

# Exam Winter Semester 2022

## Student Group

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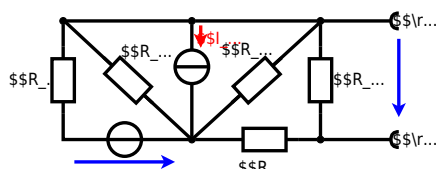
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**Exercise E5 Equivalent linear Source  
(written test, approx. 14 % of a 60-minute written test, WS2022)**

The circuit in the following has to be simplified.  
Result

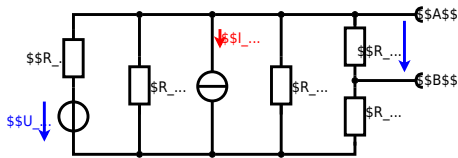
$$\begin{aligned} U_{\text{rs}} &= U_{\text{AB}} = 4.5 \text{ V} \\ R_{\text{i}} &= R_{\text{AB}} \\ &= 6 \Omega \end{aligned}$$



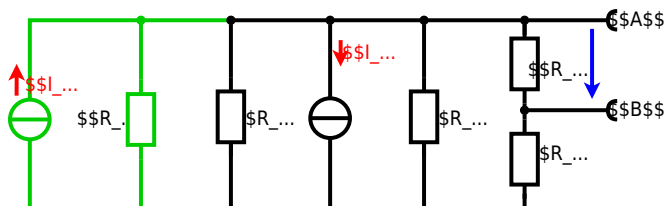
Calculated the internal resistance  $R_{\text{i}}$  and the source voltage  $U_{\text{rs}}$  of an equivalent linear voltage source on the connectors  $\text{A}$  and  $\text{B}$ . 
$$\begin{aligned} R_1 &= 5.0 \Omega, & U_2 &= 6.0 \text{ V}, & R_3 &= 10 \Omega, & I_4 &= 4.2 \text{ A}, & R_5 &= 10 \Omega, \\ & & & & R_6 &= 7.5 \Omega, & R_7 &= 15 \Omega \end{aligned}$$
 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  $I_4$ :

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

$$I_{24} = I_2 - I_4 = \frac{U_2}{R_1} - I_4$$

The resulting circuit can again be transformed:



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

$$U_{24} = I_{24} \cdot R_{67}$$

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

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

$$U_{AB} = \left( \frac{6.0 \text{ V}}{5.0 \Omega} \right) - 4.2 \text{ A} \cdot 15 \Omega \cdot 2.5 \Omega \cdot \frac{1}{7.5 \Omega + 15 \Omega + 2.5 \Omega}$$

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

**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 the refrigeration system. The circuit has a resistance of  $10 \Omega$  at  $25^\circ \text{C}$  and  $2.5 \Omega$  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  $-40^\circ \text{C}$ .

$$R_{25} = 10 \Omega$$

The power transfer is  $P = U \cdot I = \frac{U^2}{R}$  and  $Q = P \cdot t$ . Therefore, a solution is to use a heat pump.

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 E9 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the complex power  $\underline{S}$  and the real power  $P$  in a circuit with the following components.  $\underline{U}$  and  $\underline{X}_L$  shall be given.

After analysis, the full bridge network can be simplified to a series circuit with a voltage source  $\underline{U}$  and an inductor  $\underline{X}_L$  and a capacitor  $\underline{X}_C$ .

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

Solution  
$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \angle 0^\circ}{j4.68 + 0.24 - j2} = \frac{50 \angle 0^\circ}{-j1.72 + 0.24} = \frac{50 \angle 0^\circ}{1.72 \angle -110.7^\circ} = 29.07 \angle 110.7^\circ \text{ A}$$
  
The voltage over the voltage source is  $\underline{U} = 50 \angle 0^\circ \text{ V}$  and the current is  $\underline{I} = 29.07 \angle 110.7^\circ \text{ A}$ .  
The resulting complex power is  $\underline{S} = \underline{U} \cdot \underline{I}^* = 50 \angle 0^\circ \cdot 29.07 \angle -110.7^\circ = 1453.5 \angle -110.7^\circ \text{ VA}$ .  
The real power is  $P = \text{Re}(\underline{S}) = 1453.5 \cdot \cos(-110.7^\circ) = -468.5 \text{ W}$ .  
The reactive power is  $Q = \text{Im}(\underline{S}) = 1453.5 \cdot \sin(-110.7^\circ) = -1370.5 \text{ var}$ .  
The phase angle  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{\text{Im}(\underline{S})}{\text{Re}(\underline{S})}\right) = \arctan\left(\frac{-1370.5}{-468.5}\right) = 71.1^\circ$ .

### Exercise E13 Complex Impedance Circuit (written test, approx. 15 % of a 60-minute written test, WS2022)

2. Calculate the complex power  $\underline{S}$  in a circuit with the following components.  $\underline{U}$  and  $\underline{Z}$  shall be given.  
Result  $\underline{S} = 10.2 - j3.1 \text{ VA}$

Solution  
.. Draw the circuit diagram of the given circuit.  
The circuit consists of a voltage source  $\underline{U} = 3.0 \angle 0^\circ \text{ V}$  and an inductor  $\underline{Z}_L = j330 \mu\text{H}$  and a capacitor  $\underline{Z}_C = -j0.22 \mu\text{F}$ , all in series.

Result  
.. Draw the circuit diagram of the given circuit.  
The circuit consists of a voltage source  $\underline{U} = 3.0 \angle 0^\circ \text{ V}$  and an inductor  $\underline{Z}_L = j330 \mu\text{H}$  and a capacitor  $\underline{Z}_C = -j0.22 \mu\text{F}$ , all in series.  
The total impedance is  $\underline{Z} = j330 \mu\text{H} - j0.22 \mu\text{F} = j(330 - 0.22) \mu\text{H} = j329.78 \mu\text{H} = j0.32978 \text{ mH}$ .  
The current is  $\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{3.0 \angle 0^\circ}{j0.32978} = 9.1 \angle -90^\circ \text{ A}$ .  
The complex power is  $\underline{S} = \underline{U} \cdot \underline{I}^* = 3.0 \angle 0^\circ \cdot 9.1 \angle 90^\circ = 27.3 \angle 90^\circ = j27.3 \text{ VA}$ .  
The real power is  $P = \text{Re}(\underline{S}) = 0 \text{ W}$ .  
The reactive power is  $Q = \text{Im}(\underline{S}) = 27.3 \text{ var}$ .





**Exercise E11 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  $R_1 = 1.00 \text{ k}\Omega$  and a capacitor with a capacitance of  $C_1 = 40 \text{ nF}$ . The voltage across the resistor is  $U_{R_1} = 100 \text{ V}$  at a frequency of  $f = 4 \text{ MHz}$ . Calculate the absolute value of the impedance of the capacitor  $Z_C$  and the total impedance  $Z_{\text{total}}$  of the circuit.

**Solution**

$$Z_C = \frac{1}{j\omega C_1} = \frac{1}{j \cdot 2\pi \cdot 4 \cdot 10^6 \cdot 40 \cdot 10^{-9}} = -j10 \text{ }\Omega$$

$$Z_{\text{total}} = R_1 + Z_C = 1.00 \text{ k}\Omega - j10 \text{ }\Omega$$

A series circuit means that the current is constant on every component.  
 The equivalent impedance for  $R$  and  $Z_C$  combined is given by  $Z_{\text{total}} = R + Z_C$ .  
 Parallel circuit means that the voltage is the same on  $R_1$  and  $Z_C$ .  

$$\frac{1}{Z_{\text{total}}} = \frac{1}{R_1 + Z_C} = \frac{1}{R_1 - j10} = \frac{R_1 + j10}{(R_1 - j10)(R_1 + j10)} = \frac{R_1 + j10}{R_1^2 + 10^2}$$

Therefore, the resulting current of the parallel circuit is given as:  

$$I_{\text{total}} = \frac{U_{R_1}}{Z_{\text{total}}} = \frac{100 \text{ V}}{1.00 \text{ k}\Omega - j10 \text{ }\Omega} = \frac{100 \text{ V} \cdot (1.00 \text{ k}\Omega + j10 \text{ }\Omega)}{(1.00 \text{ k}\Omega)^2 + (10 \text{ }\Omega)^2} = \frac{100 \text{ V} \cdot (1.00 \text{ k}\Omega + j10 \text{ }\Omega)}{1.01 \text{ M}\Omega}$$

**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  $180 \text{ }^\circ\text{C}$ . The electric power dissipation (= heat flow) of  $P = 40 \text{ W}$  is necessary.  
 Calculate the current  $I$  and the voltage  $U$  for heating elements.  
 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  $d = 3.57 \text{ mm}$ .  
 Calculate the resistance  $R$  of the heating element.

**Solution**

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

$$R = \rho \cdot \frac{l}{A} = \rho \cdot \frac{l}{\pi \cdot \left(\frac{d}{2}\right)^2} = 1.10 \cdot 10^{-6} \cdot \frac{3}{\pi \cdot \left(\frac{3.57 \cdot 10^{-3}}{2}\right)^2} = 0.00013 \text{ }\Omega$$

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

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

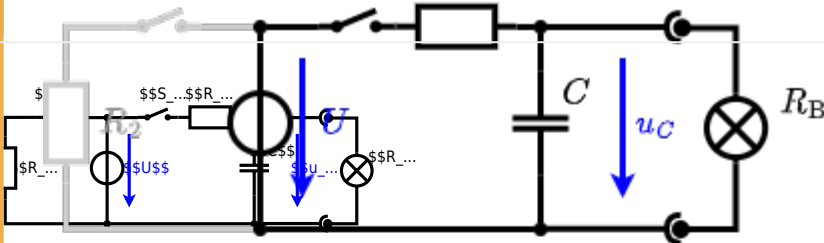
**Exercise E7 Charging Capacitors**  
 (written test, approx. 16 % of a 60-minute written test, WS2022)

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 combination.

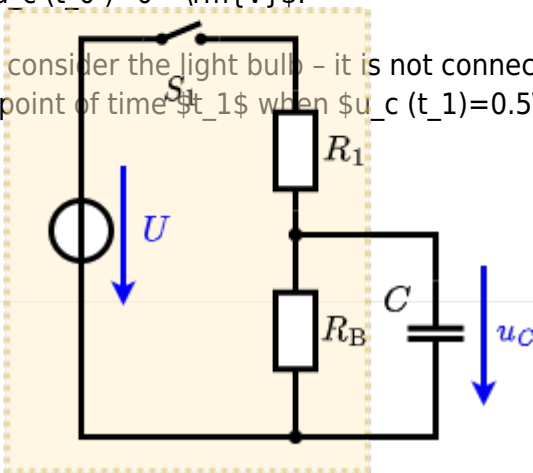
On an alternative view, one can try to create an equivalent linear voltage source again. Then, the internal resistance is given by substituting the ideal voltage source is again short-circuiting  $S_1$ .



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 ( $R_1 = 0 \Omega$ , short-circuit).

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

$$u_c(t) = U_s \cdot (1 - e^{-t/(R_1 \cdot C)}) = \frac{1}{2} \cdot U \cdot (1 - e^{-t/(10 \cdot 100 \mu F)})$$

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 simplified to a one-port network with  $R_{eq}$  and the voltage  $U_{oc}$  between terminals A and B.

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:

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

**Exercise E6 Equivalent linear Source  
(written test, approx. 14 % of a 60-minute written test, WS2022)**

The circuit in the following has to be simplified.  
Result

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



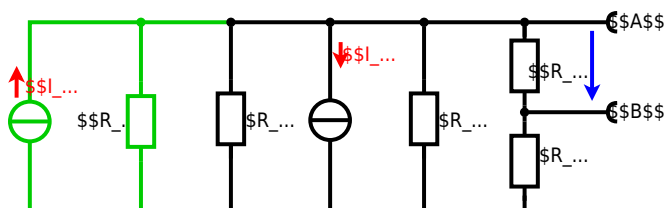
Calculate the internal resistance  $R_{in}$  and the source voltage  $U_{s}$  of an equivalent linear voltage source on the connectors  $A$  and  $B$ .  $R_1=5.0 \Omega$ ,  $U_2=6.0 \text{ V}$ ,  $R_3=10 \Omega$ ,  $I_4=4.2 \text{ A}$ ,  $R_5=10 \Omega$ ,  $R_6=7.5 \Omega$ ,  $R_7=15 \Omega$ . Use equivalent 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:

$$U_{24} = I_{24} \cdot (R_6 + R_7)$$

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

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. The diagram explains the effect of resistance on refrigeration systems. The refrigerant 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  $-40^\circ\text{C}$ .

$$R_{25} = 10 \Omega$$

The power transfer is  $P = U \cdot I$  and  $I = \frac{U}{R}$ . Therefore, a solution is to heat 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.

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

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

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

**Exercise E10 Analyzing complex Impedances**  
 (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the complex power  $\underline{S}$  and the real power  $P$  in the circuit shown through the components.  $\underline{U}$  and  $\underline{X}_L$  shall be given.

After analysis, the full bridge circuit can be simplified to a series circuit with a voltage source  $\underline{U}$  and a load impedance  $\underline{Z}$ . The load impedance is  $\underline{Z} = (2 + j4) \parallel (3 - j4) + 5j$ .

Solution  
 .. Calculate the physical values of the load components.  
 Solution  $R = 2 \Omega$ ,  $X_L = 4 \Omega$ ,  $X_C = -4 \Omega$ ,  $X_L = 5 \Omega$

Solution  

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \angle 0^\circ}{(2 + j4) \parallel (3 - j4) + 5j} = \frac{50 \angle 0^\circ}{2.4 - j0.68} = 20.8 \angle 15.5^\circ \text{ A}$$
 The voltage across the load is  $\underline{U}_L = \underline{I} \cdot \underline{Z} = 104 \angle 15.5^\circ \text{ V}$ .  
 The real power is  $P = \text{Re}\{\underline{S}\} = \text{Re}\{\underline{I} \cdot \underline{U}_L^*\} = 20.8 \cdot 104 \cdot \cos(15.5^\circ) = 2100 \text{ W}$ .  
 The reactive power is  $Q = \text{Im}\{\underline{S}\} = \text{Im}\{\underline{I} \cdot \underline{U}_L^*\} = 20.8 \cdot 104 \cdot \sin(15.5^\circ) = 600 \text{ var}$ .  
 The phase angle  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{\text{Im}\{\underline{S}\}}{\text{Re}\{\underline{S}\}}\right) = \arctan\left(\frac{600}{2100}\right) = 15.5^\circ$ .

**Exercise E14 Complex Impedance Circuit**  
 (written test, approx. 15 % of a 60-minute written test, WS2022)

2. Calculate the circuit impedance  $\underline{Z}$  for a source  $\underline{u}(t) = 3.0 \cdot \sin(2\pi \cdot 15 \cdot t) \text{ V}$ . The circuit consists of a voltage source  $\underline{u}(t) = 3.0 \cdot \sin(2\pi \cdot 15 \cdot t) \text{ V}$ , a resistor of  $1 \text{ k}\Omega$ , an inductor of  $330 \mu\text{H}$ , and a capacitor of  $0.22 \mu\text{F}$ , all in series.

Solution  
 Result  $\underline{Z} = 1.197 - j3.1 \text{ k}\Omega$

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

Solution  

$$\underline{Z} = R + j\omega L - j\omega C = 1000 + j2\pi \cdot 15 \cdot 330 \cdot 10^{-6} - j2\pi \cdot 15 \cdot 0.22 \cdot 10^{-6} = 1.197 - j3.1 \text{ k}\Omega$$





**Exercise E12 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 inductor with an inductance of  $L_1 = 4.7 \text{ }\mu\text{H}$ . The circuit is connected to 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

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

$$|Z| = \sqrt{1.00^2 + (2\pi \cdot 4 \cdot 10^6 \cdot 4.7 \cdot 10^{-6} - \frac{1}{2\pi \cdot 4 \cdot 10^6 \cdot 40 \cdot 10^{-9}})^2}$$

A series circuit means that the current is constant on every component.  
 The equivalent impedance for  $R$  and  $L$  combined is given by  $Z = R + jX_L$   
 Parallel circuit means that the voltage is the same on  $R$  and  $C$ .  

$$\frac{1}{Z} = \frac{1}{R} + \frac{1}{jX_C}$$
  

$$Z = \frac{R \cdot jX_C}{R + jX_C}$$
  

$$|Z| = \frac{R \cdot X_C}{\sqrt{R^2 + X_C^2}}$$
  
 Therefore, the resulting current of the parallel circuit is given as:  

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

$$I = \frac{10 \cdot \sqrt{1.00^2 + (2\pi \cdot 4 \cdot 10^6 \cdot 40 \cdot 10^{-9})^2}}{1.00 \cdot 2\pi \cdot 4 \cdot 10^6 \cdot 40 \cdot 10^{-9}}$$
  
 Back to the first formula:  

$$|Z| = \frac{R \cdot X_C}{I} = \frac{1.00 \cdot 2\pi \cdot 4 \cdot 10^6 \cdot 40 \cdot 10^{-9}}{0.0001}$$

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

2. For heating elements used to heat the oven in a domestic use electric oven, a power dissipation (= heat flow) of  $P = 40 \text{ W}$  is necessary. Calculate the current  $I$  needed to operate the heating elements.  
 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

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

$$R = \rho \cdot \frac{l}{A} = \rho \cdot \frac{l}{\pi \cdot \left(\frac{d}{2}\right)^2}$$

$$I = \sqrt{\frac{P \cdot \pi \cdot \left(\frac{d}{2}\right)^2}{\rho \cdot l}}$$

$$I = \sqrt{\frac{40 \cdot \pi \cdot \left(\frac{3.57 \cdot 10^{-3}}{2}\right)^2}{1.10 \cdot 10^{-6} \cdot 3}}$$

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

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

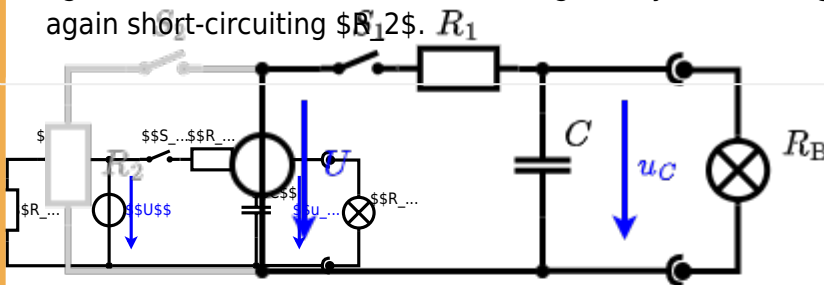
**Exercise E8 Charging Capacitors**  
**(written test, approx. 16 % of a 60-minute written test, WS2022)**

The circuit (with the light bulb) is a series of  $R_1$  and  $R_2$  and a capacitor  $C$  as shown in Figure 8.5. Initially the switch  $S_1$  is open. 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 combination.

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  $S_2$ .

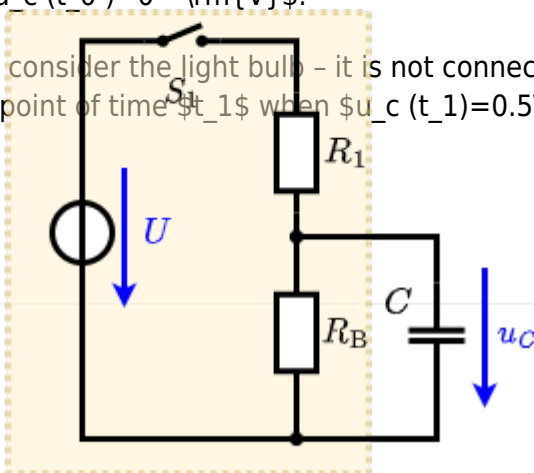


The circuit contains a voltage source  $U = 12 \text{ V}$ , a switch  $S_1$ , a resistor of  $R_1 = 20 \Omega$  and a capacitor of  $C = 100 \mu\text{F}$ .

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 E4 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)**

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

Solution

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

Now a wye-delta transformation is necessary.

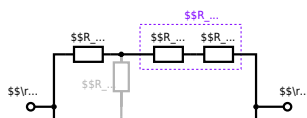


Since  $R_2=R_3$  and based on the equations for the transformation, the transformed  $R_Y$  is given as: 
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \text{ } \Omega)^2}{3 \cdot 100 \text{ } \Omega} = \frac{1}{3} \cdot 100 \text{ } \Omega = 33.33 \text{ } \Omega$$

The equivalent resistor is given by a parallel configuration of resistors in series: 
$$R_{\text{eq}} = R_Y + (R_Y + R_1 + R_1) \parallel (R_Y + R_2) \parallel R_{\text{eq}} = 33.33 \text{ } \Omega + (33.33 \text{ } \Omega + 400 \text{ } \Omega) \parallel (33.33 \text{ } \Omega + 100 \text{ } \Omega)$$

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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