

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 nichrome wire with a temperature coefficient of $1.80 \times 10^{-4} \text{ K}^{-1}$ 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 .
Calculate the resistance R of the heating element.

Solution

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

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

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

Exercise E2 Temperature-dependent Resistance

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

A. The following exhibits a temperature sensitive component, which is used in a refrigerator. The component 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 .

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

Resistance transfer resistor R is part of the circuit and generates heat. Therefore, a solution is to heat 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.

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2)$$

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

temperature dependent resistance, power, heat, exam ee1 ws2022

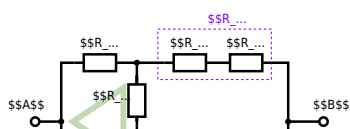
Exercise E3 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

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

Solution

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

Now a wye-delta transformation is necessary.

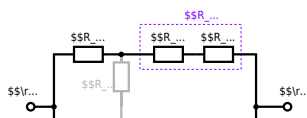


Since $R_2=R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

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:

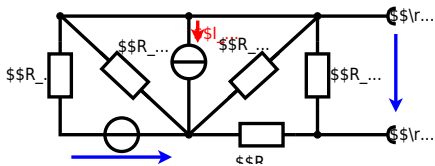
$$R_{\text{eq}} = (R_2 + R_1 + R_1) \parallel (R_2 + R_2) \parallel R_{\text{eq}} = (100 \Omega + 200 \Omega + 200 \Omega) \parallel (100 \Omega + 100 \Omega) \parallel R_{\text{eq}} = (500 \Omega) \parallel (200 \Omega) \parallel R_{\text{eq}} = \frac{500 \Omega \cdot 200 \Omega}{500 \Omega + 200 \Omega}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

[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

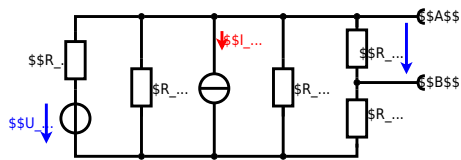
$$U_{\text{s}} = U_{\text{AB}} = 4.5 \text{ V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \Omega$$



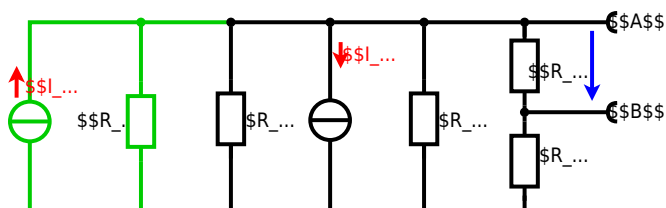
Calculated the internal resistance R_{i} and the source voltage U_{s} of an equivalent linear voltage source on the connectors A and B . $R_1=5.0 \text{ } \Omega$, $U_2=6.0 \text{ V}$, $R_3= 10 \text{ } \Omega$, $I_4=4.2 \text{ A}$, $R_5=10 \text{ } \Omega$, $R_6=7.5 \text{ } \Omega$, $R_7=15 \text{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

$$U_{24} = I_{24} \cdot (R_6 || R_7)$$

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

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:

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

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

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

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

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

Exercise E4 Charging Capacitors

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

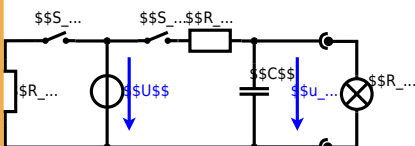
The circuit below (realization) consists of a DC voltage source U , a switch S_1 , a capacitor C , and a resistor R_2 . The voltage across the capacitor is again U at the moment $t_0=0 \text{ s}$ when the switch S_1 is closed. Calculate the voltage $u_c(t_2)$ across the capacitor at $t_2=1 \text{ ms}$ after closing the switch.

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

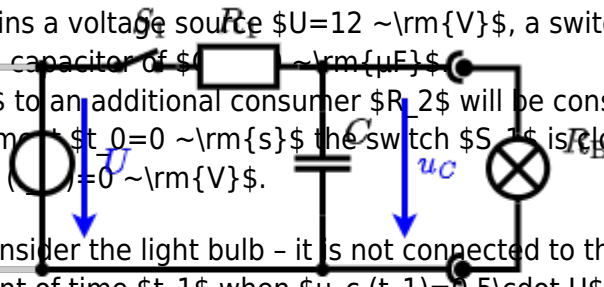
$$U_{eq} = U \cdot \frac{R_2}{R_1 + R_2}$$

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

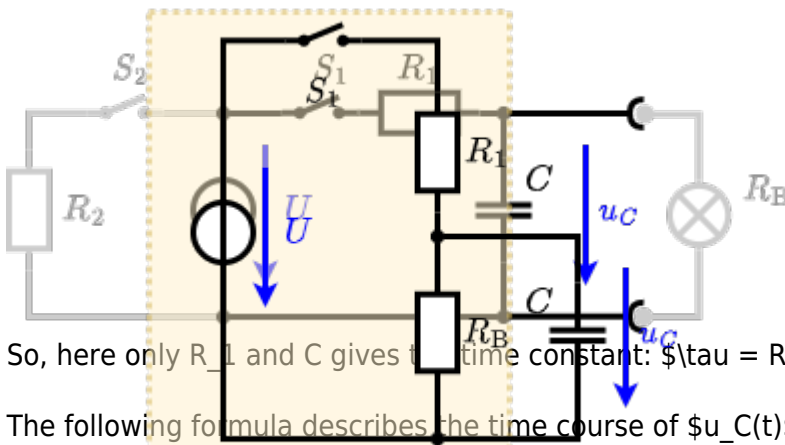


The circuit contains a voltage source $U=12\text{ V}$, a switch S_1 , a resistor of $R_1=20\text{ }\Omega$ and a capacitor of $C=100\text{ }\mu\text{F}$. The switch S_2 to an additional consumer R_2 will be considered to be open for the first task. At the moment $t_0=0\text{ s}$ the switch S_1 is closed, 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: $U_s = U \cdot \frac{R_B}{R_1 + R_B} = 1/2 \cdot U$. 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 E5 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the phasor voltage $\underline{u}_C(\omega)$ of the capacitor C in the circuit shown in the figure. The phasor voltage $\underline{u}_C(\omega)$ shall be given. After analysis, the full low dimensional form impedance Z shall be extracted and given in phasor form $Z = \frac{1}{\sqrt{2}} \cdot (2 + j) \cdot 10^3 + 5j\text{ }\Omega$.

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 once there is only a pure ohmic (= pure real) impedance.

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

The absolute value of the impedance can be calculated as:

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

$$|Z| = \sqrt{103^2 + (4.68 - 0.24)^2}$$

$$|Z| = \sqrt{103^2 + 4.44^2}$$

$$|Z| = \sqrt{10609 + 19.71}$$

$$|Z| = \sqrt{10628.71}$$

$$|Z| = 103.1 \text{ } \Omega$$

With the complex part comes the physical value:

$$X_L = \omega L$$

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

$$4.68 = 2\pi \cdot 4.7 \cdot L$$

$$L = \frac{4.68}{2\pi \cdot 4.7}$$

$$L = 0.157 \text{ } \text{mH}$$

The phase φ can be calculated as:

$$\varphi = \arctan\left(\frac{X_L - X_C}{R}\right)$$

$$\varphi = \arctan\left(\frac{4.68 - 0.24}{103}\right)$$

$$\varphi = \arctan\left(\frac{4.44}{103}\right)$$

$$\varphi = 2.48^\circ$$

complex impedance, exam ee1 ws2022

Exercise E6 Impedances at different Frequencies
 (written test, approx. 18 % of a 60-minute written test, WS2022)

Exercise E6 The resistor values $R_1 = 1 \text{ } \Omega$ and $R_2 = 10 \text{ } \Omega$ are in a series circuit with a capacitor $C = 40 \text{ nF}$ and an inductor $L = 4.7 \text{ } \mu\text{H}$. The current $I = 100 \text{ mA}$ flows through the circuit. The voltage $U = 10 \text{ V}$ is applied across the series combination. Calculate the frequency f of the AC source.

Solution

$$R_1 = 1 \text{ } \Omega$$

$$R_2 = 10 \text{ } \Omega$$

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:

$$R_{\text{eq}} = R_1 + R_2 = 11 \text{ } \Omega$$

Parallel circuit means that the voltage is the same on R_1 and R_2 :

$$U = I \cdot R_{\text{eq}} = 100 \text{ mA} \cdot 11 \text{ } \Omega = 1.1 \text{ V}$$

Since $U = I \cdot Z$, the impedance Z is perpendicular to R_{eq} .

$$Z = \sqrt{R_{\text{eq}}^2 + (X_L - X_C)^2}$$

$$1.1 = \sqrt{11^2 + (X_L - X_C)^2}$$

$$1.21 = 121 + (X_L - X_C)^2$$

$$(X_L - X_C)^2 = 1.21 - 121 = -119.79$$

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

$$I_{\text{3R}} = I_{\text{R1}} + I_{\text{R2}}$$

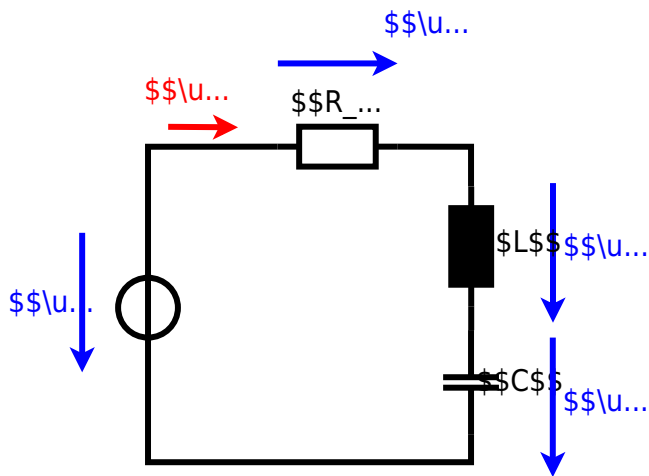
This circuit is a parallel circuit. The current I_{3R} is given by:

$$I_{\text{3R}} = \sqrt{I_{\text{R1}}^2 + I_{\text{R2}}^2}$$

$$I_{\text{3R}} = \sqrt{100^2 + 100^2} = 141.4 \text{ mA}$$

Back to the first formula:

$$R_3 \cdot I_{\text{3R}} = X_{\text{3C}} \cdot I_{\text{3R}}$$



complex impedance, exam ee1 ws2022

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