

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 $1.80 \cdot 10^{-3} \text{ K}^{-1}$ is selected.

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

Determine 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

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

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

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

Exercise E3 Temperature-dependent Resistance

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

A. The following exhibits a temperature sensitive component used in a refrigerator. The component has a resistance of $10 \text{ k}\Omega$ at 25°C . Its temperature coefficients are: $\alpha = 0.01 \text{ } \frac{1}{\text{K}}$ 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 .

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

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.

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

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

[temperature dependent resistance, power, heat, exam ee1 ws2022](#)

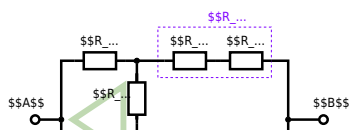
Exercise E1 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be solved. $R_1 = 20 \text{ }\Omega$, $R_2 = 10 \text{ }\Omega$, $R_3 = 15 \text{ }\Omega$, $R_4 = 10 \text{ }\Omega$, $R_5 = 10 \text{ }\Omega$ and the voltage $U = 10 \text{ V}$. Result: R_{eq} .

Solution

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

Now a wye-delta transformation is necessary.

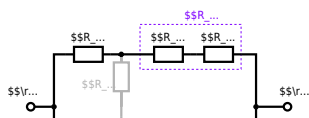


Since $R_2=R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

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:

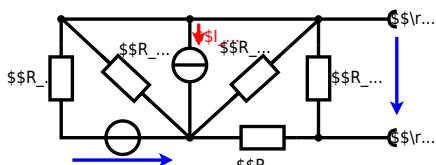
$$R_{\text{eq}} = (R_2 + R_1 + R_1) \parallel (R_2 + R_2) \parallel R_{\text{eq}} = (100 \sim\Omega + 200 \sim\Omega + 200 \sim\Omega) \parallel (100 \sim\Omega + 100 \sim\Omega) \parallel R_{\text{eq}} = (500 \sim\Omega) \parallel (200 \sim\Omega) \parallel R_{\text{eq}} = \frac{\{500 \sim\Omega \cdot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

[network simplification, exam ee1 ws2022](#)

**Exercise E2 Equivalent linear Source
(written test, approx. 14 % of a 60-minute written test, WS2022)**

The circuit in the following has to be simplified.
Result

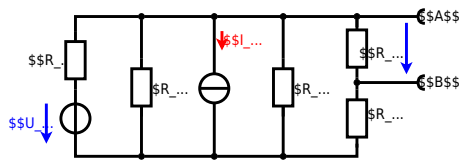
$$U_{\text{s}} = U_{\text{AB}} = 4.5 \text{ V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \sim\Omega$$



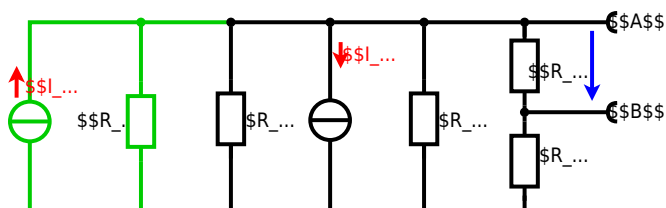
Calculated the internal resistance R_{int} and the source voltage U_{oc} of an equivalent linear voltage source on the connectors A and B . $R_1=5.0 \text{ }\Omega$, $U_2=6.0 \text{ V}$, $R_3= 10 \text{ }\Omega$, $I_4=4.2 \text{ A}$, $R_5=10 \text{ }\Omega$, $R_6=7.5 \text{ }\Omega$, $R_7=15 \text{ }\Omega$ 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:
$$U_{24} = I_{24} \cdot R_{135} + I_3 \cdot R_5$$

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

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

Therefore the voltage between A and B is given as:

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

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

$$U_{AB} = \frac{6.0 \text{ V}}{5.0 \Omega} \cdot \frac{15 \Omega \cdot 2.5 \Omega}{7.5 \Omega + 15 \Omega + 2.5 \Omega}$$

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

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

Exercise E1 Charging Capacitors

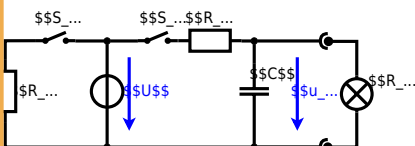
(written test, approx. 16 % of a 60-minute written test, WS2022)

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.

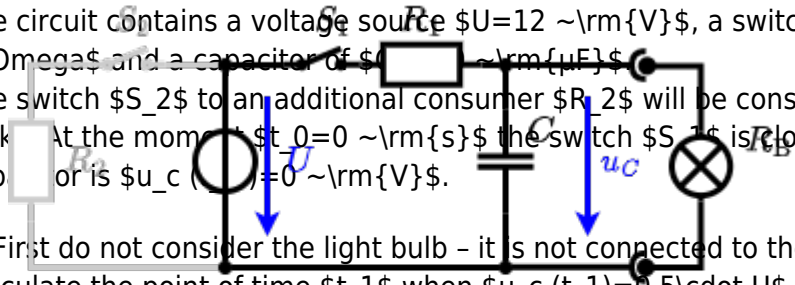
Solution: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

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

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 .

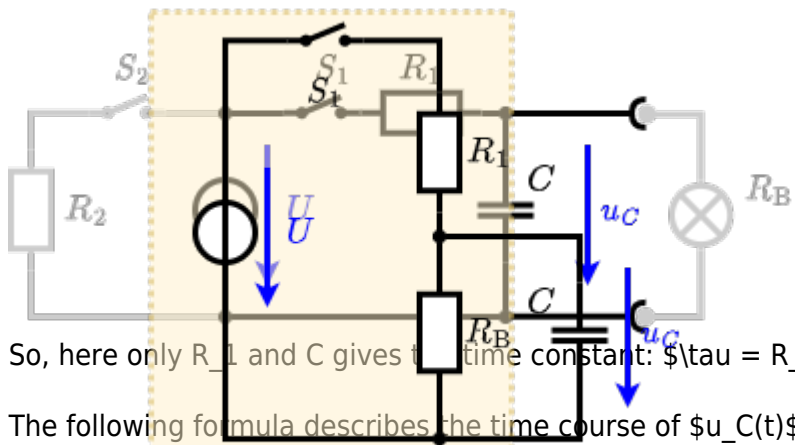


The circuit contains a voltage source $U=12 \text{ V}$, a switch S_1 , a resistor of $R_1=20 \text{ }\Omega$ and a capacitor of $C=100 \text{ }\mu\text{F}$. The switch S_2 to an additional consumer R_2 will be considered to be open for the first task. At the moment $t_0=0 \text{ s}$ the switch S_1 is 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 ($R_i = 0 \text{ }\Omega$, 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 E1 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 bi-dimensional complex impedance Z shall be extracted and given in polar form $Z = |Z| \cdot e^{j\phi}$ where ϕ is the phase angle in degrees. $Z = (2 + j4) \text{ }\Omega + 5j \text{ }\Omega$

Solution Calculate the physical values of the two components.

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

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

Solution

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

Therefore, over $\omega = 10^6 \text{ rad/s}$ the same value of impedance $Z = R + j\omega L - j/\omega C$ must be $Z = R$.

$$R = 10 = 4.68 - \frac{1}{\omega C} + \omega L$$

$$\omega L = \frac{1}{\omega C} + 5.32$$

$$L = \frac{1}{\omega^2 C} + \frac{5.32}{\omega}$$

$$L = \frac{1}{(10^6)^2 \cdot 103 \cdot 10^{-6}} + \frac{5.32}{10^6}$$

$$L = 9.7 \cdot 10^{-12} + 5.32 \cdot 10^{-6} \text{ H}$$

$$L \approx 5.32 \text{ } \mu\text{H}$$

The absolute value $|Z|$ can be calculated as:

$$|Z| = \sqrt{R^2 + (\omega L - 1/\omega C)^2}$$

With the complex part comes the physical value: $X_L = \omega L$

$$X_L = 10^6 \cdot 5.32 \cdot 10^{-6} = 5.32 \text{ } \Omega$$

The phase φ can be calculated as:

$$\varphi = \arctan\left(\frac{\omega L - 1/\omega C}{R}\right)$$

$$\varphi = \arctan\left(\frac{5.32 - 4.68}{10}\right)$$

$$\varphi \approx 3.4^\circ$$

complex impedance, exam ee1 ws2022

Exercise E9 Impedances at different Frequencies
 (written test, approx. 18 % of a 60-minute written test, WS2022)

Exercise E9 The resistor values $R_1 = 1 \text{ } \Omega$, $R_2 = 10 \text{ } \Omega$ and $R_3 = 100 \text{ } \Omega$ are connected in a series circuit of $3 \text{ } \Omega$. A current $I = 10 \text{ } \text{mA}$ flows through the circuit. The high-frequency capacitor $C = 10 \text{ } \text{nF}$ is connected in parallel to R_3 . The resistor R_1 shall have the same absolute value of the impedance as a capacitor $C = 40 \text{ } \text{nF}$ at $f = 4 \text{ } \text{MHz}$.

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_2 and R_3 combined is given by:

$$Z_{23} = R_2 + \frac{R_3}{1 + j\omega C R_3}$$

Parallel circuit means that the voltage is the same on R_2 and C .

$$I_{R_2} = I_{C_1}$$

Since $I_{R_2} = I_{C_1}$ and $V_{R_2} = V_{C_1}$ (voltage is the same), we get:

$$I_{R_2} R_2 = I_{C_1} \frac{1}{j\omega C}$$

$$I_{R_2} R_2 = I_{C_1} \frac{1}{j\omega C}$$

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

$$I_{3R} = I_{R_2} + I_{C_1}$$

This current I_{3R} is the current through R_1 and Z_{23} in series:

$$I_{3R} = I_{R_1} = I_{Z_{23}}$$

$$I_{3R} R_1 = I_{3R} Z_{23}$$

$$R_1 = Z_{23}$$

Back to the first formula:

$$R_1 = R_2 + \frac{R_3}{1 + j\omega C R_3}$$

$$\begin{aligned} |I|_{3C} \parallel R_3 \ \&= \ X_{3C} \ \cdot \ \frac{|I|_{3C}}{|I|_{3R}} \ \parallel \ \&= \\ \frac{1}{2\pi \cdot f \cdot C_3} \ \cdot \ \frac{|\sqrt{|I|_3|^2 - |I|_{3R}|^2}|}{|I|_{3R}} \ \parallel \ \end{aligned}$$

complex impedance, exam ee1 ws2022

Exercise E1 Complex Impedance Circuit
(written test, approx. 15 % of a 60-minute written test, WS2022)

2. Calculate the circuit impedance Z , and the current I in a series circuit. The voltage source is $u(t) = 3.0 \cdot \sin(2\pi \cdot 15 \cdot t)$ V. The circuit consists of a resistor of $10 \ \Omega$, an inductor of $330 \ \mu\text{H}$, and a capacitor of $0.22 \ \mu\text{F}$, all in series.

Result
 $Z = 19.8 \ \Omega$ and $I = 48.2 \ \text{mA}$

Draw the circuit diagram of the given circuit. Label all components, voltages, and currents.

$$\begin{aligned} Z \ \&= \ \frac{U}{I} \ \parallel \ I \ \&= \ \frac{U}{Z} \ \parallel \\ Z_C \ \&= \ \frac{1}{2\pi \cdot f \cdot C} \ \parallel \ \&= \ \frac{1}{2\pi \cdot 15 \ \text{kHz} \cdot 0.22 \ \mu\text{F}} \end{aligned}$$

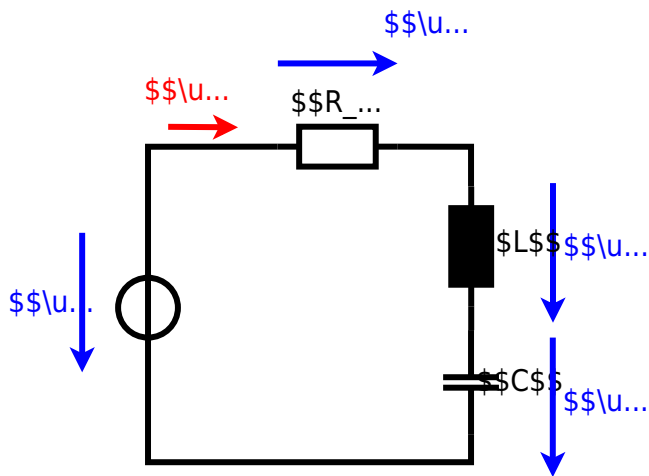
$$\begin{aligned} Z_L \ \&= \ 2\pi \cdot f \cdot L \ \parallel \ \&= \ 2\pi \cdot 15 \ \text{kHz} \cdot 330 \ \mu\text{H} \end{aligned}$$

$$\begin{aligned} Z \ \&= \ \sqrt{R^2 + (Z_L - Z_C)^2} \ \parallel \ \&= \ \sqrt{10^2 + (19.28 - 1.92)^2} \end{aligned}$$

$$\begin{aligned} \underline{Z} \ \&= \ R + j \cdot (Z_L - Z_C) \ \parallel \ \&= \ 10 + j \cdot (19.28 - 1.92) \end{aligned}$$

$$\begin{aligned} |\underline{Z}| \ \&= \ \sqrt{R^2 + (Z_L - Z_C)^2} \ \parallel \ \end{aligned}$$





complex impedance, exam ee1 ws2022

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