

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 E2 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)	2
Exercise E3 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)	3
Exercise E4 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022)	5
Exercise E5 Charging Capacitors (written test, approx. 16 % of a 60-minute written test, WS2022)	9
Exercise E6 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)	10
Exercise E7 Impedances at different Frequencies (written test, approx. 18 % of a 60-minute written test, WS2022)	11
Exercise E8 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 solid nichrome wire with a cross-section of 1.80 mm^2 is used. Electric power dissipation (= heat flow) of $P = 40 \text{ W}$ is necessary.

Calculate the current I needed for operation.

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

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

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

[resistivity](#), [power](#), [exam ee1 ws2022](#)

Exercise E2 Temperature-dependent Resistance

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

2. A refrigerator, which has a temperature coefficient of temperature sensitivity of 0.01 K^{-1} and a temperature coefficient of resistance of 71 K^{-2} , has a resistance of $10 \text{ k}\Omega$ at 25°C . Calculate the resistance of the thermistor at -40°C .

Its temperature coefficients are: $\alpha = 0.01 \text{ K}^{-1}$ and $\beta = 71 \text{ K}^{-2}$.

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

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

Resistance of the resistor is given by the circuit and given heat. Therefore, a solution is to 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.

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

temperature dependent resistance, power, heat, exam ee1 ws2022

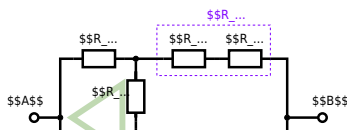
Exercise E3 Pure Resistor Network Simplification**(written test, approx. 13 % of a 60-minute written test, WS2022)**

The following shall be calculated: $R_1 = 20 \text{ k}\Omega$, $R_2 = 10 \text{ k}\Omega$, $R_3 = 15 \text{ k}\Omega$, $R_4 = 10 \text{ k}\Omega$ and the voltage $U = 10 \text{ V}$.

Solution

$$R_{\text{eq}} = 13.8 \text{ k}\Omega$$

Now a wye-delta transformation is necessary.



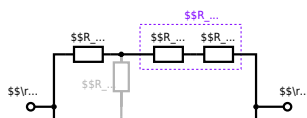
Since $R_2 = R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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:

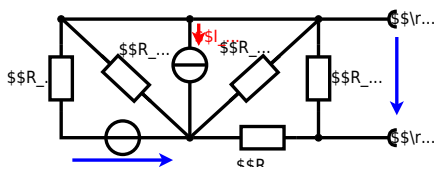
$$\begin{aligned} R_{\text{eq}} &= (R_2 + R_1 + R_1) \parallel (R_2 + R_2) \\ R_{\text{eq}} &= (100 \, \Omega + 200 \, \Omega + 200 \, \Omega) \parallel (100 \, \Omega + 100 \, \Omega) \\ R_{\text{eq}} &= (500 \, \Omega) \parallel (200 \, \Omega) \\ R_{\text{eq}} &= \frac{500 \, \Omega \cdot 200 \, \Omega}{500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

network simplification, exam ee1 ws2022

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

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



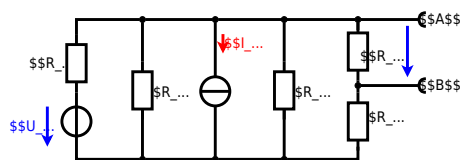
Calculate the internal resistance R_{int} and the source voltage U_{AB} of an equivalent linear voltage source on the connectors A and B.

$R_1 = 5.0 \, \Omega$, $U_2 = 6.0 \, \text{V}$, $R_3 = 10 \, \Omega$, $I_4 = 4.2 \, \text{A}$, $R_5 = 10 \, \Omega$, $R_6 = 7.5 \, \Omega$, $R_7 = 15 \, \Omega$

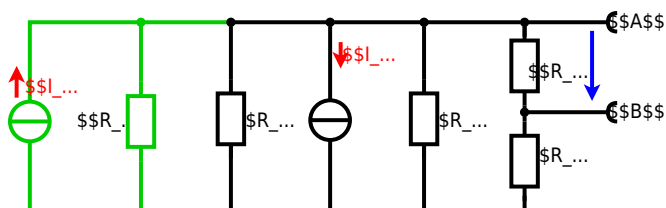
Use equivalent sources in order to simplify the circuit!

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 :

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

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

The resulting circuit can again be transformed:



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

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

$$I_{24} = \frac{U_{24}}{R_6 + R_7 + R_1 || R_3 || R_5}$$

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

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

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

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

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

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

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

Exercise E5 Charging Capacitors

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

The circuit (shown in the figure) dissipates a power of 0.1 W in the 20Ω resistor. 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.

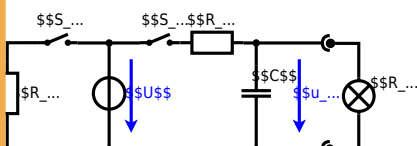
Solution
To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 :

$$U_{\text{eq}} = \frac{U \cdot R_2}{R_1 + R_2} = \frac{12 \text{ V} \cdot 20 \Omega}{10 \Omega + 20 \Omega} = 8 \text{ V}$$

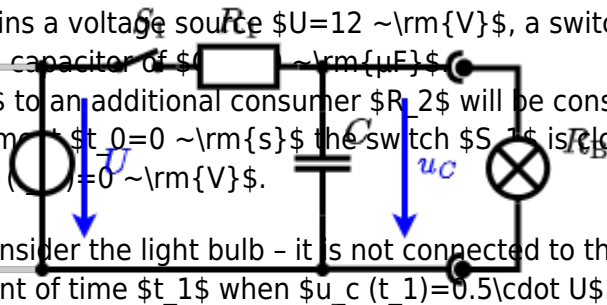
Solution
The internal resistance R_i is given by substituting the ideal voltage source by a short-circuit:

$$R_i = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{10 \Omega \cdot 20 \Omega}{10 \Omega + 20 \Omega} = 6.67 \Omega$$

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 .

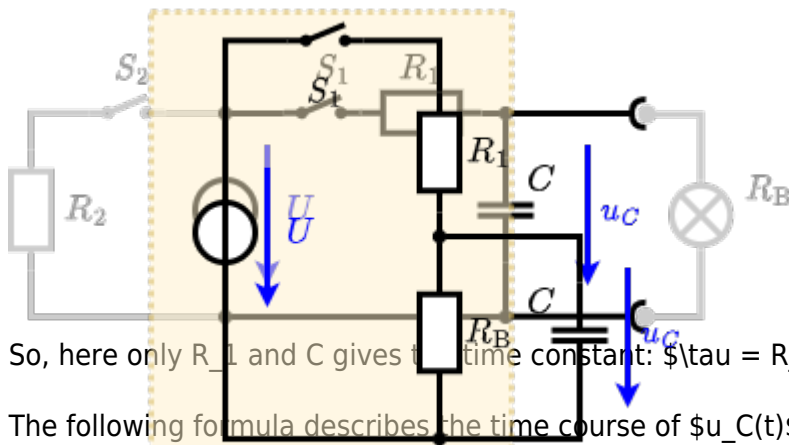


The circuit contains a voltage source $U=12\text{ V}$, a switch S_1 , a resistor of $R_1=20\text{ }\Omega$ and a capacitor of $C=100\text{ }\mu\text{F}$. The switch S_2 to an additional consumer R_2 will be considered to be open for the first task. At the moment $t_0=0\text{ s}$ the switch S_1 is closed, 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 $U_s = \frac{U \cdot R_B}{R_1 + R_B}$ and $R_i = R_1 \parallel R_B$ 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).
$$R_i = R_1 \parallel R_B = 10\text{ }\Omega$$

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

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

Exercise E6 Analyzing complex Impedances

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

2. Calculate the phasor impedance Z of the circuit shown in the figure. The voltage source U is $U = 10\text{ V}$ and the frequency is $f = 50\text{ Hz}$. The components R and X_1 shall be given.

After analysis, the full complex impedance Z has to be extracted and given in the form $Z = |Z| \cdot e^{j\phi}$ with $|Z|$ in Ω and ϕ in $^\circ$.
$$Z = \frac{1}{\frac{1}{R} + \frac{1}{j\omega L} + \frac{1}{-j\omega C}} + 5j\text{ }\Omega$$

Solution Calculate the physical values of the two components.

$$C = 103 \sim \mu\text{F}$$

$$R = 0.12 \sim \Omega$$

Solution

The current and voltage are in phase once there is only a pure ohmic (= pure real)

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

Therefore, over complex impedance a capacitor with the same absolute value of

$$\underline{Z} = j\omega L = -j\omega C$$

$$\omega L = \omega C \Rightarrow L = C$$

$$\underline{Z} = R + j\omega L = R - j\omega C$$

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complex impedance, exam ee1 ws2022

Exercise E7 Impedances at different Frequencies

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

Exercise E7 The resistor values $R_1 = 1.00 \sim \Omega$, $R_2 = 10.0 \sim \Omega$, $R_3 = 1.00 \sim \Omega$ and the capacitor value $C = 40 \sim \text{nF}$ are given in the AC-circuit diagram.

Result: R_1 and R_2 have the same absolute value of the impedance as a capacitor $C = 40 \sim \text{nF}$ at $f = 4 \sim \text{MHz}$.

Solution

The equivalent impedance for R_1 and R_2 combined is given by

$$\underline{Z}_{R1R2} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$

$$\underline{Z}_{R1R2} = \frac{1.00 \cdot 10.0}{1.00 + 10.0} = 0.909 \sim \Omega$$

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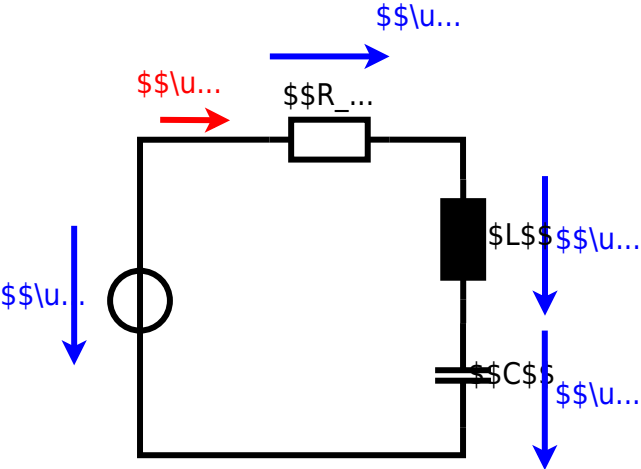
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complex impedance, exam ee1 ws2022

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