

Exam Winter Semester 2022

Student Group

First Name	Surname	Matrikel Nr.

Table of Contents

Exercise E1 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022)	3
Exercise E1 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)	6
Exercise E1 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)	7
Exercise E1 Complex Impedance Circuit (written test, approx. 15 % of a 60-minute written test, WS2022)	7
Exercise E1 Impedances at different Frequencies (written test, approx. 18 % of a 60-minute written test, WS2022)	10
Exercise E1 Resistance of a Wire by Resistivity (written test, approx. 6 % of a 60-minute written test, WS2022)	10
Exercise E1 Charging Capacitors (written test, approx. 16 % of a 60-minute written test, WS2022)	11
Exercise E1 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)	12
Exercise E4 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022)	14
Exercise E2 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)	18
Exercise E6 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)	19
Exercise E8 Complex Impedance Circuit (written test, approx. 15 % of a 60-minute written test, WS2022)	19
Exercise E7 Impedances at different Frequencies (written test, approx. 18 % of a 60-minute written test, WS2022)	22
Exercise E1 Resistance of a Wire by Resistivity (written test, approx. 6 % of a 60-minute written test, WS2022)	22
Exercise E5 Charging Capacitors (written test, approx. 16 % of a 60-minute written test,	

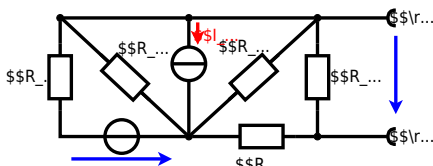
WS2022)	23
Exercise E3 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)	24

1

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

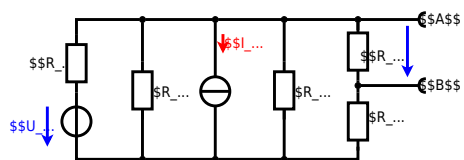
$$\begin{aligned} U_{\text{rs}} &= U_{\text{AB}} = 4.5 \text{ V} \\ R_{\text{i}} &= R_{\text{AB}} = 6 \Omega \end{aligned}$$



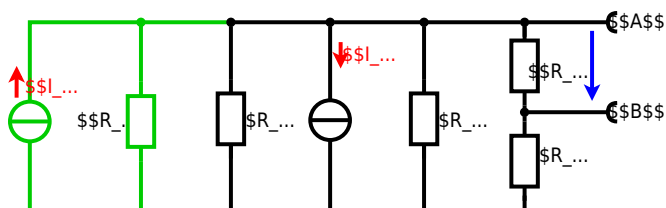
Calculated the internal resistance R_{i} and the source voltage U_{rs} of an equivalent linear voltage source on the connectors A and B .
$$\begin{aligned} R_1 &= 5.0 \Omega, \quad U_2 = 6.0 \text{ V}, \quad R_3 = 10 \Omega, \quad I_4 = 4.2 \text{ A}, \\ R_5 &= 10 \Omega, \quad R_6 = 7.5 \Omega, \quad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

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

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

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 E1 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)

2. According to question 2, the effect of resistance on power can be identified. The resistor is a thermistor with a resistance of $R_0 = 10\Omega$ at $T_0 = 25^\circ\text{C}$. 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°C .

Calculate the resistance of the thermistor at -40°C .

$$R = 6.5\text{k}\Omega$$

The power of the resistor is $P = \frac{U^2}{R}$ and $Q = P$. Therefore, a solution is to let 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.

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2) \quad | \quad \Delta T = T_{\text{end}} - T_{\text{start}} \\ R = 10\text{k}\Omega \cdot \left(1 + 0.01\text{K}^{-1} \cdot (-40^\circ\text{C} - 25^\circ\text{C}) + 71 \cdot 10^{-6}\text{K}^{-2} \cdot (-40^\circ\text{C} - 25^\circ\text{C})^2 \right)$$

Exercise E1 Analyzing complex Impedances

(written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the complex impedance $\underline{Z}$ of the circuit shown in the figure. The components R and X_L shall be given.

After analysis, the full bidimensional complex impedance has been extracted and written in the form $\underline{Z} = R + jX_L$ with $R = 4 \Omega$ and $X_L = 5 \Omega$.

.. Calculate the physical values of the two components.

Solution $R = 4 \Omega$ and $X_L = 5 \Omega$ and $\varphi = 51.9^\circ$

Solution

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \text{ V}}{4 + j5 \Omega} = \frac{50}{4 + j5} \text{ A}$$
 The voltage $U = 50 \text{ V}$ is the only voltage source in the circuit. The resulting impedance $\underline{Z} = 4 + j5 \Omega$ is the sum of the two impedances. Therefore, the component 4Ω is a resistor with the same absolute value 4Ω and the component $j5 \Omega$ is an inductor with the same absolute value 5Ω . The phase φ can be calculated as $\varphi = \arctan\left(\frac{X_L}{R}\right) = \arctan\left(\frac{5}{4}\right) = 51.9^\circ$. With the complex part $\underline{Z} = 4 + j5 \Omega$ and $\underline{U} = 50 \text{ V}$, the current $\underline{I}$ is $\underline{I} = \frac{50}{4 + j5} \text{ A}$. The phase φ can be calculated as $\varphi = \arctan\left(\frac{X_L}{R}\right) = \arctan\left(\frac{5}{4}\right) = 51.9^\circ$.

Exercise E1 Complex Impedance Circuit

(written test, approx. 15 % of a 60-minute written test, WS2022)

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

Solution $R = 4 \Omega$ and $X_L = 5 \Omega$ and $\varphi = 51.9^\circ$

Result

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

$$\underline{Z} = \frac{\underline{U}}{\underline{I}} = \frac{3.0 \text{ V}}{0.22 \text{ A}} = 13.6 \Omega$$

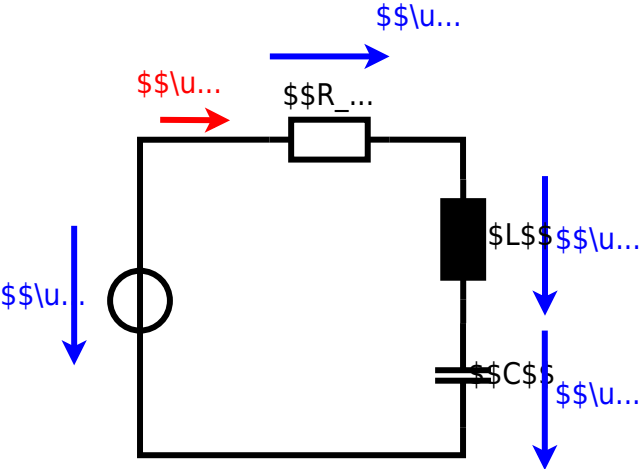
$$\underline{Z}_C = \frac{1}{j\omega C} = \frac{1}{j \cdot 2\pi \cdot 15 \text{ kHz} \cdot 0.22 \mu\text{F}} = -j1.59 \Omega$$

$$\underline{Z}_L = j\omega L = j \cdot 2\pi \cdot 15 \text{ kHz} \cdot 330 \mu\text{H} = j3.14 \Omega$$

$$\underline{Z} = \underline{Z}_L + \underline{Z}_C = j3.14 \Omega - j1.59 \Omega = j1.55 \Omega$$

$$\varphi = \arctan\left(\frac{X_L}{R}\right) = \arctan\left(\frac{1.55}{0}\right) = 90^\circ$$

With $\underline{Z} = j1.55 \Omega$ and $\underline{U} = 3.0 \text{ V}$, the current $\underline{I}$ is $\underline{I} = \frac{3.0}{j1.55} \text{ A} = -1.94 \text{ A}$. The phase φ can be calculated as $\varphi = \arctan\left(\frac{X_L}{R}\right) = \arctan\left(\frac{1.55}{0}\right) = 90^\circ$.



Exercise E1 Impedances at different Frequencies

(written test, approx. 18 % of a 60-minute written test, WS2022)

2. A series circuit with two resistors $R_1 = 1.00 \text{ k}\Omega$ and $R_2 = 10.0 \text{ k}\Omega$ is connected to an AC voltage source of $U = 230 \text{ V}$ at $f = 50 \text{ Hz}$. A capacitor $C = 40 \text{ nF}$ is connected in parallel with R_2 . Calculate the total impedance Z of the circuit.

Solution

$$Z = \sqrt{R_1^2 + \left(\frac{R_2}{\sqrt{1 + (\omega C R_2)^2}} \right)^2}$$

$$Z = \sqrt{1.00^2 + \left(\frac{10.0}{\sqrt{1 + (2\pi \cdot 50 \cdot 40 \cdot 10^{-9} \cdot 10.0 \cdot 10^3)^2}} \right)^2}$$

A series circuit means that the current is constant on every component.

The equivalent impedance for R_1 and R_2 combined is given by $Z = \sqrt{R_1^2 + R_2^2}$

Parallel circuit means that the voltage is the same on R_2 and C . $Z = \sqrt{R_2^2 + \left(\frac{1}{\omega C} \right)^2}$

Since $\omega C R_2 \gg 1$, the impedance of the parallel combination is $Z \approx R_2$. Therefore, the resulting current of the parallel circuit is given as:

$$I = \frac{U}{Z} = \frac{U}{\sqrt{R_1^2 + R_2^2}}$$

$$I = \frac{230 \text{ V}}{\sqrt{1.00^2 + 10.0^2}} = 22.9 \text{ mA}$$

$$Z = \frac{U}{I} = \frac{230 \text{ V}}{22.9 \text{ mA}} = 10.0 \text{ k}\Omega$$

$$R_3 \cdot I = X_C \cdot I \Rightarrow R_3 = X_C = \frac{1}{\omega C} = \frac{1}{2\pi \cdot 50 \cdot 40 \cdot 10^{-9}} = 79.6 \text{ k}\Omega$$

$$Z = \sqrt{R_1^2 + \left(\frac{R_2}{\sqrt{1 + (\omega C R_2)^2}} \right)^2} = \sqrt{1.00^2 + \left(\frac{10.0}{\sqrt{1 + (2\pi \cdot 50 \cdot 40 \cdot 10^{-9} \cdot 10.0 \cdot 10^3)^2}} \right)^2} = 10.0 \text{ k}\Omega$$

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 $d = 0.5 \text{ mm}$ and a length of $L = 3 \text{ m}$ is connected to a power supply of $U = 230 \text{ V}$. Calculate the power dissipation P of the heating element.

Result: The power dissipation $P = 40 \text{ W}$ is necessary.

Calculate the current I in 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 3 m long and has a diameter of 0.5 mm .

Calculate the resistance R of the heating element.

Solution

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

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

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

Exercise E1 Charging Capacitors

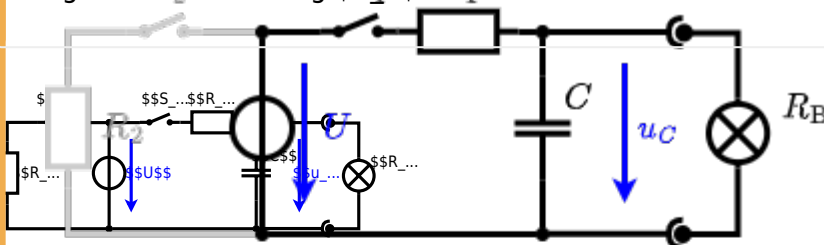
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit (without the light bulb) also is the circuit of a RC circuit. The capacitor is again short-circuited. The voltage across the capacitor is again 0 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 Hint: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

Solution The ideal voltage source $U = 12 \text{ V}$ is in series with the resistor $R_1 = 20 \Omega$. The voltage $u_c(t_2)$ 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 .

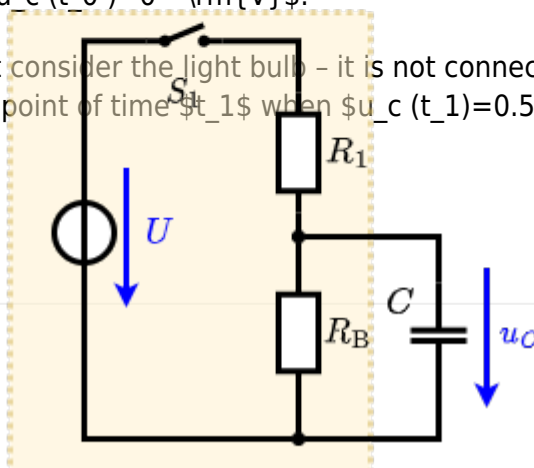


The circuit contains a voltage source $U = 12 \text{ V}$, a switch S_1 , a resistor of $R_1 = 20 \Omega$ and a capacitor of $C = 100 \mu\text{F}$.

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

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

$$u_c(t_2) = U_s \cdot (1 - e^{-t_2/(R_i \cdot C)}) = \frac{1}{2} \cdot U$$

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
$$(1 - e^{-t/\tau}) = 0.5$$

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

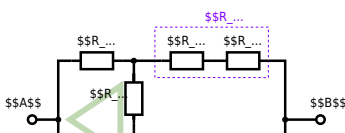
Exercise E1 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be simplified with $R_1 = 200 \Omega$, $R_2 = 100 \Omega$, $R_3 = 150 \Omega$, $R_4 = 100 \Omega$ and the voltage source $U = 10 \text{ V}$.
Result 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:

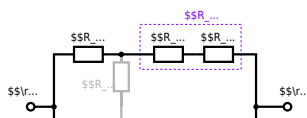
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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_{eq} between A and B .

Solution



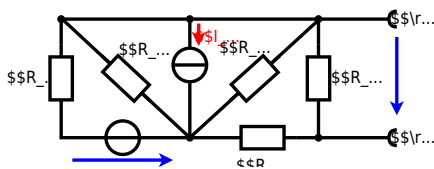
The equivalent resistor is given by a parallel configuration of resistors in series:

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

Exercise E4 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022)

The circuit in the following has to be simplified.
Result

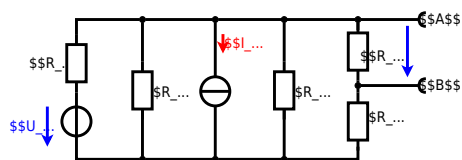
$$U_{\text{s}} = U_{\text{AB}} = 4.5 \, \text{V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \, \Omega$$



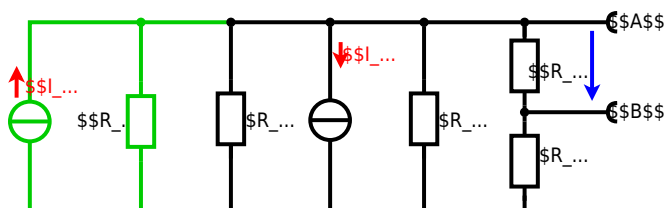
Calculate the internal resistance R_{int} and the source voltage U_s of an equivalent linear voltage source on the connectors A and B. $\begin{aligned} R_1 &= 5.0 \, \Omega, \quad U_2 = 6.0 \, \text{V}, \quad R_3 = 10 \, \Omega, \quad I_4 = 4.2 \, \text{A}, \\ R_5 &= 10 \, \Omega, \quad R_6 = 7.5 \,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

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

$$I_{24} = \frac{U_{24}}{R_6 + R_1 || R_3 || R_5} = \frac{(U_1 - U_4) \cdot R_1 || R_3 || R_5}{R_6 + R_1 || R_3 || R_5}$$

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

$$U_{AB} = U_{24} \cdot \frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} = \frac{(U_1 - U_4) \cdot R_7 \cdot R_1 || R_3 || R_5}{R_6 + R_7 + R_1 || R_3 || R_5}$$

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

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

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

2. According to question 2, the effect of temperature on the resistance of the thermistor is not linear. The thermistor has a resistance of $10 \text{ k}\Omega$ at 25°C and $6.5 \text{ k}\Omega$ at -40°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°C .

$$R = 6.5 \text{ k}\Omega \quad \text{at } -40^\circ\text{C}$$

The power transfered to the load is $P = \frac{U^2}{R}$ and $Q = P \cdot t$. Therefore, a solution is to use a heat exchanger to pre-heat the refrigeration system.

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

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2) \quad | \quad \Delta T = T_{\text{end}} - T_{\text{start}} \\ R = 10 \text{ k}\Omega \cdot \left(1 + 0.01 \text{ K}^{-1} \cdot (-40^\circ\text{C} - 25^\circ\text{C}) + 71 \cdot 10^{-6} \text{ K}^{-2} \cdot (-40^\circ\text{C} - 25^\circ\text{C})^2\right)$$

Exercise E6 Analyzing complex Impedances**(written test, approx. 14 % of a 60-minute written test, WS2022)**

2. Calculate the complex impedance $\underline{Z}$ of the circuit shown in the figure. The components $\underline{U}_R$ and $\underline{U}_L$ shall be given.

After analysis, the full bidimensional complex impedance has been extracted and the magnitude in phase (in $^\circ$) is $\varphi = 27.06^\circ$ and the magnitude in Ω is 19.8Ω .

.. Calculate the physical value of the two components.

Solution $\underline{R} = 10 \Omega$ and $\underline{L} = 1.07 \text{ mH}$ and $\underline{C} = 22 \text{ nF}$ and $\varphi = 27.06^\circ$

Solution

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} \quad \underline{U} = 50 \text{ V} \quad \underline{Z} = 19.8 \angle 27.06^\circ \Omega$$

 The voltage $\underline{U}_R$ and $\underline{U}_L$ are $\underline{U}_R = 10 \text{ V}$ and $\underline{U}_L = 1.07 \text{ V}$ and $\underline{U}_C = 22 \text{ V}$ and $\underline{U}_R$ is real and $\underline{U}_L$ and $\underline{U}_C$ are imaginary.
 Therefore, the complex impedance is $\underline{Z} = 10 + j1.07 - j22 = 10 - j20.93 \Omega$ and the magnitude is 19.8Ω and the phase is 27.06° .
 With the complex part comes the physical value $R = 10 \Omega$ and $L = 1.07 \text{ mH}$ and $C = 22 \text{ nF}$ and $\varphi = 27.06^\circ$.
 The phase φ can be calculated as $\varphi = \arctan\left(\frac{\text{Im}(\underline{Z})}{\text{Re}(\underline{Z})}\right) = \arctan\left(\frac{-20.93}{10}\right) = -27.06^\circ$ and the magnitude is 19.8Ω .

Exercise E8 Complex Impedance Circuit**(written test, approx. 15 % of a 60-minute written test, WS2022)**

2. Calculate the complex impedance $\underline{Z}$ of the circuit shown in the figure. The components $\underline{U}_R$ and $\underline{U}_L$ shall be given. The voltage source is $u(t) = 3.0 \sin(2\pi \cdot 15 \cdot t) \text{ V}$ and the frequency is $f = 15 \text{ kHz}$.

Solution The linear source is connected with an inductor of $330 \mu\text{H}$ and a capacitor of $0.22 \mu\text{F}$, all in series.

Result

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

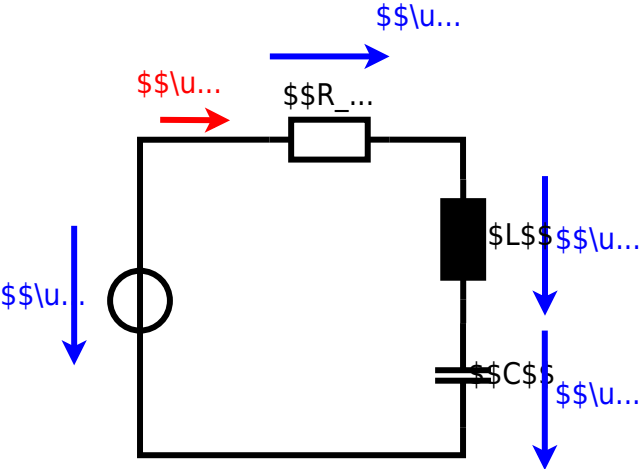
$$\underline{Z} = \frac{\underline{U}}{\underline{I}} \quad \underline{U} = 3.0 \text{ V} \quad \underline{I} = 1.07 \text{ A} \quad \underline{Z} = 19.8 \angle 27.06^\circ \Omega$$

$$\underline{Z}_C = \frac{1}{j\omega C} = \frac{1}{j \cdot 2\pi \cdot 15 \cdot 0.22 \cdot 10^{-6}} = -j1.07 \text{ k}\Omega$$

$$\underline{Z}_L = j\omega L = j \cdot 2\pi \cdot 15 \cdot 330 \cdot 10^{-6} = j3.16 \text{ k}\Omega$$

$$\underline{Z} = \underline{Z}_L + \underline{Z}_C = j3.16 \text{ k}\Omega - j1.07 \text{ k}\Omega = j2.09 \text{ k}\Omega$$

$$\underline{Z} = 2.09 \text{ k}\Omega \quad \varphi = 90^\circ$$



Exercise E7 Impedances at different Frequencies

(written test, approx. 18 % of a 60-minute written test, WS2022)

2. A series circuit consists of a resistor with $R_1 = 1.00 \text{ k}\Omega$ and a capacitor with $C_1 = 40 \text{ nF}$. The voltage across the resistor is $U_R = 10.0 \text{ V}$ at a frequency of $f = 4 \text{ MHz}$. Calculate the voltage across the capacitor U_C at the same frequency.

Solution

$$R_1 = 1.00 \text{ k}\Omega$$

$$C_1 = 40 \text{ nF}$$

A series circuit means that the current is constant on every component.

The equivalent impedance for R and C combined is given by

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

Parallel circuit means that the voltage is the same on R and C . Since $U_R = 10.0 \text{ V}$ and $U_C = 10.0 \text{ V}$, the voltage across the combination is $U = 14.14 \text{ V}$.

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

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

$$I = \frac{14.14 \text{ V}}{\sqrt{1.00^2 + 1.00^2} \text{ k}\Omega} = 1.00 \text{ mA}$$

$$U_C = I \cdot X_C = 1.00 \text{ mA} \cdot 10.0 \text{ k}\Omega = 10.0 \text{ V}$$

$$U_C = 10.0 \text{ V}$$

$$U_C = 10.0 \text{ V}$$

$$U_C = 10.0 \text{ V}$$

$$U_C = 10.0 \text{ V}$$

$$U_C = 10.0 \text{ V}$$

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 $d = 0.5 \text{ mm}$ and a length of $L = 3 \text{ m}$ is used for heating. The 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 3 m long and has a diameter of 0.5 mm .

Calculate the resistance R of the heating element.

Solution

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

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

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

Exercise E5 Charging Capacitors

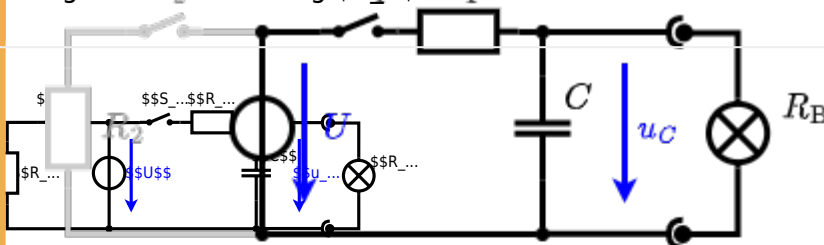
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit (without the light bulb) also is the circuit of Exercise 2. The voltage across the capacitor is again 0 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 Hint: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

Solution The ideal voltage source $U = 12 \text{ V}$ is in series with the resistor $R_1 = 20 \Omega$. The voltage $u_c(t)$ 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 .

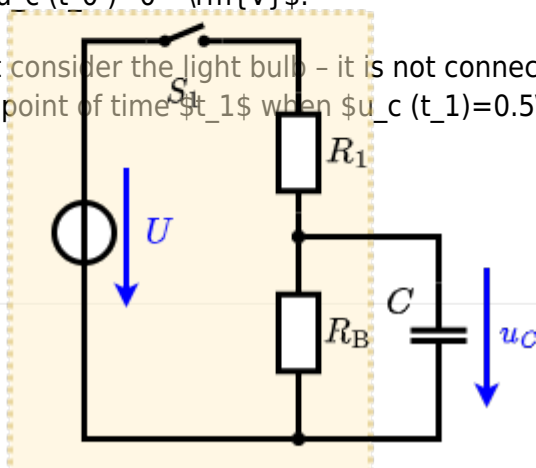


The circuit contains a voltage source $U = 12 \text{ V}$, a switch S_1 , a resistor of $R_1 = 20 \Omega$ and a capacitor of $C = 100 \mu\text{F}$.

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

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

$$u_c(t_2) = U_s \cdot (1 - e^{-t_2/(R_i \cdot C)}) = \frac{1}{2} \cdot U$$

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
$$(1 - e^{-t/\tau}) = 0.5$$

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

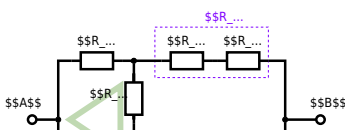
Exercise E3 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be shown with $R_1 = 200 \Omega$, $R_2 = 100 \Omega$, $R_3 = 150 \Omega$, $R_4 = 100 \Omega$ and the voltage $U = 10 \text{ V}$.
Result 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:

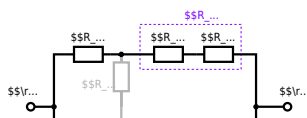
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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_{eq} between A and B .

Solution



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

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

From:

<https://wiki.mexle.te.hs-heilbronn.de/> - MEXLE Wiki

Permanent link:

https://wiki.mexle.te.hs-heilbronn.de/electrical_engineering_1/ws2022_exam?rev=1680241422

Last update: **2023/03/31 07:43**

