

Exam Winter Semester 2022

Student Group

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Table of Contents

- Exam Winter Semester 2022** 2
- Additional permitted Aids 2
- Hits 2
- Tasks 2
- Exercise E1 Resistance of a Wire by Resistivity (written test, approx. 6 % of a 60-minute written test, WS2022) 2
- Exercise E1 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022) 3
- Exercise E2 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022) 3
- Exercise E3 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022) 5
- Exercise E1 Charging Capacitors (written test, approx. 16 % of a 60-minute written test, WS2022) 9
- Exercise E4 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022) 11
- Exercise E1 Impedances at different Frequencies (written test, approx. 18 % of a 60-minute written test, WS2022) 11
- Exercise E1 Complex Impedance Circuit (written test, approx. 15 % of a 60-minute written test, WS2022) 12

Exam Winter Semester 2022

Additional permitted Aids

- non-programmable calculator,
- formulary (2 DIN A4 pages)

Hits

- The duration of the exam is 60 min.
- Attempts to cheat will lead to exclusion and failure of the exam.
- Withdrawal is no longer possible after these exam has been handed out.
- Please write down intermediate calculations and results on the assignment sheet. (when more space is needed also on the reverse side. In this case: Mark it clearly).
- Always use units in the calculation.
- Use a document-proof, non-red pen.

Tasks

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

A heating element made of a nichrome wire with a temperature coefficient of $1.80 \cdot 10^{-4} \text{ K}^{-1}$ is electrically connected to a 180 V AC power source. The electric power dissipation (= heat flow) of $P=40 \text{ W}$ is necessary. Calculate the current I needed to operate the heating element.

The Nichrome wire has a resistivity of $1.10 \cdot 10^{-6} \text{ } \Omega \text{ m}$. The heating element is 3 m long and has a diameter of 3.57 mm .
 Solution: $R = 1.10 \cdot 10^{-6} \text{ } \Omega \text{ m} \cdot \frac{4 \cdot 3 \text{ m}}{(3.57 \cdot 10^{-3} \text{ m})^2 \cdot \pi}$

Solution

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

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

[electrical_engineering_and_electronics:task_rj0r6j4apumukrj6_with_calculation_resistivity, power, exam ee1 ws2022](#)

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

2. A digital display explains a kitchen refrigerator's temperature sensor. The sensor has a resistance of $10 \text{ k}\Omega$ at 25°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 .

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

Solution: The resistance of the thermistor at -40°C is $R = 6.5 \text{ k}\Omega$.

Therefore, a solution is to use a resistor that is ten times the resistance of the thermistor.

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

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\begin{align*} R &= R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2) && | \\ \text{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) && \\ &= 6.5 \text{ k}\Omega && \end{align*}
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[electrical_engineering_and_electronics:task_70jg4yzznocarsq_with_calculation](#)
[temperature dependent resistance, power, heat, exam ee1 ws2022](#)

Exercise E2 Pure Resistor Network Simplification
(written test, approx. 13 % of a 60-minute written test, WS2022)

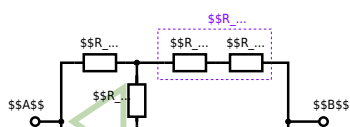
The following circuit has a voltage source $U = 10 \text{ V}$ and resistors $R_1 = 1 \text{ k}\Omega$, $R_2 = 2 \text{ k}\Omega$, $R_3 = 3 \text{ k}\Omega$, and $R_4 = 4 \text{ k}\Omega$. Calculate the current I through R_4 .

Result: $I = 1.1 \text{ mA}$.

Solution: The current I through R_4 is $I = 1.1 \text{ mA}$.

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\begin{align*} R_{\text{eq}} &= 1.1 \text{ k}\Omega && \end{align*}
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Now a wye-delta transformation is necessary.

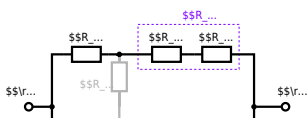


Since $R_2=R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

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

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:

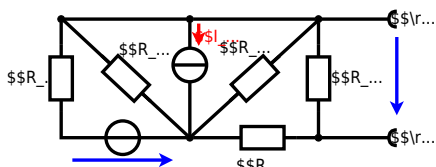
$$R_{\text{eq}} = (R_2 + R_1 + R_1) \parallel (R_2 + R_2) \parallel R_{\text{eq}} = (100 \sim \Omega + 200 \sim \Omega + 200 \sim \Omega) \parallel (100 \sim \Omega + 100 \sim \Omega) \parallel R_{\text{eq}} = (500 \sim \Omega) \parallel (200 \sim \Omega) \parallel R_{\text{eq}} = \frac{500 \sim \Omega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

[electrical_engineering_and_electronics:task_x357drkaqv84jnsc_with_calculation](#)
[network simplification, exam ee1 ws2022](#)

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

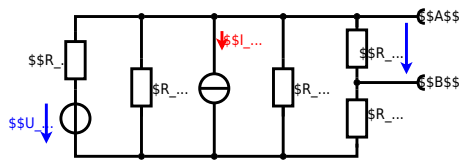
$$U_{\text{s}} = U_{\text{AB}} = 4.5 \text{ V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \sim \Omega$$



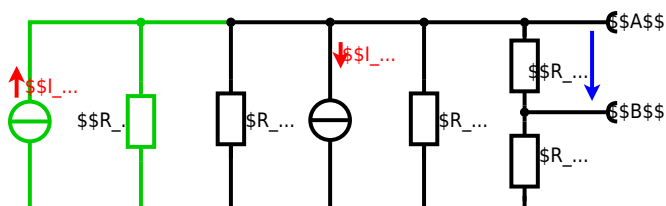
Calculated the internal resistance R_{int} and the source voltage U_{oc} of an equivalent linear voltage source on the connectors A and B . $R_1=5.0 \text{ } \Omega$, $U_2=6.0 \text{ V}$, $R_3= 10 \text{ } \Omega$, $I_4=4.2 \text{ A}$, $R_5=10 \text{ } \Omega$, $R_6=7.5 \text{ } \Omega$, $R_7=15 \text{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

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

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

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:

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

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

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

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

[electrical_engineering_and_electronics:task_6tqtqtque1e2nf2c7_with_calculation](#)
[dc network analysis, pure resistor network simplification, delta wye transformation, exam ee1 ws2022](#)

Exercise E1 Charging Capacitors
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit below (reality) also consists of $R_1 = 6\Omega$, $R_2 = 20\Omega$ and a capacitor $C = 2\mu\text{F}$ as indicated in the figure. The switch S_1 is open. The voltage across the capacitor is again 0V 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.

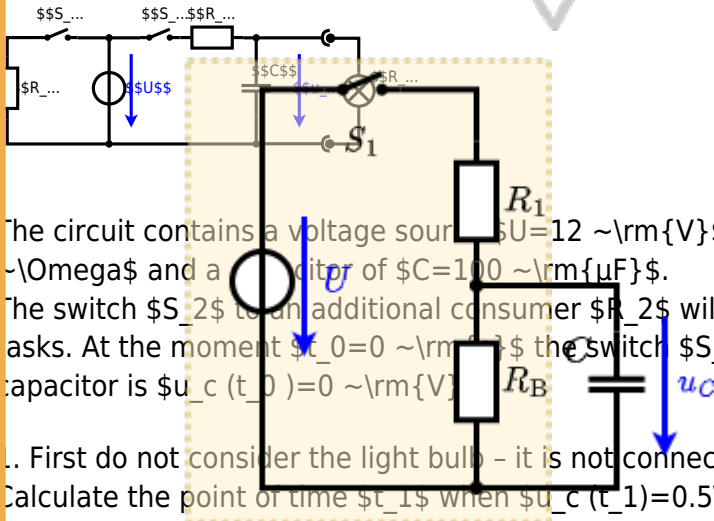
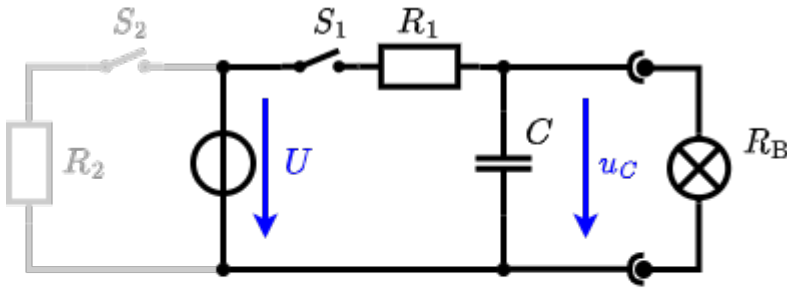
Result: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

$$U_{\Delta} = \frac{U \cdot R_2}{R_1 + R_2} = \frac{12\text{V} \cdot 20\Omega}{6\Omega + 20\Omega} = 4.615\text{V}$$

Solution: The internal resistance R_i is given by substituting the ideal voltage source with its internal resistance R_2 .

$$R_i = R_2 || (R_1 + R_2) = 20\Omega || (6\Omega + 20\Omega) = 12\Omega$$

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 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 $u_c(t_1)=0.5 \cdot U$.

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

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

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

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

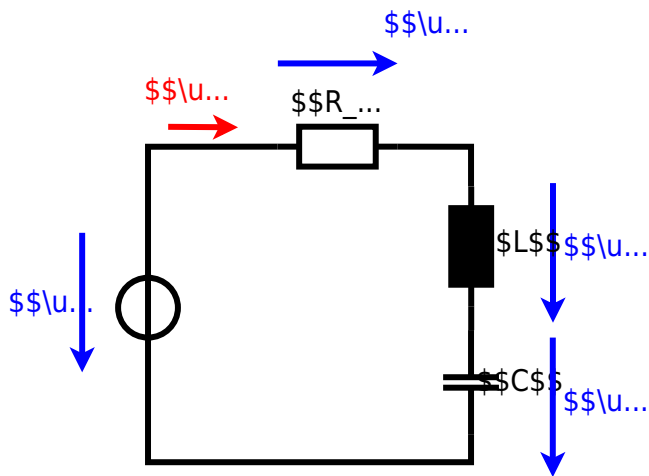


So, here only R_1 and C gives the time constant: $\tau = R_1 \cdot C$

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



electrical_engineering_and_electronics:task_kricv9fh7haauo6q_with_calculation
complex impedance, exam ee1 ws2022

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