

# ws2022\_exam

## Student Group

First Name	Surname	Matrikel Nr.

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

A heating element made of solid nichrome wire with a diameter of  $1.80 \text{ mm}$  is used for electric power dissipation (= heat flow) of  $P=40 \text{ W}$  is necessary.

Determine the current  $I$  linked to the operating voltage for heating elements.

The Nichrome wire has a resistivity of  $1.10 \cdot 10^{-6} \text{ } \Omega \cdot \text{m}$ .

The heating element is  $3 \text{ m}$  long and has a diameter of  $3.57 \text{ mm}$ .

∴ Calculate the resistance  $R$  of the heating element.

Solution

$$\begin{aligned} P &= U \cdot I = R \cdot I^2 \quad \rightarrow \quad I = \sqrt{\frac{P}{R}} \\ &= \sqrt{\frac{40 \text{ W}}{0.33 \text{ } \Omega}} \end{aligned}$$

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

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**Exercise E2 Temperature-dependent Resistance**

**(written test, approx. 6 % of a 60-minute written test, WS2022)**

2. A refrigerator exhibits a temperature coefficient of resistance in a refrigeration system. The refrigerator has a resistance of  $10 \text{ k}\Omega$  at  $25^\circ\text{C}$ . 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 thermal sensor at  $-40^\circ\text{C}$ .

The power transfer resistor  $P$  is a part of the circuit and generates heat. Therefore, a solution is to use a heat sink 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.

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

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

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

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

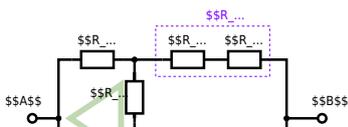
**Exercise E3 Pure Resistor Network Simplification**  
**(written test, approx. 13 % of a 60-minute written test, WS2022)**

The following shall be solved at 100% of the given points. The result shall be given.

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:

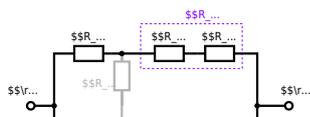
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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

$$R_{\text{eq}} = R_Y + (R_Y + R_1 + R_1) \parallel (R_Y + R_2) \parallel R_4$$

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

Solution



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

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

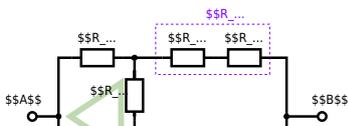
**Exercise E1 Pure Resistor Network Simplification**  
 (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be solved with  $R_1 = 200 \Omega$ ,  $R_2 = R_3 = 100 \Omega$  and the source  $B = 10 \text{ V}$ .  
 Result given:  $R_{\text{eq}} = 132.8 \Omega$ .

Solution

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

Now a wye-delta transformation is necessary.

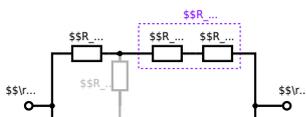


Since  $R_2=R_3$  and based on the equations for the transformation, the transformed  $R_Y$  is given as: 
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

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

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

Solution



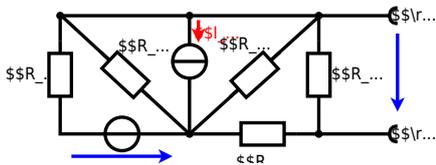
The equivalent resistor is given by a parallel configuration of resistors in series:

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

### 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

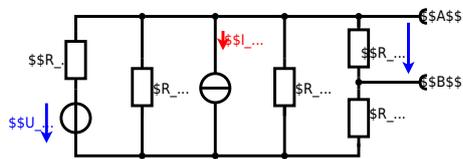
$$U_{\text{s}} = U_{\text{AB}} = 4.5 \text{ V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \Omega$$



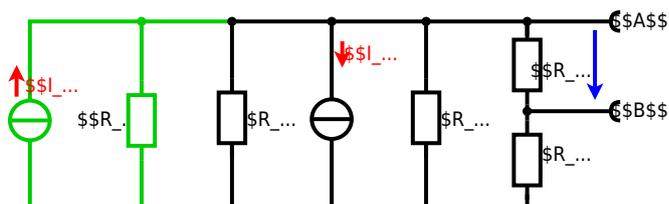
Calculate the internal resistance  $R_i$  and the source voltage  $U_s$  of an equivalent linear voltage source on the connectors A and B.  $R_1=5.0 \Omega$ ,  $U_2=6.0 \text{ V}$ ,  $R_3=10 \Omega$ ,  $I_4=4.2 \text{ A}$ ,  $R_5=10 \Omega$ ,  $R_6=7.5 \Omega$ ,  $R_7=15 \Omega$  Use equivalent sources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

Solution

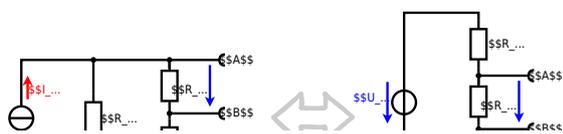
The best thing is to re-think the wiring like rubber bands and adjust them:



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: 
$$U_{24} = I_{24} \cdot R_{135}$$

$$U_{24} = U_2 \cdot I_{24} \quad \&= \left( \frac{U_2}{R_1} - I_4 \right) \cdot R_1 \parallel R_3 \parallel R_5$$

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:

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

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

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

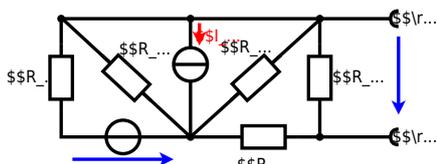
with  $R_1 \parallel R_3 \parallel R_5 = 5\Omega \parallel 10\Omega \parallel 10\Omega = 5\Omega \parallel 5\Omega = 2.5\Omega$ :

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

### 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

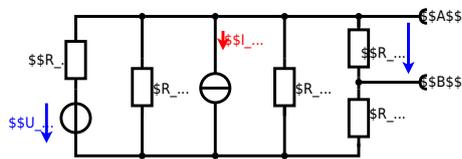
$$U_s = U_{AB} = 4.5\text{V} \quad R_i = R_{AB} = 6\Omega$$



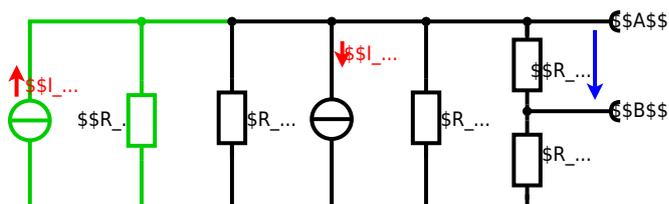
Calculated the internal resistance  $R_{\text{int}}$  and the source voltage  $U_{\text{oc}}$  of an equivalent linear voltage source on the connectors  $\text{A}$  and  $\text{B}$ .  $R_1=5.0 \text{ }\Omega$ ,  $U_2=6.0 \text{ V}$ ,  $R_3= 10 \text{ }\Omega$ ,  $I_4=4.2 \text{ A}$ ,  $R_5=10 \text{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

Solution

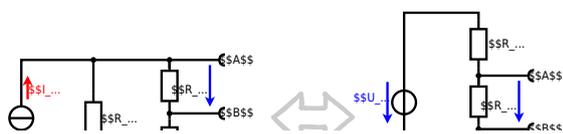
The best thing is to re-think the wiring like rubber bands and adjust them:



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: 
$$U_{24}$$

$$U_{AB} = R_{135} \cdot I_{24} = \left( \frac{U_2}{R_1} - I_4 \right) \cdot R_1 \parallel R_3 \parallel R_5$$

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:

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

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

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

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

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

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

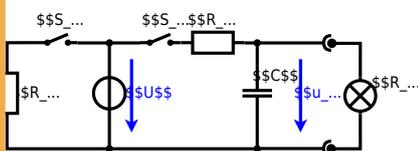
**Exercise E4 Charging Capacitors**  
 (written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit below is a RC circuit. It consists of a DC voltage source  $U$ , a resistor  $R_1$ , a resistor  $R_2$ , a capacitor  $C$ , and a switch  $S_1$ . The switch  $S_1$  is initially 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.

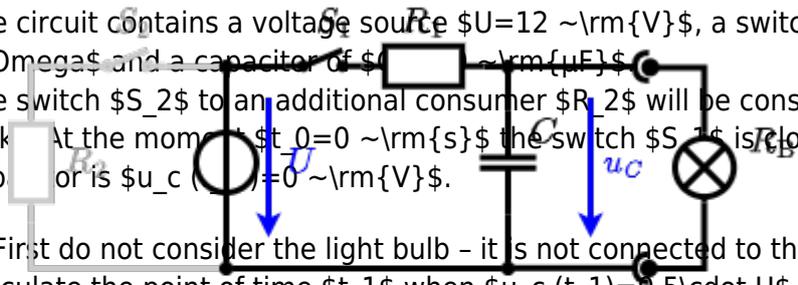
**Result:** To solve this, first create an equivalent linear voltage source from  $U$ ,  $R_1$ , and  $R_2$ .

**Solution:** The ideal voltage source  $U_{eq}$  is given by  $U_{eq} = \frac{U \cdot R_2}{R_1 + R_2}$  and the internal resistance  $R_{eq} = R_1 \parallel R_2$ .

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  $R_2$ .

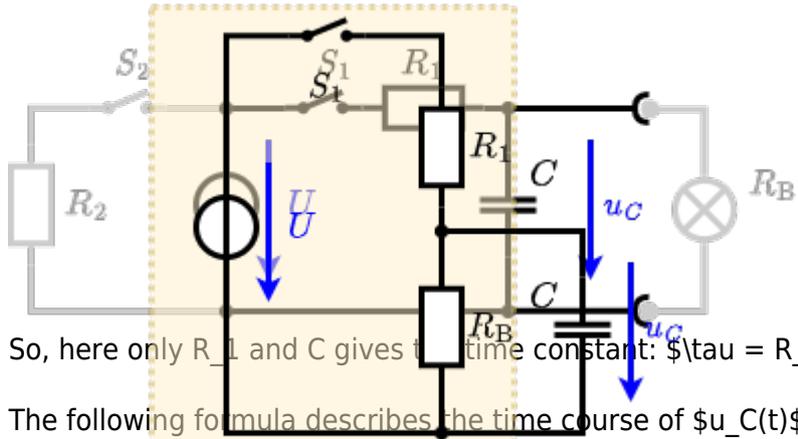
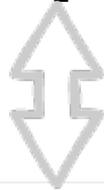


The circuit contains a voltage source  $U=12\text{ V}$ , a switch  $S_1$ , a resistor of  $R_1=20\text{ }\Omega$  and a capacitor of  $C=100\text{ }\mu\text{F}$ . The switch  $S_2$  to an additional consumer  $R_2$  will be considered to be open for the first task. At the moment  $t_0=0\text{ s}$  the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



So, here only  $R_1$  and  $C$  gives the time constant:  $\tau = R_1 \cdot C$

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  $(1 - e^{-t/\tau}) = 0.5$   
 An equivalent linear voltage source can be given with  $U_s$ ,  $R_1$  and  $R_B$  as seen in yellow:  

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

$$R_i = R_1 \parallel R_B = 10\text{ }\Omega$$

Therefore, the voltage of the equivalent linear voltage source is:  

$$u_c(t_2) = U_s \cdot (1 - e^{-t_2/(R_i \cdot C)}) = \frac{1}{2} \cdot U \cdot (1 - e^{-1\text{ ms}/(10\text{ }\Omega \cdot 100\text{ }\mu\text{F})})$$

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

The circuit (as shown in the figure) consists of a DC voltage source  $U=6\text{ V}$ , a resistor  $R_1=20\text{ }\Omega$ , a capacitor  $C=20\text{ }\mu\text{F}$  and a light bulb  $R_B=20\text{ }\Omega$ . 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  $R_B$ :  

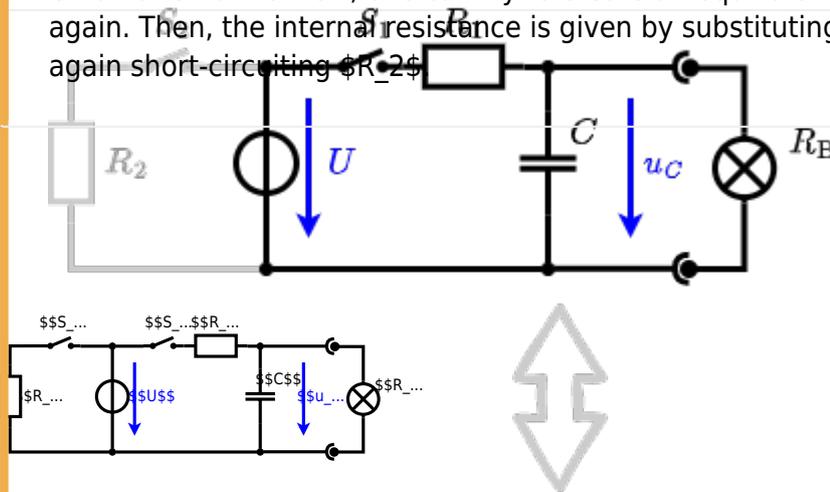
$$U_s = U \cdot \frac{R_B}{R_1 + R_B} = 3\text{ V}$$

$$R_i = R_1 \parallel R_B = 10\text{ }\Omega$$

Solution

The ideal voltage source is  $U = 12 \text{ V}$ . The internal voltage source is  $U_s = U \cdot \frac{R_B}{R_1 + R_B} = 6 \text{ V}$ . The internal resistance is  $R_i = R_1 \parallel R_B = 10 \text{ }\Omega$ .

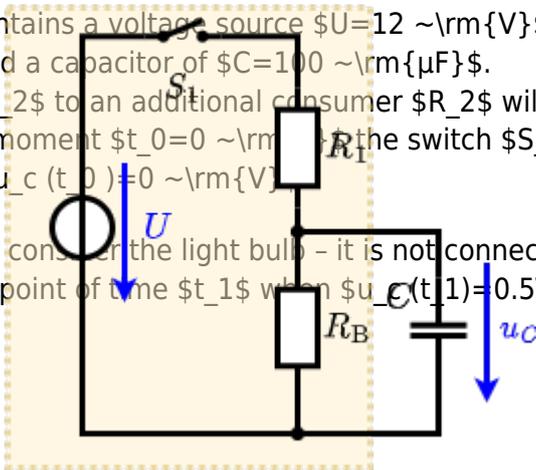
On an alternative view, one can try to create an equivalent linear voltage source again. Then, the internal resistance is given by substituting the ideal voltage source is again short-circuiting  $R_2$ .



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  $R_2$  will be considered to be open for the first asks. At the moment  $t_0 = 0$  the switch  $S_1$  is closed, the voltage across the capacitor is  $u_c(t_0) = 0$ .

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:  $U_s = U \cdot \frac{R_B}{R_1 + R_B} = 6 \text{ V}$ . The internal resistance is given by substituting the ideal voltage source with its resistance ( $R_i = 0 \text{ }\Omega$ , short-circuit).

$$u_c(t_2) = U_s \cdot (1 - e^{-t_2/(R_i \cdot C)}) = \frac{1}{2} \cdot U \cdot (1 - e^{-t_2/(10 \text{ }\Omega \cdot 100 \text{ }\mu\text{F})})$$

So, here only  $R_1$  and  $C$  gives the time constant:  $\tau = R_1 \cdot C$

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  $t$

$$(1 - e^{-t/\tau}) = 0.5 \implies e^{-t/\tau} = 0.5 \implies -t/\tau = \ln(0.5) \implies t = \tau \cdot \ln(0.5) \implies t = R_1 \cdot C \cdot \ln(0.5)$$

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

2. Given that the phasor voltage source  $\underline{U} = 50 \angle 0^\circ \text{ V}$  and the load impedance  $\underline{Z} = 50 \angle 90^\circ \Omega$  are connected in series through the components  $\underline{R}$  and  $\underline{X}_L$  shall be given.

After analysis, the full load impedance  $\underline{Z}$  can be extracted and the magnitude  $I$  in phase with the voltage  $\underline{U}$  is  $I = 0.24 \angle -90^\circ \text{ A}$ .

Solution  
.. Calculation of physical values of the load components.  
Solution  $\varphi = \arctan\left(\frac{-4.68}{0.24}\right) = -87.06^\circ$

Solution  
$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \angle 0^\circ \text{ V}}{209.96 \angle 90^\circ \Omega} = 0.24 \angle -90^\circ \text{ A}$$

The current  $I$  is  $0.24 \text{ A}$  and the phase angle is  $-90^\circ$ .  
The resulting impedance  $\underline{Z} = 209.96 \angle 90^\circ \Omega$ .  
Therefore, the component  $\underline{X}_L$  is  $4.68 \text{ mH}$  and the component  $\underline{R}$  is  $209.96 \Omega$ .  
Impedance  $\underline{Z} = \underline{R} + j\underline{X}_L = 209.96 + j4.68 \Omega$ .  
$$\varphi = \arctan\left(\frac{4.68}{209.96}\right) = 1.27^\circ$$
  
The phase angle  $\varphi$  is  $1.27^\circ$ .  
The phase angle  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{4.68}{209.96}\right) = 1.27^\circ$ .

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The phase angle  $\varphi$  is  $1.27^\circ$ .  
The phase angle  $\varphi$  can be calculated as  $\varphi = \arctan\left(\frac{4.68}{209.96}\right) = 1.27^\circ$ .

The absolute value of the impedance is  $Z = \sqrt{R^2 + (X_L - X_C)^2}$  with  $R = 5 \Omega$ ,  $X_L = \omega L = 2\pi \cdot 4 \text{ MHz} \cdot 100 \text{ nH} = 2.51 \text{ m}\Omega$  and  $X_C = \frac{1}{\omega C} = \frac{1}{2\pi \cdot 4 \text{ MHz} \cdot 40 \text{ nF}} = 0.99 \text{ m}\Omega$ .  
 The phase  $\phi$  is given by  $\phi = \arctan\left(\frac{X_L - X_C}{R}\right) = \arctan\left(\frac{2.51 - 0.99}{5}\right) = 0.28 \text{ rad} = 16^\circ$ .

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

At a series circuit with a resistor  $R_1 = 1 \text{ k}\Omega$ , a capacitor  $C_1 = 40 \text{ nF}$  and an inductor  $L_1 = 4.7 \text{ }\mu\text{H}$  in AC with a frequency of  $f = 450 \text{ kHz}$ .  
 Result:  $Z = 1.00 \text{ }\Omega$ ,  $\phi = 0^\circ$ .  
 A resistor  $R_1$  shall have the same absolute value of the impedance as a capacitor  $C_1 = 40 \text{ nF}$  at  $f_1 = 4 \text{ MHz}$ .

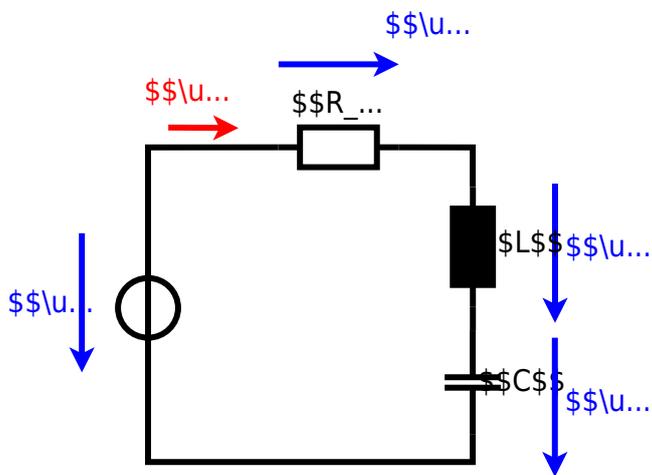
Solution  
 Solution:  $R_1 = 1.00 \text{ }\Omega$   
 Solution:  $R_2 = 10.0 \text{ }\Omega$

A series circuit means that the current is constant on every component.  
 The equivalent impedance for  $R$  and  $L$  combined is given by  $Z_{RL} = \sqrt{R^2 + X_L^2}$ .  
 Parallel circuit means that the voltage is the same on  $R_2$  and  $C_2$ .  
 $Z_{RC} = \frac{R_2 \cdot X_C}{\sqrt{R_2^2 + X_C^2}}$ . Since  $X_C$  is perpendicular to  $R_2$ , this can be simplified to  $Z_{RC} = \frac{R_2 \cdot X_C}{X_C} = R_2$ . (It has to, since  $R_2$  is perpendicular to  $X_C$ .)  
 Therefore, the resulting current of the parallel circuit is given as:  
 $I_{RC} = \frac{U}{Z_{RC}} = \frac{U}{R_2}$ .  
 This current has to be the same as the current through the series circuit:  
 $I_{RL} = \frac{U}{Z_{RL}} = \frac{U}{\sqrt{R^2 + X_L^2}} = \frac{U}{R_2}$   
 $\sqrt{R^2 + X_L^2} = R_2$   
 $R^2 + X_L^2 = R_2^2$   
 $R^2 + (\omega L)^2 = R_2^2$   
 $R^2 + (2\pi \cdot 450 \text{ kHz} \cdot 4.7 \text{ }\mu\text{H})^2 = R_2^2$   
 Back to the first formula:  $R_2 \cdot \frac{1}{2\pi f C} = \frac{R_2}{\sqrt{R^2 + X_L^2}}$   
 $R_2 \cdot \frac{1}{2\pi f C} = \frac{R_2}{R_2}$   
 $\frac{1}{2\pi f C} = 1$   
 $f = \frac{1}{2\pi C}$

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

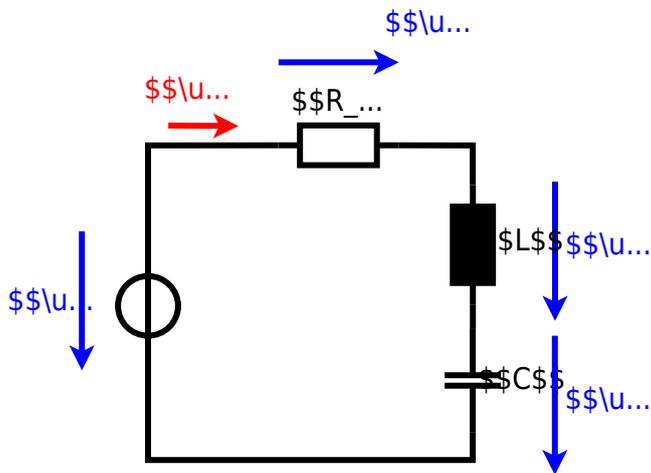












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