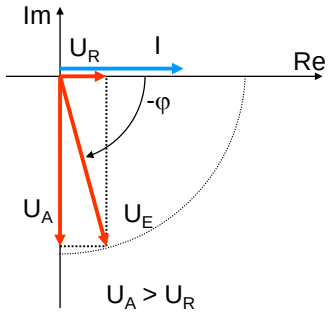
RC - Glied
Zeiger am RC - Glied bei R = X_C





RC - Glied
Zeiger am RC - Glied bei R < X_C





RC - Glied
Zeiger und Berechnungsgleichungen

$$Z = \sqrt{R^2 + (-X_C)^2} \quad X_C = \frac{1}{\omega \cdot C} = \frac{1}{2 \cdot \pi \cdot f \cdot C}$$

$$\varphi = \arctan \frac{-X_C}{R}$$

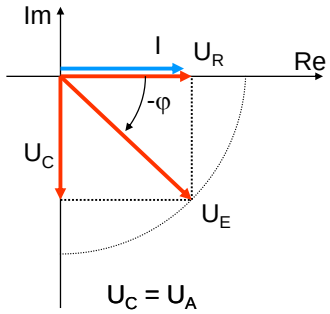
$$\underline{Z} = Z \cdot e^{j\varphi}$$

$$\underline{U}_C = \frac{\underline{Z}_C}{\underline{Z}} \cdot \underline{U}_E$$

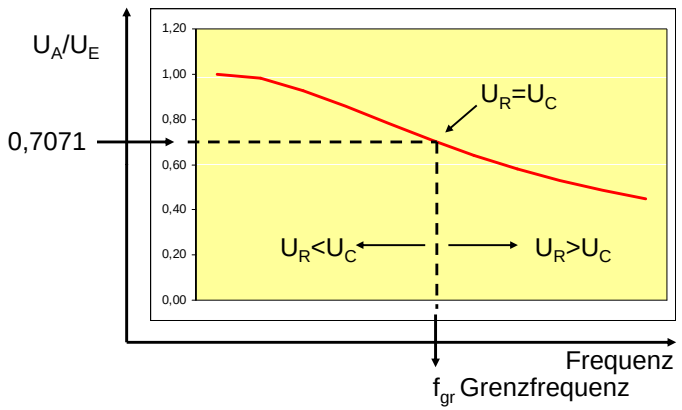
$$\underline{U}_C = \frac{X_C \cdot e^{-j90^\circ}}{Z \cdot e^{-j\varphi}} \cdot U_E \cdot e^{j\varphi_u}$$

$$\underline{U}_C = \frac{X_C}{Z} \cdot U_E \cdot e^{j(-j90^\circ + \varphi + \varphi_u)}$$

$$\underline{U}_C = \frac{X_C \cdot U_E}{\sqrt{R^2 + (-X_C)^2}} \cdot e^{j(-j90^\circ + \varphi + \varphi_u)}$$



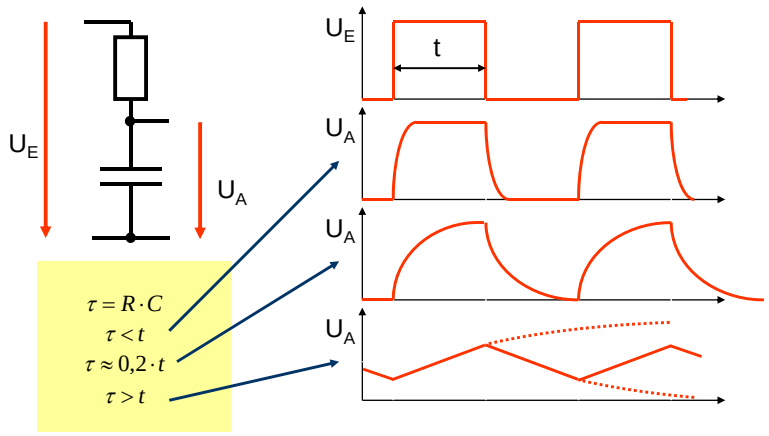
RC - Glied
RC - Glied als Tiefpassfilter



RC - Glied
Grenzfrequenzberechnung für das Tiefpassfilter

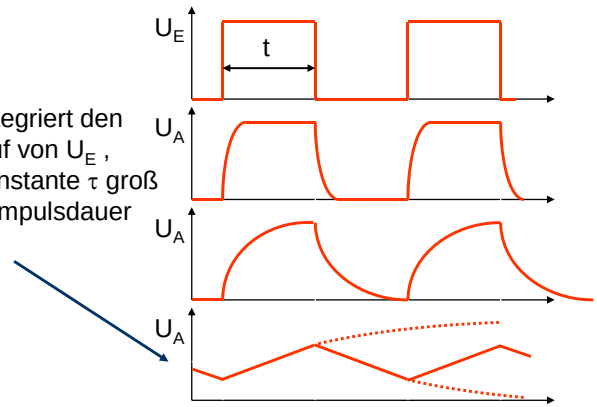
$$U_C = U_R$$
$$I \cdot X_C = I \cdot R$$
$$X_C = R$$
$$\frac{1}{\omega \cdot C} = R$$
$$f_{gr} = \frac{1}{2 \cdot \pi \cdot C \cdot R}$$

RC - Glied
als Integrierglied

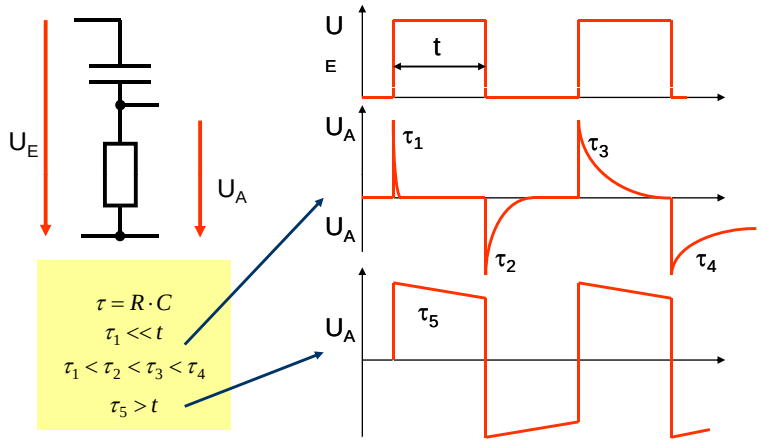


RC - Glied
als Integrierglied

Ein RC-Glied integriert den zeitlichen Verlauf von U_E, wenn die Zeitkonstante τ groß gegenüber der Impulsdauer von U_E ist.

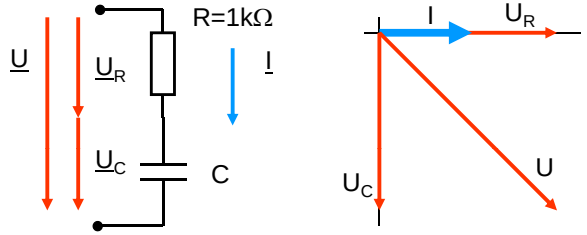


CR - Glied
als Differenzierglied



$$\tau = R \cdot C$$
$$\tau_1 << t$$
$$\tau_1 < \tau_2 < \tau_3 < \tau_4$$
$$\tau_5 > t$$

Berechnung
von Phasenverschiebungen



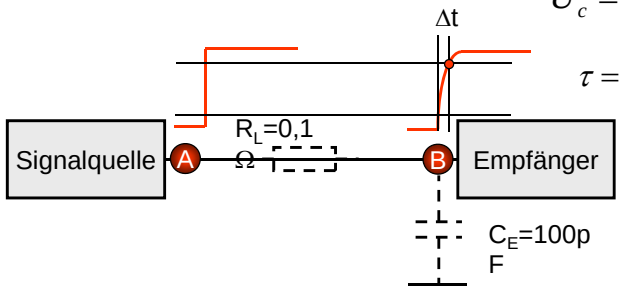
Berechnen Sie C für eine Grenzfrequenz von 1kHz.
Welche Phasenverschiebung zwischen U und U_C
ergibt sich für das berechnete C bei einer Frequenz von 20kHz?

Berechnung
von Laufzeiten in Digitalen Schaltungen

Berechnen Sie die Spannung am Knotenpunkt B,
5 Picosekunden nach Auftreten einer LH Flanke
Von 0 auf 5V am Knotenpunkt A.

$$U_c = U \cdot \left(1 - e^{-\frac{t}{R \cdot C}}\right)$$

$$\tau = R \cdot C$$



Anwendungsbereites Wissen

- Darstellung der Grundgrößen
  - Strom
  - Spannung
  - Frequenz
- Rechnen mit komplexen Zahlen
- Impedanz, Wirk- und Blindwiderstand
- Einfache Netzwerksberechnung
- Elektrisches Verhalten von
  - CR-Glieder
  - RC-Gliedern