

Exam Winter Semester 2022

Student Group

First Name	Surname	Matrikel Nr.

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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)

A heating element made of nichrome wire with a temperature coefficient of $1.80 \cdot 10^{-3} \text{ K}^{-1}$ is electrically connected to a power supply.

Result: power dissipation (= heat flow) of $P = 40 \text{ W}$ is necessary.

Determine the current I needed for operation.

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

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

Calculate the resistance R of the heating element.

Solution

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

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

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

Exercise E4 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 .

$$R = 10 \text{ k}\Omega \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2)$$

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

temperature dependent resistance, power, heat, exam ee1 ws2022

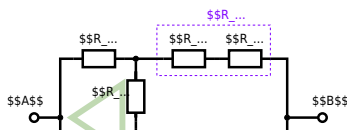
Exercise E6 Pure Resistor Network Simplification**(written test, approx. 13 % of a 60-minute written test, WS2022)**

The following shall be calculated: $R_1 = 10 \text{ k}\Omega$, $R_2 = 15 \text{ k}\Omega$, $R_3 = 20 \text{ k}\Omega$, $R_4 = 30 \text{ k}\Omega$, $R_5 = 40 \text{ k}\Omega$, $R_6 = 50 \text{ k}\Omega$, $R_7 = 60 \text{ k}\Omega$, $R_8 = 70 \text{ k}\Omega$, $R_9 = 80 \text{ k}\Omega$, $R_{10} = 90 \text{ k}\Omega$, $R_{11} = 100 \text{ k}\Omega$.

Solution

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

Now a wye-delta transformation is necessary.



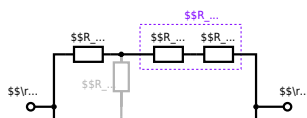
Since $R_2 = R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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

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

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:

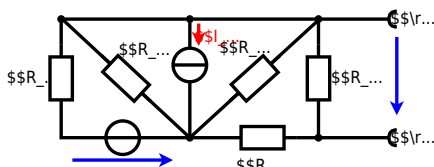
$$R_{\text{eq}} = (R_2 + R_1 + R_1) \parallel (R_2 + R_2) \parallel R_{\text{eq}} = (100 \, \Omega + 200 \, \Omega + 200 \, \Omega) \parallel (100 \, \Omega + 100 \, \Omega) \parallel R_{\text{eq}} = (500 \, \Omega) \parallel (200 \, \Omega) \parallel R_{\text{eq}} = \frac{500 \, \Omega \cdot 200 \,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

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

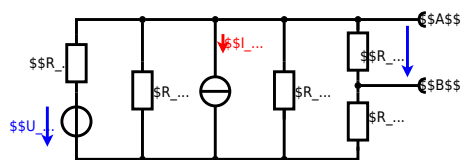
$$U_{\text{S}} = U_{\text{AB}} = 4.5 \, \text{V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \, \Omega$$



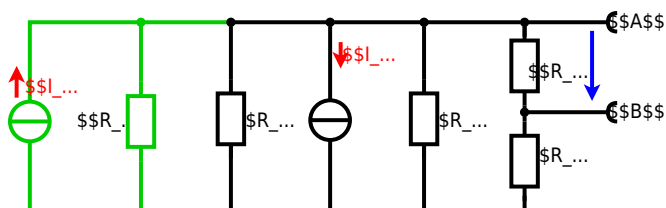
Calculate the internal resistance R_i and the source voltage U_s of an equivalent linear voltage source on the connectors A and B. $\begin{aligned} R_1 &= 5.0 \, \Omega, \quad U_2 = 6.0 \, \text{V}, \quad R_3 = 10 \, \Omega, \quad I_4 = 4.2 \, \text{A}, \\ R_5 &= 10 \, \Omega, \quad R_6 = 7.5 \, \Omega, \quad R_7 = 15 \, \Omega \end{aligned}$ 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 $R_1 \parallel R_3 \parallel R_5 = 5 \Omega \parallel 10 \Omega \parallel 10 \Omega = 5 \Omega \parallel 5 \Omega = 2.5 \Omega$:

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

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

Exercise E10 Charging Capacitors

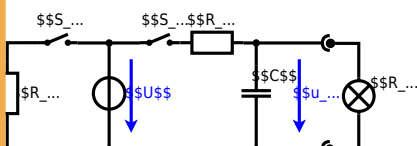
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit (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.

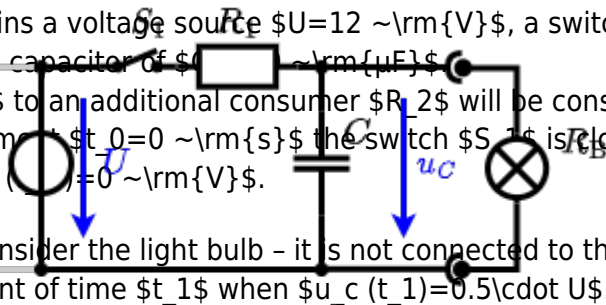
Solution
To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

Diagram
The equivalent circuit is shown in the figure. The voltage source is $U_{eq} = \frac{U \cdot R_2}{R_1 + R_2}$ and the internal resistance is $R_{eq} = R_1 \parallel R_2$.

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 .

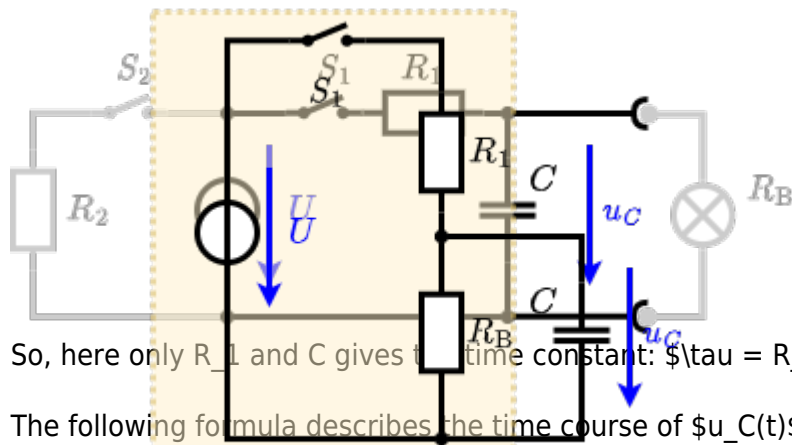


The circuit contains a voltage source $U=12\text{ V}$, a switch S_1 , a resistor of $R_1=20\text{ }\Omega$ and a capacitor of $C=100\text{ }\mu\text{F}$. The switch S_2 to an additional consumer R_2 will be considered to be open for the first task. At the moment $t_0=0\text{ s}$ the switch S_1 is closed, 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 $U_s = U \cdot \frac{R_B}{R_1 + R_B}$ 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 E12 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the phasor impedance $\underline{Z}$ of the circuit shown in the figure. The voltage source $\underline{U}$ and the load impedance $\underline{Z}_L$ shall be given.

After analysis, the full expression for the impedance $\underline{Z}$ shall be extracted and given in phasor notation: $\underline{Z} = \frac{1}{j\omega} \left(\frac{1}{R_1 + j\omega L} + \frac{1}{R_2 + j\omega L} \right) + \underline{Z}_L$

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

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

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

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

$$R = 0.12 \sim \Omega$$

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complex impedance, exam ee1 ws2022

Exercise E14 Impedances at different Frequencies

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

Exercise E14 The resistor values $R_1 = 1.00 \sim \Omega$ and $R_2 = 10.0 \sim \Omega$ are in a series circuit with a capacitor $C = 40 \sim \text{nF}$ at $f = 4 \sim \text{MHz}$.

Result: $R_3 = 1.00 \sim \Omega$ and $R_4 = 10.0 \sim \Omega$ are in a parallel circuit with a capacitor $C = 40 \sim \text{nF}$ at $f = 4 \sim \text{MHz}$.

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Result: $R_3 = 1.00 \sim \Omega$ and $R_4 = 10.0 \sim \Omega$ are in a parallel circuit with a capacitor $C = 40 \sim \text{nF}$ at $f = 4 \sim \text{MHz}$.

Solution

$$R_1 = 1.00 \sim \Omega$$

$$R_2 = 10.0 \sim \Omega$$

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

$$\underline{Z} = R_1 + R_2$$

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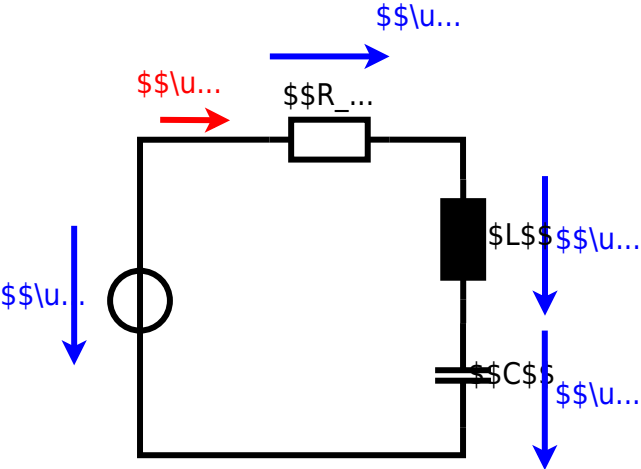
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complex impedance, exam ee1 ws2022

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