

# Exam Winter Semester 2022

## Student Group

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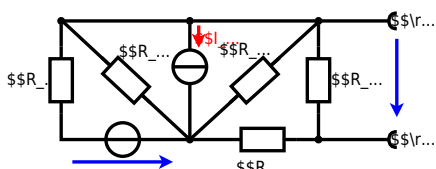
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### Exercise E1 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022)

The circuit in the following has to be simplified.  
Result

$$U_{\text{rs}} = U_{\text{AB}} = 4.5 \text{ V}$$
$$R_{\text{i}} = R_{\text{AB}} = 6 \text{ } \Omega$$



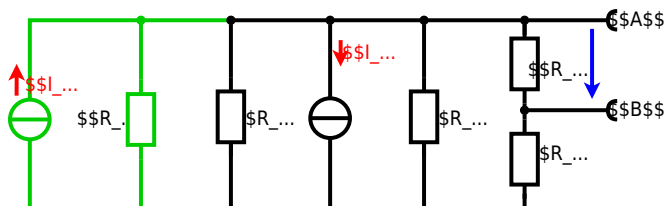
Calculated the internal resistance  $R_{\text{i}}$  and the source voltage  $U_{\text{rs}}$  of an equivalent linear voltage source on the connectors  $\text{A}$  and  $\text{B}$ .  
 $R_1=5.0 \text{ } \Omega$ ,  $U_2=6.0 \text{ V}$ ,  $R_3= 10 \text{ } \Omega$ ,  $I_4=4.2 \text{ A}$ ,  $R_5=10 \text{ } \Omega$ ,  $R_6=7.5 \text{ } \Omega$ ,  $R_7=15 \text{ } \Omega$  Use equivalent sources in order to simplify the circuit!

Solution

The best thing is to re-think the wiring like rubber bands and adjust them:



The linear voltage source of  $U_2$  and  $R_1$  can be transformed into a current source  $I_2 = \frac{U_2}{R_1}$  and  $R_1$ :



Now a lot of them can be combined. The resistors  $R_1$ ,  $R_3$ ,  $R_5$  are in parallel, like also  $I_2$  and  $I_4$ :  

$$R_{135} = R_1 || R_3 || R_5$$

$$I_{24} = I_2 - I_4$$
 The resulting circuit can again be transformed:



Here, the  $U_{24}$  is calculated by  $I_{24}$  as the following:

$$U_{AB} = U_{24} \cdot \left( \frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} \right) - I_4 \cdot R_1 || R_3 || R_5$$

On the right side of the last circuit, there is a voltage divider given by  $R_{135}$ ,  $R_6$ , and  $R_7$ .

Therefore the voltage between  $A$  and  $B$  is given as:

$$U_{AB} = U_{24} \cdot \left( \frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} \right) - \left( \frac{U_2}{R_1} - I_4 \right) \cdot \left( R_1 || R_3 || R_5 \right)$$

For the internal resistance  $R_i$  the ideal voltage source is substituted by its resistance ( $=0 \Omega$ , so a short-circuit):

$$R_{AB} = R_7 || (R_6 + R_1 || R_3 || R_5)$$

with  $R_1 || R_3 || R_5 = 5 \Omega || 10 \Omega || 10 \Omega = 5 \Omega || 5 \Omega = 2.5 \Omega$ :

$$U_{AB} = \left( \frac{6.0 \text{ V}}{5.0 \Omega} \right) - 4.2 \Omega \cdot \left( \frac{15 \Omega \cdot 2.5 \Omega}{7.5 \Omega + 15 \Omega + 2.5 \Omega} \right)$$

$$R_{AB} = 15 \Omega || (7.5 \Omega + 2.5 \Omega)$$

**Exercise E2 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)**

2. A refrigerator is explained with the effect of resistance on refrigeration system. The circuit has a resistance of  $10 \Omega$  at  $25^\circ\text{C}$  and  $25 \Omega$  at  $0^\circ\text{C}$ . Your answer.

Its temperature coefficients are:  $\alpha = 0.01 \text{ K}^{-1}$  and  $\beta = 71 \cdot 10^{-6} \text{ K}^{-2}$

**Result**  
The temperature inside the refrigeration system can reach down to  $-40^\circ\text{C}$ .

$$R_0 = 10 \Omega$$

The power of the resistor is  $P = U^2 / R$  and  $Q = P \cdot t$ . Therefore, a solution is to increase the resistance to reduce the heat flow.

Therefore, with constant  $U$  and increasing  $R$  the power decreases. Ten times more resistance decreases the heat flow to one-tenth.

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2)$$

$$\Delta T = T_{\text{end}} - T_{\text{start}}$$

$$R = 10 \Omega \cdot \left( 1 + 0.01 \text{ K}^{-1} \cdot (-40^\circ\text{C} - 25^\circ\text{C}) + 71 \cdot 10^{-6} \text{ K}^{-2} \cdot (-40^\circ\text{C} - 25^\circ\text{C})^2 \right)$$

**Exercise E5 Analyzing complex Impedances**  
 (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the complex impedance  $Z$  of the circuit shown in the figure through the components.  $R$  and  $X_L$  shall be given.

After analysis, the full bridge network can be simplified and the voltage  $U$  in phase with the current  $I$  can be determined.

Solution  
 .. Calculate the physical values of the two components.  
 Solution  $R = 10 \Omega$  and  $X_L = 20 \Omega$

Solution  

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} \quad \text{with } \underline{U} = 50 \text{ V}$$
 The voltage  $U$  is the voltage across the  $10 \Omega$  resistor and the  $20 \Omega$  inductor. The resulting impedance is  $Z = 10 + j20 \Omega$ .  
 Therefore, the current  $I$  is  $I = \frac{50}{10 + j20} = 1.96 - j0.98 \text{ A}$ .  
 The phase angle  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{-0.98}{1.96}\right) = -26.6^\circ$ .  
 With the complex part  $\cos(\varphi) = 0.899$  and  $\sin(\varphi) = -0.438$ .  
 The phase  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{-0.98}{1.96}\right) = -26.6^\circ$ .

**Exercise E7 Complex Impedance Circuit**  
 (written test, approx. 15 % of a 60-minute written test, WS2022)

2. Calculate the complex impedance  $Z$  of the circuit shown in the figure. The voltage source  $u(t) = 3.0 \sin(2\pi \cdot 15 \cdot t) \text{ V}$  is connected to a series combination of an inductor of  $330 \mu\text{H}$  and a capacitor of  $0.22 \mu\text{F}$ .

Solution  
 Result

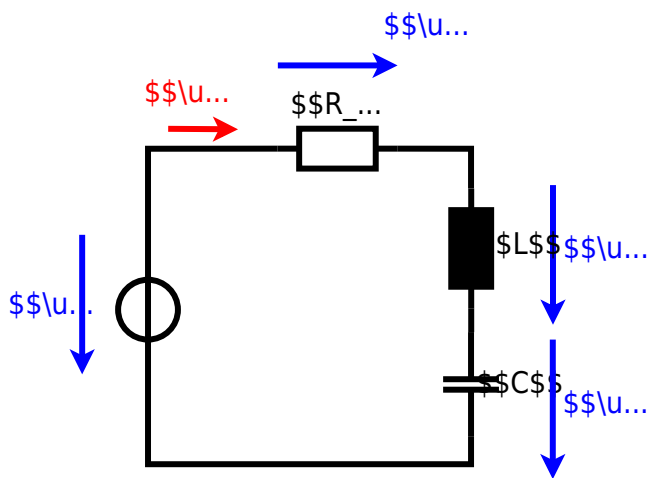
.. Draw the equivalent circuit of the network.  

$$Z = 10 + j20 \Omega$$

$$Z_C = \frac{1}{j\omega C} = \frac{1}{j \cdot 2\pi \cdot 15 \cdot 0.22 \cdot 10^{-6}} = -j15.9 \text{ k}\Omega$$

$$Z = 10 + j20 - j15.9 = 10 + j4.1 \text{ k}\Omega$$





**Exercise E6 Impedances at different Frequencies**  
**(written test, approx. 18 % of a 60-minute written test, WS2022)**

2. A series circuit consists of a resistor with a resistance of  $R_1 = 1.00 \text{ k}\Omega$ , a capacitor with a capacitance of  $C_1 = 40 \text{ nF}$ , and an AC voltage source with a voltage of  $U = 10 \text{ V}$  and a frequency of  $f = 4 \text{ MHz}$ . Calculate the absolute value of the impedance  $Z$  of the circuit.

Solution

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

$$Z = \sqrt{(1.00 \text{ k}\Omega)^2 + \left(\frac{10 \text{ V}}{2\pi \cdot 4 \text{ MHz} \cdot 40 \text{ nF}}\right)^2}$$

$$Z = \sqrt{(1000 \text{ }\Omega)^2 + \left(\frac{10}{2\pi \cdot 4 \cdot 10^6 \cdot 40 \cdot 10^{-9}}\right)^2}$$

$$Z = \sqrt{(1000 \text{ }\Omega)^2 + \left(\frac{10}{100530.96}\right)^2}$$

$$Z = \sqrt{(1000 \text{ }\Omega)^2 + (0.0001)^2}$$

$$Z = \sqrt{1000000.0001}$$

$$Z = 1000.000025 \text{ }\Omega$$

$$Z \approx 1.00 \text{ k}\Omega$$

**Exercise E1 Resistance of a Wire by Resistivity**  
**(written test, approx. 6 % of a 60-minute written test, WS2022)**

2. A heating element made of nichrome wire with a diameter of  $d = 0.5 \text{ mm}$  is used for heating. The power dissipation (= heat flow) of  $P = 40 \text{ W}$  is necessary. Calculate the current  $I$  and the length  $l$  of the heating element. The nichrome wire has a resistivity of  $\rho = 1.10 \cdot 10^{-6} \text{ }\Omega \cdot \text{m}$ .

Solution

$$P = U \cdot I = R \cdot I^2 \Rightarrow I = \sqrt{\frac{P}{R}}$$

$$I = \sqrt{\frac{40 \text{ W}}{1.10 \cdot 10^{-6} \text{ }\Omega \cdot \text{m} \cdot \frac{l}{d^2}}}$$

$$I = \sqrt{\frac{40 \cdot d^2}{1.10 \cdot 10^{-6} \cdot l}}$$

$$I = \sqrt{\frac{40 \cdot (0.5 \cdot 10^{-3})^2}{1.10 \cdot 10^{-6} \cdot l}}$$

$$I = \sqrt{\frac{0.01}{1.10 \cdot 10^{-6} \cdot l}}$$

$$I = \sqrt{\frac{10000}{1.10 \cdot l}}$$

$$I = \sqrt{\frac{9090.909}{l}}$$

$$I = \frac{95.346}{\sqrt{l}}$$

$$I = \frac{95.346}{\sqrt{0.5}}$$

$$I = 134.5 \text{ A}$$

$$\sqrt{\frac{P}{R}} = \sqrt{\frac{40 \text{ W}}{0.33 \cdot \Omega}} \quad \text{align*}$$

$$\begin{aligned} R &= \rho \cdot l \cdot \frac{1}{A} \quad \& \quad | \quad \text{with } A = r^2 \cdot \pi = \\ &= \frac{1}{4} d^2 \cdot \pi \quad \& \quad \rho = \frac{4 \cdot l}{d^2 \cdot \pi} \quad \& \quad R = \\ &= 1.10 \cdot 10^{-6} \cdot \Omega \cdot \frac{4 \cdot 3 \text{ m}}{(3.57 \cdot 10^{-3} \text{ m})^2 \cdot \pi} \quad \& \quad \end{aligned}$$

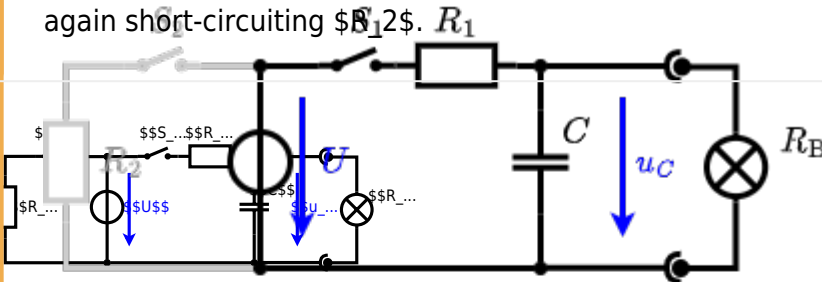
**Exercise E4 Charging Capacitors**  
 (written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit (with the light bulb) is a series of  $R_1$  and  $R_2$  and a capacitor  $C$  and a switch  $S_1$  and a switch  $S_2$ . The voltage across the capacitor is again  $0 \text{ V}$  at the moment  $t_0 = 0 \text{ s}$  when the switch  $S_1$  is closed. Calculate the voltage  $u_c(t_2)$  across the capacitor at  $t_2 = 1 \text{ ms}$  after closing the switch.

**Solution:** To solve this, first create an equivalent linear voltage source from  $U$ ,  $R_1$ , and  $R_2$ .

The ideal voltage source  $U$  is in series with  $R_1$  and  $R_2$ . The voltage  $u_c$  is independent of this series.

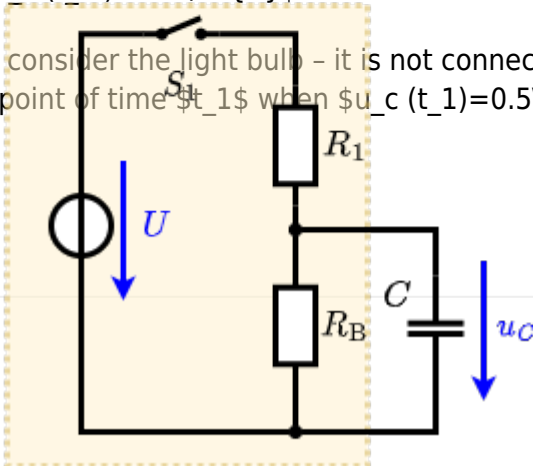
On an alternative view, one can try to create an equivalent linear voltage source again. Then, the internal resistance is given by substituting the ideal voltage source is again short-circuiting  $S_2$ .



The circuit contains a voltage source  $U = 12 \text{ V}$ , a switch  $S_1$ , a resistor of  $R_1 = 20 \Omega$  and a capacitor of  $C = 100 \mu\text{F}$ . The switch  $S_2$  to an additional consumer  $R_2$  will be considered to be open for the first tasks. At the moment  $t_0 = 0 \text{ s}$  the switch  $S_1$  is closed, the voltage across the capacitor is  $u_c(t_0) = 0 \text{ V}$ .

... First do not consider the light bulb - it is not connected to the RC circuit. Calculate the point of time  $t_1$  when  $u_c(t_1) = 0.5 \cdot U$ .

**Solution**



An equivalent linear voltage source can be given with  $U_s$ ,  $R_1$ , and  $R_B$  as seen in yellow.

Therefore, the voltage of the equivalent linear voltage source is:  $U_s = U \cdot \frac{R_B}{R_1 + R_B} = \frac{1}{2} \cdot U$  The internal resistance is given by substituting the ideal voltage source with its resistance ( $R = 0 \Omega$ , short-circuit).

$$R_i = R_1 \parallel R_B = 10 \Omega$$

$$u_c(t) = U_s \cdot (1 - e^{-t/(R_i \cdot C)}) = \frac{1}{2} \cdot U \cdot (1 - e^{-t/(10 \Omega \cdot 100 \mu F)})$$

The following formula describes the time course of  $u_c(t)$  which has to be  $u_c(t_1) = 0.5 \cdot U$ : 
$$u_c(t) = U \cdot (1 - e^{-t/\tau}) = 0.5 \cdot U$$
 It has to be rearranged to  $(1 - e^{-t/\tau}) = 0.5 \implies e^{-t/\tau} = 0.5 \implies t/\tau = \ln(0.5) \implies t = \tau \cdot \ln(0.5) = R_1 \cdot C \cdot \ln(0.5)$



**Exercise E3 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)**

The following shall be solved at 0.10 A,  $R_1 = R_2 = R_3 = 10 \Omega$  and the voltage  $U = 10 V$  is given.  $R_B$ .

Solution

$$R_{\text{eq}} = 132.8 \Omega$$

Now a wye-delta transformation is necessary.



Since  $R_2=R_3$  and based on the equations for the transformation, the transformed  $R_Y$  is given as:

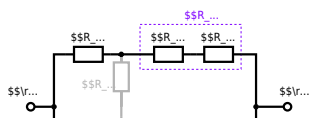
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

The equivalent resistor is given by a parallel configuration of resistors in series:

$$R_{\text{eq}} = R_Y + (R_Y + R_1 + R_1) \parallel (R_Y + R_2) \parallel R_{\text{eq}} = 33.33 \Omega + (33.33 \Omega + 400 \Omega) \parallel (33.33 \Omega + 100 \Omega)$$

1. The switch shall now be open. Calculate the equivalent resistance  $R_{\text{eq}}$  between  $A$  and  $B$ .

Solution



The equivalent resistor is given by a parallel configuration of resistors in series:

$$R_{\text{eq}} = (R_2 + R_1 + R_{-1}) \parallel (R_2 + R_2) \parallel R_{\text{eq}} = (100 \Omega + 200 \Omega + 200 \Omega) \parallel (100 \Omega + 100 \Omega) \parallel R_{\text{eq}} = (500 \Omega) \parallel (200 \Omega) \parallel R_{\text{eq}} = \frac{500 \Omega \cdot 200 \Omega}{500 \Omega + 200 \Omega}$$

**Exercise E3 Equivalent linear Source  
(written test, approx. 14 % of a 60-minute written test, WS2022)**

The circuit in the following has to be simplified.  
Result

$$U_{\text{s}} = U_{\text{AB}} = 4.5 \text{ V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \Omega$$



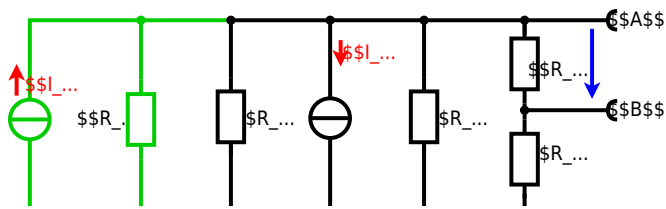
Calculated the internal resistance  $R_{\text{int}}$  and the source voltage  $U_{\text{oc}}$  of an equivalent linear voltage source on the connectors  $\text{A}$  and  $\text{B}$ .  $R_1=5.0 \text{ } \Omega$ ,  $U_2=6.0 \text{ V}$ ,  $R_3= 10 \text{ } \Omega$ ,  $I_4=4.2 \text{ A}$ ,  $R_5=10 \text{ } \Omega$ ,  $R_6=7.5 \text{ } \Omega$ ,  $R_7=15 \text{ } \Omega$  Use equivalent sources in order to simplify the circuit!

Solution

The best thing is to re-think the wiring like rubber bands and adjust them:



The linear voltage source of  $U_2$  and  $R_1$  can be transformed into a current source  $I_2 = \frac{U_2}{R_1}$  and  $R_1$ :



Now a lot of them can be combined. The resistors  $R_1$ ,  $R_3$ ,  $R_5$  are in parallel, like also  $I_2$  and  $I_4$ :

$$R_{135} = R_1 || R_3 || R_5$$

$$I_{24} = I_2 - I_4$$

The resulting circuit can again be transformed:



Here, the  $U_{24}$  is calculated by  $I_{24}$  as the following:

$$U_{24} = I_{24} \cdot (R_4 || R_6)$$

$$U_{AB} = U_{24} \cdot \left( \frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} \right) - I_4 \cdot (R_1 || R_3 || R_5)$$

On the right side of the last circuit, there is a voltage divider given by  $R_{135}$ ,  $R_6$ , and  $R_7$ .

Therefore the voltage between  $A$  and  $B$  is given as:

$$U_{AB} = U_{24} \cdot \left( \frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} \right) - I_4 \cdot (R_1 || R_3 || R_5)$$

For the internal resistance  $R_i$  the ideal voltage source is substituted by its resistance ( $=0 \Omega$ , so a short-circuit):

$$R_{AB} = R_7 || (R_6 + R_1 || R_3 || R_5)$$

with  $R_1 || R_3 || R_5 = 5 \Omega || 10 \Omega || 10 \Omega = 5 \Omega || 5 \Omega = 2.5 \Omega$ :

$$U_{AB} = \left( \frac{6.0 \text{ V}}{5.0 \Omega} \right) - 4.2 \Omega \cdot \left( \frac{15 \Omega \cdot 2.5 \Omega}{7.5 \Omega + 15 \Omega + 2.5 \Omega} \right)$$

$$R_{AB} = 15 \Omega || (7.5 \Omega + 2.5 \Omega)$$

**Exercise E2 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)**

2. A refrigerator is explained with the effect of resistance on power. The refrigerator has a resistance of  $10 \Omega$  at  $25^\circ \text{C}$  and  $25 \Omega$  at  $0^\circ \text{C}$ . Its temperature coefficients are:  $\alpha = 0.01 \text{ K}^{-1}$  and  $\beta = 71 \cdot 10^{-6} \text{ K}^{-2}$ .

Result: The temperature inside the refrigeration system can reach down to  $-40^\circ \text{C}$ .

Calculate the resistance of the thermistor at  $-40^\circ \text{C}$ .

The power transferred is  $P = U \cdot I$  and  $I = \frac{U}{R}$ . Therefore, a solution is to increase the heat flow up the refrigeration system.

Therefore, with constant  $U$  and increasing  $R$  the power decreases. Ten times more resistance decreases the heat flow to one-tenth.

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2)$$

$$\text{with } \Delta T = T_{\text{end}} - T_{\text{start}} \implies R = 10 \Omega \cdot \left( 1 + 0.01 \text{ K}^{-1} \cdot (-40^\circ \text{C} - 25^\circ \text{C}) + 71 \cdot 10^{-6} \text{ K}^{-2} \cdot (-40^\circ \text{C} - 25^\circ \text{C})^2 \right)$$

**Exercise E5 Analyzing complex Impedances**  
 (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the complex power  $\underline{S}$  (W and var) of the load  $\underline{Z}_L$  through the components.  $\underline{S}_R$  and  $\underline{S}_{X_1}$  shall be given.

After analysis, the full load impedance  $\underline{Z}_L$  can be extracted and legitimated in phasorical  $\underline{Z}_L = \underline{Z}_R + j\underline{X}_L = 2 + j4 \text{ (ohm)}$

Solution  
 .. Calculate the physical values of the load components.  
 Solution  $\underline{Z}_L = 2 + j4 \text{ (ohm)}$

Solution  

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \text{ V}}{2 + j4 \text{ ohm}}$$
 The voltage  $\underline{U}$  is a phasor with a magnitude of 50 V and a phase angle of 0°. The resulting impedance  $\underline{Z} = 2 + j4 \text{ ohm}$  has a magnitude of  $\sqrt{2^2 + 4^2} = 4.47 \text{ ohm}$  and a phase angle of  $\arctan(4/2) = 63.4^\circ$ .  
 Therefore, the current  $\underline{I}$  has a magnitude of  $\frac{50}{4.47} = 11.19 \text{ A}$  and a phase angle of  $-63.4^\circ$ .  
 The complex power  $\underline{S} = \underline{I} \cdot \underline{U} = 11.19 \text{ A} \cdot 50 \text{ V} = 559.5 \text{ VA}$ .  
 The real power  $P = \text{Re}(\underline{S}) = 559.5 \cdot \cos(63.4^\circ) = 250 \text{ W}$ .  
 The reactive power  $Q = \text{Im}(\underline{S}) = 559.5 \cdot \sin(63.4^\circ) = 500 \text{ var}$ .  
 The phase  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{-4.68}{0.24}\right) = -89.8^\circ$ .  
 With the complex power  $\underline{S} = 250 - j500 \text{ VA}$ , the real power  $P = 250 \text{ W}$  and the reactive power  $Q = -500 \text{ var}$ .  
 The phase  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{-500}{250}\right) = -63.4^\circ$ .

**Exercise E7 Complex Impedance Circuit**  
 (written test, approx. 15 % of a 60-minute written test, WS2022)

2. Calculate the complex power  $\underline{S}$  (W and var) of the load  $\underline{Z}_L$  through the components.  $\underline{S}_R$  and  $\underline{S}_{X_1}$  shall be given.  
 The voltage  $\underline{u}(t) = 3.0 \cdot \sin(2\pi \cdot 15 \cdot t) \text{ V}$  is a phasor with a magnitude of 3.0 V and a phase angle of 0°. The resulting impedance  $\underline{Z} = 2 + j4 \text{ ohm}$  has a magnitude of  $\sqrt{2^2 + 4^2} = 4.47 \text{ ohm}$  and a phase angle of  $\arctan(4/2) = 63.4^\circ$ .  
 Therefore, the current  $\underline{I}$  has a magnitude of  $\frac{3.0}{4.47} = 0.67 \text{ A}$  and a phase angle of  $-63.4^\circ$ .  
 The complex power  $\underline{S} = \underline{I} \cdot \underline{U} = 0.67 \text{ A} \cdot 3.0 \text{ V} = 2.01 \text{ VA}$ .  
 The real power  $P = \text{Re}(\underline{S}) = 2.01 \cdot \cos(63.4^\circ) = 0.9 \text{ W}$ .  
 The reactive power  $Q = \text{Im}(\underline{S}) = 2.01 \cdot \sin(63.4^\circ) = 1.8 \text{ var}$ .  
 The phase  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{1.8}{0.9}\right) = 63.4^\circ$ .

Solution  
 Result  
 .. Draw the circuit diagram of the given circuit and label all components, voltages, and currents.

Solution  

$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{48.2 \text{ V}}{1.92 \text{ A}} = 25 \text{ ohm}$$

$$\underline{Z}_C = \frac{1}{j\omega C} = \frac{1}{j \cdot 2\pi \cdot 15 \cdot 0.22 \cdot 10^{-6}} = -j19.2 \text{ ohm}$$

$$\underline{Z}_L = \underline{Z} - \underline{Z}_C = 25 \text{ ohm} + j19.2 \text{ ohm} = 32.2 \text{ ohm}$$

$$\underline{I} = \frac{\underline{U}}{\underline{Z}_L} = \frac{48.2 \text{ V}}{32.2 \text{ ohm}} = 1.5 \text{ A}$$

$$\underline{S} = \underline{I} \cdot \underline{U} = 1.5 \text{ A} \cdot 48.2 \text{ V} = 72.3 \text{ VA}$$

$$P = \text{Re}(\underline{S}) = 72.3 \cdot \cos(63.4^\circ) = 32.2 \text{ W}$$

$$Q = \text{Im}(\underline{S}) = 72.3 \cdot \sin(63.4^\circ) = 65.5 \text{ var}$$

$$\varphi = \arctan\left(\frac{65.5}{32.2}\right) = 63.4^\circ$$





**Exercise E6 Impedances at different Frequencies**  
**(written test, approx. 18 % of a 60-minute written test, WS2022)**

2. A series circuit contains a resistor with  $R = 1.00 \text{ k}\Omega$ , a capacitor with  $C = 40 \text{ nF}$ , and an AC voltage source of  $U = 10 \text{ V}$ .  
 Result:  $I = 10 \text{ mA}$  at  $f = 100 \text{ kHz}$ .  
 Question: What is the absolute value of the impedance of the capacitor  $Z_C$  at  $f = 100 \text{ kHz}$ ?

Solution

$Z_C = \frac{1}{j\omega C} = \frac{1}{j \cdot 2\pi \cdot 100 \cdot 10^3 \cdot 40 \cdot 10^{-9}} = -j12.5 \text{ }\Omega$

$|Z_C| = 12.5 \text{ }\Omega$

A series circuit means that the current is constant on every component.  
 The equivalent impedance for  $R$  and  $Z_C$  combined is given by  $Z_{eq} = R + Z_C$   
 $Z_{eq} = 1.00 \text{ k}\Omega - j12.5 \text{ }\Omega$   
 $|Z_{eq}| = \sqrt{1.00^2 + 12.5^2} \text{ k}\Omega \approx 12.5 \text{ k}\Omega$   
 $I = \frac{U}{|Z_{eq}|} = \frac{10 \text{ V}}{12.5 \text{ k}\Omega} = 0.8 \text{ mA}$

**Exercise E1 Resistance of a Wire by Resistivity**  
**(written test, approx. 6 % of a 60-minute written test, WS2022)**

2. Heating elements are used to heat the oven with a temperature of  $180 \text{ }^\circ\text{C}$ .  
 Result:  $P = 40 \text{ W}$  is necessary.  
 Question: Calculate the resistance  $R$  of the heating element.  
 The Nichrome wire has a resistivity of  $\rho = 1.10 \cdot 10^{-6} \text{ }\Omega \cdot \text{m}$ .  
 The heating element is  $l = 3 \text{ m}$  long and has a diameter of  $d = 3.57 \text{ mm}$ .

Solution

$R = \frac{P}{I^2} = \frac{40 \text{ W}}{(10 \text{ A})^2} = 0.4 \text{ }\Omega$

$R = \rho \cdot \frac{l}{A} = 1.10 \cdot 10^{-6} \text{ }\Omega \cdot \text{m} \cdot \frac{3 \text{ m}}{\pi \cdot (\frac{3.57 \text{ mm}}{2})^2} = 0.4 \text{ }\Omega$

$$\sqrt{\frac{P}{R}} = \sqrt{\frac{40 \text{ W}}{0.33 \cdot \Omega}} \quad \text{align*}$$

$$\begin{aligned} R &= \rho \cdot l \cdot \frac{1}{A} \quad \& \quad | \quad \text{with } A = r^2 \cdot \pi = \\ &= \frac{1}{4} d^2 \cdot \pi \quad \& \quad R = \rho \cdot l \cdot \frac{4 \cdot l}{d^2 \cdot \pi} \quad \& \quad R = \\ &= 1.10 \cdot 10^{-6} \cdot \Omega \cdot \text{m} \cdot \frac{4 \cdot 3 \cdot \text{m}}{(3.57 \cdot 10^{-3} \cdot \text{m})^2 \cdot \pi} \quad \& \quad \end{aligned}$$

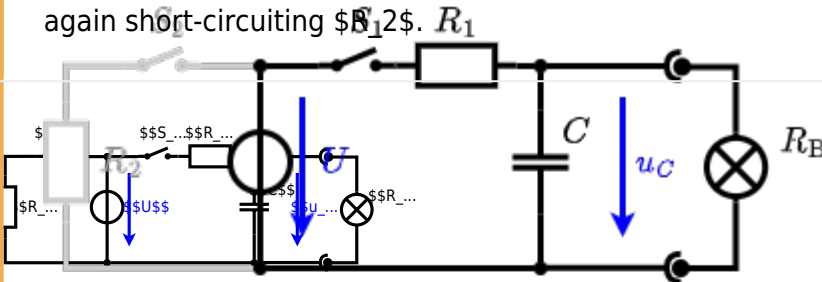
**Exercise E4 Charging Capacitors**  
**(written test, approx. 16 % of a 60-minute written test, WS2022)**

The circuit (with the light bulb) also consists of a DC voltage source  $U = 12 \text{ V}$ , a resistor  $R_1 = 20 \text{ }\Omega$ , a capacitor  $C = 100 \text{ }\mu\text{F}$ , and a light bulb  $R_B = 5 \text{ }\Omega$ . The switch  $S_1$  is closed, the voltage across the capacitor is again  $0 \text{ V}$  at the moment  $t_0 = 0 \text{ s}$  when the switch  $S_2$  is closed. Calculate the voltage  $u_c(t_2)$  across the capacitor at  $t_2 = 1 \text{ ms}$  after closing the switch.

**Solution:** To solve this, first create an equivalent linear voltage source from  $U$ ,  $R_1$ , and  $R_B$ .

$$\begin{aligned} \Delta U &= U \cdot \frac{R_B}{R_1 + R_B} = 12 \text{ V} \cdot \frac{5 \text{ }\Omega}{20 \text{ }\Omega + 5 \text{ }\Omega} = 2 \text{ V} \end{aligned}$$

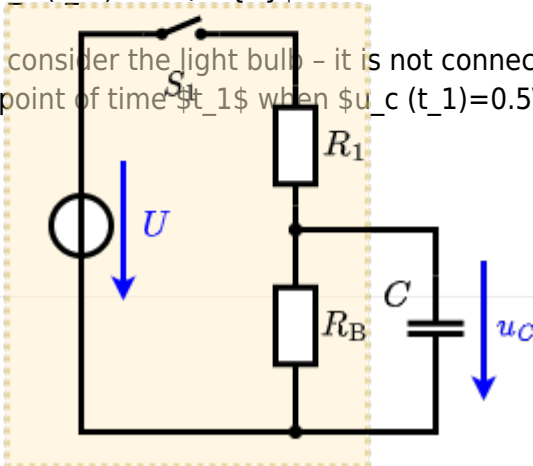
On an alternative view, one can try to create an equivalent linear voltage source again. Then, the internal resistance is given by substituting the ideal voltage source is again short-circuiting  $R_B$ .



The circuit contains a voltage source  $U = 12 \text{ V}$ , a switch  $S_1$ , a resistor of  $R_1 = 20 \text{ }\Omega$  and a capacitor of  $C = 100 \text{ }\mu\text{F}$ . The switch  $S_2$  to an additional consumer  $R_B$  will be considered to be open for the first tasks. At the moment  $t_0 = 0 \text{ s}$  the switch  $S_1$  is closed, the voltage across the capacitor is  $u_c(t_0) = 0 \text{ V}$ .

.. First do not consider the light bulb - it is not connected to the RC circuit. Calculate the point of time  $t_1$  when  $u_c(t_1) = 0.5 \cdot U$ .

**Solution**



An equivalent linear voltage source can be given with  $U_s$ ,  $R_1$ , and  $R_B$  as seen in yellow.

Therefore, the voltage of the equivalent linear voltage source is:  $U_s = U \cdot \frac{R_B}{R_1 + R_B} = \frac{1}{2} \cdot U$  The internal resistance is given by substituting the ideal voltage source with its resistance ( $R = 0 \Omega$ , short-circuit).

$$R_i = R_1 \parallel R_B = 10 \Omega$$

$$u_c(t) = U_s \cdot (1 - e^{-t/(R_i \cdot C)}) = \frac{1}{2} \cdot U \cdot (1 - e^{-t/(10 \Omega \cdot 100 \mu F)})$$

The following formula describes the time course of  $u_c(t)$  which has to be  $u_c(t_1) = 0.5 \cdot U$ :  

$$u_c(t) = U \cdot (1 - e^{-t/\tau}) = 0.5 \cdot U$$
 It has to be rearranged to  $(1 - e^{-t/\tau}) = 0.5 \implies e^{-t/\tau} = 0.5 \implies t/\tau = \ln(0.5) \implies t = \tau \cdot \ln(0.5)$



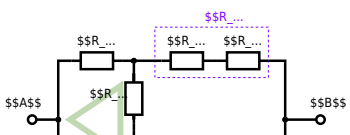
**Exercise E1 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)**

The following shall be simplified to a single resistor  $R_{eq}$  and the voltage  $U_{AB}$  across it.  $R_1 = 200 \Omega$ ,  $R_2 = R_3 = 150 \Omega$ ,  $R_4 = 100 \Omega$ ,  $R_5 = 100 \Omega$ ,  $R_6 = 100 \Omega$ ,  $R_7 = 100 \Omega$ ,  $R_8 = 100 \Omega$ ,  $R_9 = 100 \Omega$ ,  $R_{10} = 100 \Omega$ ,  $R_{11} = 100 \Omega$ ,  $R_{12} = 100 \Omega$ ,  $R_{13} = 100 \Omega$ ,  $R_{14} = 100 \Omega$ ,  $R_{15} = 100 \Omega$ ,  $R_{16} = 100 \Omega$ ,  $R_{17} = 100 \Omega$ ,  $R_{18} = 100 \Omega$ ,  $R_{19} = 100 \Omega$ ,  $R_{20} = 100 \Omega$ ,  $R_{21} = 100 \Omega$ ,  $R_{22} = 100 \Omega$ ,  $R_{23} = 100 \Omega$ ,  $R_{24} = 100 \Omega$ ,  $R_{25} = 100 \Omega$ ,  $R_{26} = 100 \Omega$ ,  $R_{27} = 100 \Omega$ ,  $R_{28} = 100 \Omega$ ,  $R_{29} = 100 \Omega$ ,  $R_{30} = 100 \Omega$ ,  $R_{31} = 100 \Omega$ ,  $R_{32} = 100 \Omega$ ,  $R_{33} = 100 \Omega$ ,  $R_{34} = 100 \Omega$ ,  $R_{35} = 100 \Omega$ ,  $R_{36} = 100 \Omega$ ,  $R_{37} = 100 \Omega$ ,  $R_{38} = 100 \Omega$ ,  $R_{39} = 100 \Omega$ ,  $R_{40} = 100 \Omega$ ,  $R_{41} = 100 \Omega$ ,  $R_{42} = 100 \Omega$ ,  $R_{43} = 100 \Omega$ ,  $R_{44} = 100 \Omega$ ,  $R_{45} = 100 \Omega$ ,  $R_{46} = 100 \Omega$ ,  $R_{47} = 100 \Omega$ ,  $R_{48} = 100 \Omega$ ,  $R_{49} = 100 \Omega$ ,  $R_{50} = 100 \Omega$ .

Solution

$$R_{eq} = 132.8 \Omega$$

Now a wye-delta transformation is necessary.



Since  $R_2=R_3$  and based on the equations for the transformation, the transformed  $R_Y$  is given as:

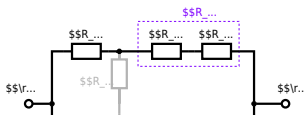
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

The equivalent resistor is given by a parallel configuration of resistors in series:

$$R_{\text{eq}} = R_Y + (R_Y + R_1 + R_1) \parallel (R_Y + R_2) \parallel R_{\text{eq}} = 33.33 \Omega + (33.33 \Omega + 400 \Omega) \parallel (33.33 \Omega + 100 \Omega)$$

1. The switch shall now be open. Calculate the equivalent resistance  $R_{\text{eq}}$  between  $A$  and  $B$ .

Solution



The equivalent resistor is given by a parallel configuration of resistors in series:

$$R_{\text{eq}} = (R_2 + R_1 + R_1) \parallel (R_2 + R_2) \parallel R_{\text{eq}} = (100 \sim \Omega + 200 \sim \Omega + 200 \sim \Omega) \parallel (100 \sim \Omega + 100 \sim \Omega) \parallel R_{\text{eq}} = \{500 \sim \Omega \cdot 200 \sim \Omega\} \over {500 \sim \Omega + 200 \sim \Omega}$$

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