

Exam Winter Semester 2022

Student Group

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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 E2 Resistance of a Wire by Resistivity

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

2. Heating elements are used to heat water with a temperature of 180°C . An electric

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 $1.10 \cdot 10^{-6}\text{ }\Omega\text{ m}$.

The heating element is 3 m long and has a diameter of 3.57 mm .

Calculate the resistance R of the heating element.

Solution

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

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

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resistivity, power, exam ee1 ws2022

Exercise E4 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)

2. According to question 2, the effect of a constant sensor configuration is not considered. The thermistor has a resistance of $10 \text{ k}\Omega$ at 25°C .

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

Result: The temperature inside the refrigeration system can reach down to -40°C .

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

The power transfer is small. The power dissipation is small. Therefore, a solution is to use a heat sink.

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

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

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temperature dependent resistance, power, heat, exam ee1 ws2022

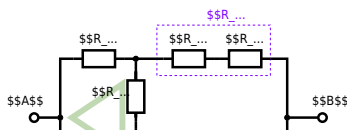
Exercise E6 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be calculated: R_{eq} between B_1 and B_2 and the power P_{B_1} .

Solution

$$R_{\text{eq}} = 12.8 \text{ }\Omega$$

Now a wye-delta transformation is necessary.



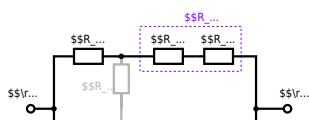
Since $R_2 = R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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

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

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:

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

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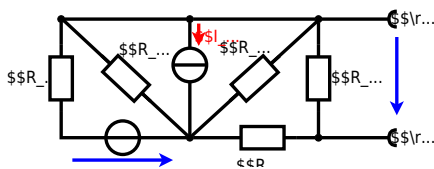
[network simplification](#), [exam ee1 ws2022](#)

Exercise E8 Equivalent linear Source

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

The circuit in the following has to be simplified.
Result

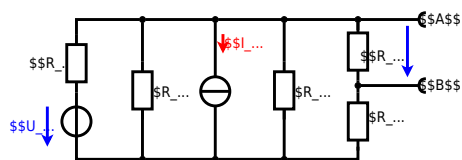
$$\begin{aligned} U_{\text{s}} &= U_{\text{AB}} = 4.5 \text{ V} \\ R_{\text{i}} &= R_{\text{AB}} = 6 \sim \Omega \end{aligned}$$



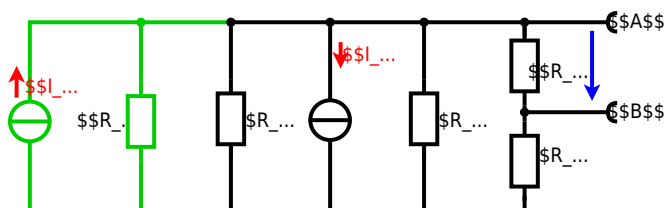
Calculate the internal resistance R_i and the source voltage U_s of an equivalent linear voltage source on the connectors A and B. $\begin{aligned} R_1 &= 5.0 \, \Omega, \quad U_2 = 6.0 \, \text{V}, \quad R_3 = 10 \, \Omega, \quad I_4 = 4.2 \, \text{A}, \\ R_5 &= 10 \, \Omega, \quad R_6 = 7.5 \, \Omega, \quad R_7 = 15 \, \Omega \end{aligned}$ 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:
$$U_{24}$$

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

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

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

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dc network analysis, pure resistor network simplification, delta wye transformation, exam ee1 ws2022

Exercise E10 Charging Capacitors

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

The circuit below (Figure 1) also represents a circuit with a charging capacitor. 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.

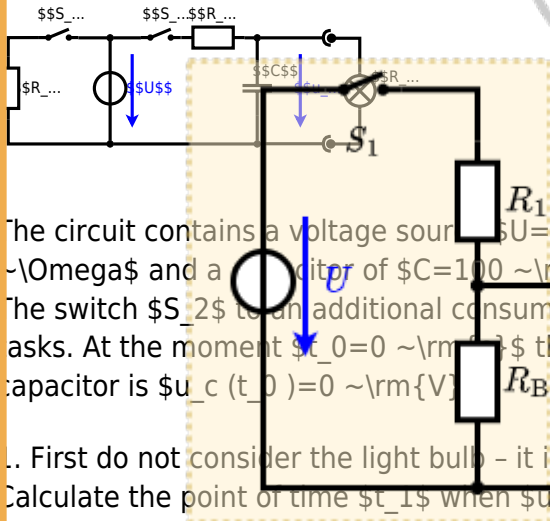
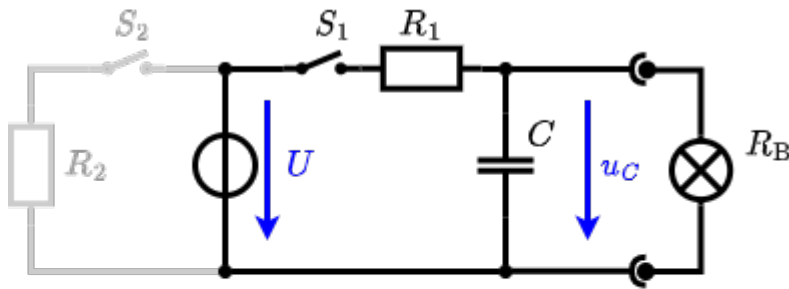
Solution: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

$$U_{\text{eq}} = \frac{U \cdot R_2}{R_1 + R_2} = \frac{12\text{V} \cdot 2\Omega}{1\Omega + 2\Omega} = 8\text{V}$$

Solution: The internal resistance R_i is given by substituting the ideal voltage source again short-circuiting R_2 .

$$R_i = R_1 \parallel R_2 = 1\Omega \parallel 2\Omega = \frac{1\Omega \cdot 2\Omega}{1\Omega + 2\Omega} = \frac{2}{3}\Omega$$

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

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

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



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

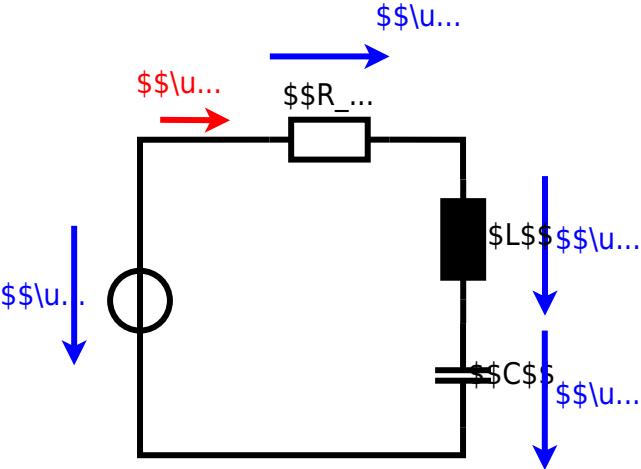
The following formula describes the time course of $u_c(t)$ which has to be $u_c(t_1)=0.5 \cdot U$:
$$u_c(t) = U \cdot (1 - e^{-t/\tau}) = 0.5 \cdot U$$
 It has to be rearranged to
$$(1 - e^{-t/\tau}) = 0.5$$

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

$$t/\tau = \ln(0.5)$$

$$t = \tau \cdot \ln(0.5)$$

$$t = R_1 \cdot C \cdot \ln(0.5)$$



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complex impedance, exam ee1 ws2022

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