

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 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 selected. The power dissipation (= heat flow) of $P=40 \text{ W}$ is necessary. Calculate the current I needed to operate it.

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: $R = 1.10 \cdot 10^{-6} \text{ } \Omega \text{ m} \cdot \frac{4 \cdot 3 \text{ m}}{\pi \cdot (3.57 \cdot 10^{-3} \text{ m})^2}$

Solution

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

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

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

Exercise E1 Temperature-dependent Resistance

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

A. The following exhibits a temperature sensitive component, which is a resistor. The resistor has a resistance of $10 \text{ k}\Omega$ at 25°C . Its temperature coefficients are: $\alpha = 0.01 \text{ } \frac{1}{\text{K}}$ and $\beta = 71 \cdot 10^{-6} \text{ } \frac{1}{\text{K}^2}$.

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

$$R = 10 \text{ k}\Omega \cdot (1 + 0.01 \cdot \Delta T + 71 \cdot 10^{-6} \cdot \Delta T^2)$$

Resistance transfer resistor P and U of the circuit and generate heat. Therefore, a solution is to use a heat sink 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.

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2) \quad | \quad \Delta T = T_{\text{end}} - T_{\text{start}}$$

$$R = 10 \text{ k}\Omega \cdot \left(1 + 0.01 \cdot \frac{1}{\text{K}} \cdot (-40^\circ\text{C} - 25^\circ\text{C}) + 71 \cdot 10^{-6} \cdot \frac{1}{\text{K}^2} \cdot (-40^\circ\text{C} - 25^\circ\text{C})^2 \right)$$

temperature dependent resistance, power, heat, exam ee1 ws2022

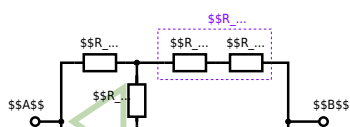
Exercise E2 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be solved. $R_1 = 20 \text{ }\Omega$, $R_2 = 10 \text{ }\Omega$, $R_3 = 15 \text{ }\Omega$, $R_4 = 10 \text{ }\Omega$ and the source $U = 10 \text{ V}$. Result: $R_{\text{eq}} = 13.8 \text{ }\Omega$.

Solution

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

Now a wye-delta transformation is necessary.

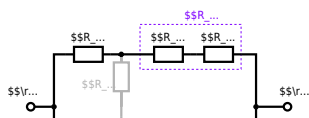


Since $R_2=R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

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

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:

$$R_{\text{eq}} = (R_2 + R_1 + R_1) \parallel (R_2 + R_2)$$

$$R_{\text{eq}} = (100 \Omega + 200 \Omega + 200 \Omega) \parallel (100 \Omega + 100 \Omega)$$

$$R_{\text{eq}} = (500 \Omega) \parallel (200 \Omega)$$

$$R_{\text{eq}} = \frac{500 \Omega \cdot 200 \Omega}{500 \Omega + 200 \Omega}$$

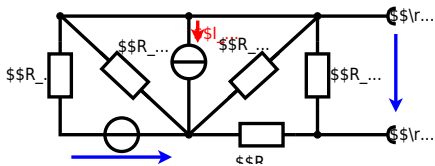
[network simplification, exam ee1 ws2022](#)

**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

$$U_s = U_{AB} = 4.5 \text{ V}$$

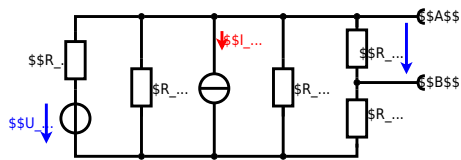
$$R_i = R_{AB} = 6 \Omega$$



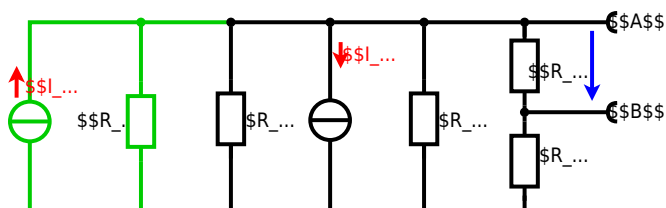
Calculate the internal resistance R_{int} and the source voltage U_s of an equivalent linear voltage source on the connectors A and B . $R_1=5.0 \Omega$, $U_2=6.0 \text{ V}$, $R_3= 10 \Omega$, $I_4=4.2 \text{ A}$, $R_5=10 \Omega$, $R_6=7.5 \Omega$, $R_7=15 \Omega$ Use equivalent sources in order to simplify 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 :

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

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

The resulting circuit can again be transformed:



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

$$U_{24}$$

$$U_{24} = U_{23} \cdot \frac{R_6}{R_6 + R_7} = (U_{21} - U_{14}) \cdot \frac{R_6}{R_6 + R_7}$$

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:

$$U_{AB} = U_{24} \cdot \frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} = (U_{21} - U_{14}) \cdot \frac{R_7 \cdot R_1 || R_3 || R_5}{R_6 + R_7 + R_1 || R_3 || R_5}$$

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

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

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

Exercise E1 Charging Capacitors

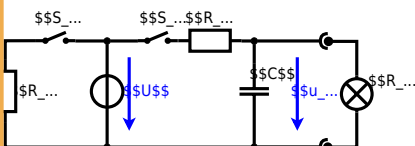
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit below (realization) consists of a DC voltage source U , a switch S_1 , a capacitor C , and a resistor R_2 . The voltage across the capacitor is again U 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.

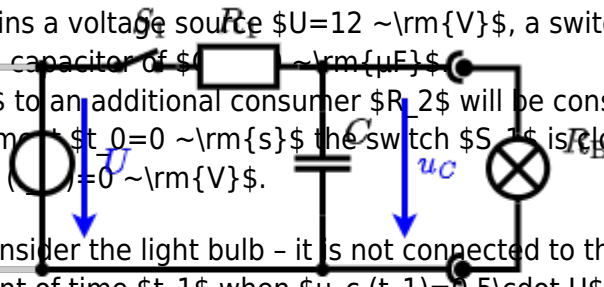
Solution: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

$$U_{eq} = U \cdot \frac{R_2}{R_1 + R_2} = U \cdot \frac{R_2}{R_1 + R_2}$$

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 .

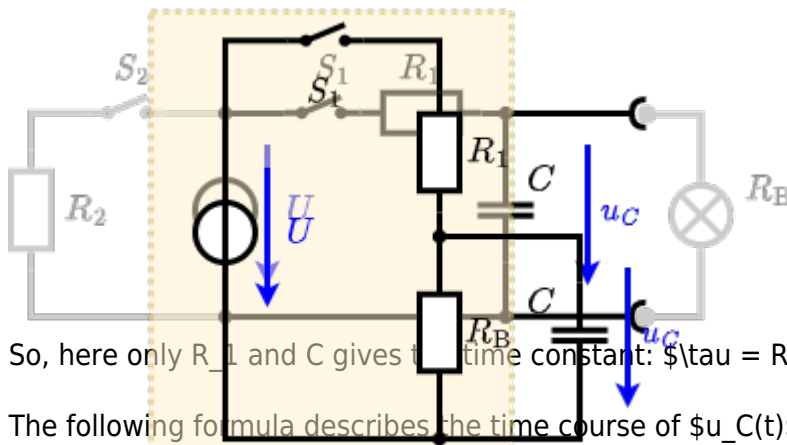


The circuit contains a voltage source $U=12\text{ V}$, a switch S_1 , a resistor of $R_1=20\text{ }\Omega$ and a capacitor of $C=100\text{ }\mu\text{F}$. The switch S_2 to an additional consumer R_2 will be considered to be open for the first task. At the moment $t_0=0\text{ s}$ the switch S_1 is closed, 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 $U_s = \frac{U \cdot R_B}{R_1 + R_B}$ 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 ($R_i = 0\text{ }\Omega$, 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 E4 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the open-circuit voltage U_{OC} and the short-circuit current I_{SC} of the circuit shown in the figure. The components R_1 and X_1 shall be given.
 After analysis, the full low-dimensional circuit impedance Z_{eq} shall be extracted and given (figure) in parallel to the late voltage U_{OC} over $R_1 + j\omega L_1 + 5j\omega$ (right) Ω .

Solution Calculate the physical values of the two components.

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

$$R = 103 \text{ } \Omega$$

Solution

The current and voltage are in phase once there is only a pure ohmic (= pure real) impedance. Therefore, the current and voltage are in phase.

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The absolute value of the impedance can be calculated as:

$$|Z| = \sqrt{R^2 + (X_L - X_C)^2}$$

$$|Z| = \sqrt{103^2 + (4.68 - 300)^2}$$

$$|Z| = \sqrt{10609 + 89952.64} = \sqrt{100561.64} \approx 317.26 \text{ } \Omega$$

With the complex part comes the physical value:

$$X_L = \omega L$$

$$X_C = \frac{1}{\omega C}$$

$$317.26 = \sqrt{103^2 + (\omega L - \frac{1}{\omega C})^2}$$

$$317.26^2 - 103^2 = (\omega L - \frac{1}{\omega C})^2$$

$$92651.64 - 10609 = (\omega L - \frac{1}{\omega C})^2$$

$$82042.64 = (\omega L - \frac{1}{\omega C})^2$$

$$\sqrt{82042.64} = \omega L - \frac{1}{\omega C}$$

$$284.68 = \omega L - \frac{1}{\omega C}$$

The phase φ can be calculated as:

$$\varphi = \arctan\left(\frac{\text{Im}(Z)}{\text{Re}(Z)}\right) = \arctan\left(\frac{-4.68}{0.24}\right)$$

complex impedance, exam ee1 ws2022

Exercise E1 Impedances at different Frequencies
 (written test, approx. 18 % of a 60-minute written test, WS2022)

Exercise E1 A series circuit consists of a resistor R_1 and a capacitor C_1 in series. The voltage across the resistor is U_{R1} and the voltage across the capacitor is U_{C1} . The total voltage across the series combination is U_{total} . The current through the circuit is I . The resistor R_1 shall have the same absolute value of the impedance as a capacitor C_1 at $f_1 = 4 \text{ MHz}$.

Solution

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

$$R_2 = 10.0 \text{ } \Omega$$

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

The equivalent impedance for R and L combined is given by:

$$Z = R + j\omega L$$

Parallel circuit means that the voltage is the same on R_2 and C_2 :

$$U_{R2} = U_{C2}$$

Since $U_{R2} = I R_2$ and $U_{C2} = I X_{C2} = I \frac{1}{\omega C_2}$, we get:

$$I R_2 = I \frac{1}{\omega C_2}$$

$$R_2 = \frac{1}{\omega C_2}$$

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

$$I_{3R} = I_{R2} + I_{C2}$$

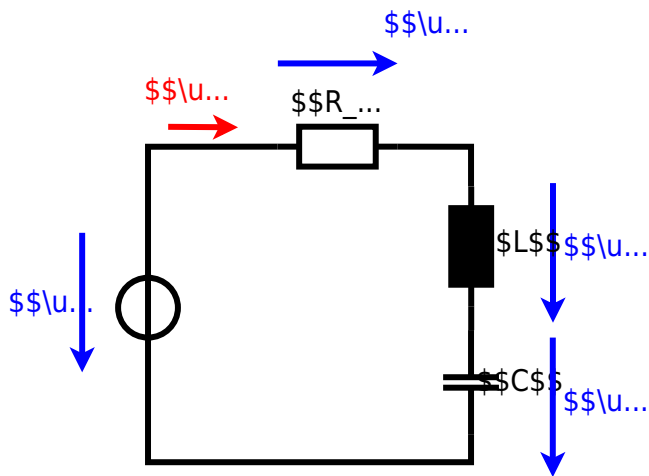
This current is the same as the current through R_1 and C_1 in series:

$$I_{3R} = I_{R1} = I_{C1}$$

$$I_{3R} = I_{R1} = I_{C1} = I \frac{1}{\sqrt{R_1^2 + (\omega L_1 - \frac{1}{\omega C_1})^2}}$$

Back to the first formula:

$$R_3 \cdot I_{3R} = X_{C3} \cdot I_{3R}$$



complex impedance, exam ee1 ws2022

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