

ws2022_exam_r

Student Group

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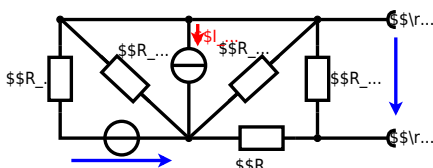
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Exercise E1 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022)

The circuit in the following has to be simplified.
Result

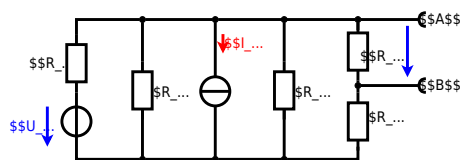
$$\begin{aligned} U_{\text{rs}} &= U_{\text{AB}} = 4.5 \text{ V} \\ R_{\text{ri}} &= R_{\text{AB}} = 6 \Omega \end{aligned}$$



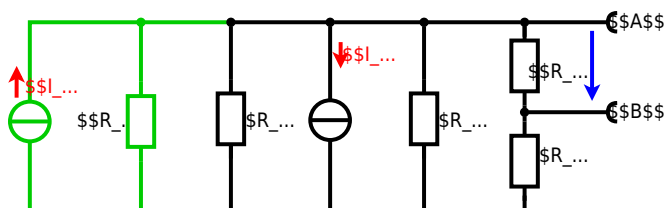
Calculated the internal resistance R_{ri} and the source voltage U_{rs} of an equivalent linear voltage source on the connectors A and B .
 $R_1 = 5.0 \Omega$, $U_2 = 6.0 \text{ V}$, $R_3 = 10 \Omega$, $I_4 = 4.2 \text{ A}$, $R_5 = 10 \Omega$, $R_6 = 7.5 \Omega$, $R_7 = 15 \Omega$
 Use equivalent sources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

$$U_{24} = R_{135} \cdot I_{24} \quad \&= \left(\frac{U_2}{R_1} - I_4 \right) \cdot R_1 \parallel R_3 \parallel R_5$$

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 ($\omega = 0$, so a short-circuit):

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

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

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

Exercise E1 Temperature-dependent Resistance (written test, approx. 6 % of a 60-minute written test, WS2022)

2. According to question 2, the effective resistance of the refrigeration system has a resistance of $6.5 \, \Omega$ at 25°C and $2.5 \, \Omega$ at 0°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 .

$$R = 6.5 \, \Omega \quad \text{at } 25^\circ\text{C}$$

The power of the electric heater is $P = U^2 / R$. Therefore, a solution is to let 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.

$$R = R_0 \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2) \quad | \quad \Delta T = T_{\text{end}} - T_{\text{start}} \\ R = 10 \, \Omega \cdot \left(1 + 0.01 \cdot (-40 - 25) + 71 \cdot 10^{-6} \cdot (-40 - 25)^2 \right)$$

Exercise E1 Analyzing complex Impedances

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

2. Calculate the complex impedance $\underline{Z}$ of the circuit shown in the figure. The components $\underline{U}_R$ and $\underline{U}_X$ shall be given.

After analysis, the full bridge network can be impedance, and be extracted and begin (align*) in phase (align*) late (align*) (2) however (align*) + 5 (align*) (rm j) (right) \Omega end (align*)

Solution
.. Calculate the physical values of the two components.

Solution
$$\underline{R} = 0.12 \cdot 10^3 \Omega = 120 \Omega$$

$$\underline{X}_L = 2 \pi \cdot 300 \text{ Hz} \cdot 0.68 \text{ mH} = 255.6 \Omega$$

Solution

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} \quad \underline{U} = 50 \text{ V}$$

The voltage $\underline{U}_R$ across the resistor is $\underline{U}_R = \underline{I} \cdot \underline{R}$ and the voltage $\underline{U}_X$ across the inductor is $\underline{U}_X = \underline{I} \cdot \underline{X}_L$.
The resulting impedance $\underline{Z}$ is $\underline{Z} = \underline{R} + j \underline{X}_L = 120 \Omega + j 255.6 \Omega$.
Therefore, the component $\underline{X}_L$ is a pure inductor with the same absolute value $\underline{X}_L = 255.6 \Omega$.
$$\underline{Z} = \underline{R} + j \underline{X}_L = 120 \Omega + j 255.6 \Omega$$

$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \text{ V}}{120 \Omega + j 255.6 \Omega} = \frac{50}{120 + j 255.6} \text{ A}$$

The absolute value $|\underline{I}|$ is $|\underline{I}| = \frac{50}{\sqrt{120^2 + 255.6^2}} = 0.12 \text{ A}$.
The phase φ is $\varphi = \arctan\left(\frac{255.6}{120}\right) = 65.5^\circ$.
With the complex part (align*) (2) however (align*) + 5 (align*) (rm j) (right) \Omega end (align*)
$$\underline{I} = 0.12 \text{ A} \cdot e^{-j 65.5^\circ}$$

The phase φ can be calculated as
$$\varphi = \arctan\left(\frac{\text{Im}(\underline{I})}{\text{Re}(\underline{I})}\right) = \arctan\left(\frac{-0.12 \sin(65.5^\circ)}{0.12 \cos(65.5^\circ)}\right) = -65.5^\circ$$

Exercise E1 Complex Impedance Circuit

(written test, approx. 15 % of a 60-minute written test, WS2022)

2. Calculate the complex impedance $\underline{Z}$ of the circuit shown in the figure. The components $\underline{U}_R$ and $\underline{U}_X$ shall be given. The voltage source $u(t) = 3.0 \cdot \sin(2\pi \cdot 15 \cdot t) \text{ V}$ is connected to a series circuit of an inductor of $330 \mu\text{H}$ and a capacitor of $0.22 \mu\text{F}$.

Solution
The linear source is connected with an inductor of $330 \mu\text{H}$ and a capacitor of $0.22 \mu\text{F}$, all in series.

Result

$$\underline{Z} = 19.8 \Omega$$

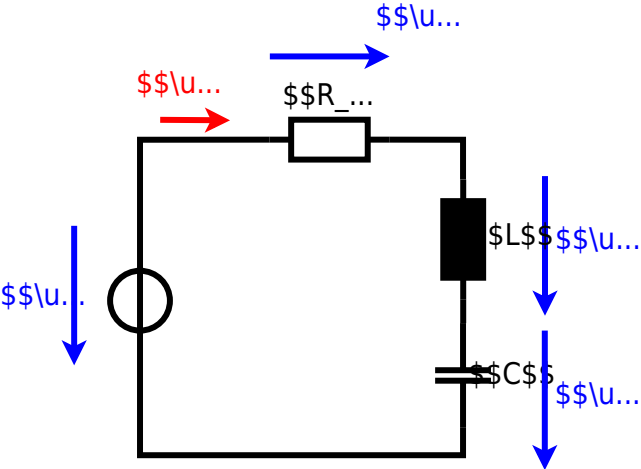
Draw the circuit diagram of the given circuit. Label all components, voltages, and currents.
$$\underline{Z} = \frac{\underline{U}}{\underline{I}} \quad \underline{U} = 3.0 \text{ V} \quad \underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{3.0 \text{ V}}{19.8 \Omega} = 0.15 \text{ A}$$

Result
$$\underline{Z} = 19.8 \Omega$$

With $\underline{Z} = 19.8 \Omega$ and $\underline{U} = 3.0 \text{ V}$, the current $\underline{I}$ is
$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{3.0 \text{ V}}{19.8 \Omega} = 0.15 \text{ A}$$

The voltage $\underline{U}_R$ across the resistor is
$$\underline{U}_R = \underline{I} \cdot \underline{R} = 0.15 \text{ A} \cdot 19.8 \Omega = 2.97 \text{ V}$$

The voltage $\underline{U}_X$ across the inductor is
$$\underline{U}_X = \underline{I} \cdot \underline{X}_L = 0.15 \text{ A} \cdot 255.6 \Omega = 38.34 \text{ V}$$



Exercise E1 Impedances at different Frequencies

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

2. A series circuit with a resistor $R_1 = 1.00 \text{ k}\Omega$ and a capacitor $C_1 = 40 \text{ nF}$ is connected to an AC voltage source $U = 10 \text{ V}$ at a frequency $f = 4 \text{ MHz}$. The impedance of the resistor R_1 shall have the same absolute value of the impedance as a capacitor C_1 at $f = 4 \text{ MHz}$.

Solution

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

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

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

The equivalent impedance for R_1 and C_1 combined is given by

$$Z_{\text{eq}} = \sqrt{R_1^2 + X_{C1}^2}$$

$$Z_{\text{eq}} = \sqrt{R_1^2 + \left(\frac{U}{I}\right)^2}$$

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Exercise E1 Resistance of a Wire by Resistivity

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

2. A heating element made of nichrome wire with a diameter $d = 0.5 \text{ mm}$ and a length $L = 3 \text{ m}$ is connected to a power supply $U = 10 \text{ V}$. The power dissipation ($=$ heat flow) of $P = 40 \text{ W}$ is necessary.

Calculate the current I and the resistance R of the heating element.

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

The heating element is 3 m long and has a diameter of 0.5 mm .

Calculate the resistance R of the heating element.

Solution

$$P = U \cdot I = R \cdot I^2 \quad \rightarrow \quad I = \sqrt{\frac{P}{R}}$$

$$\sqrt{\frac{P}{R}} = \sqrt{\frac{40 \text{ W}}{0.33 \cdot \Omega}} \quad \text{end{align*}}$$

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

Exercise E1 Charging Capacitors

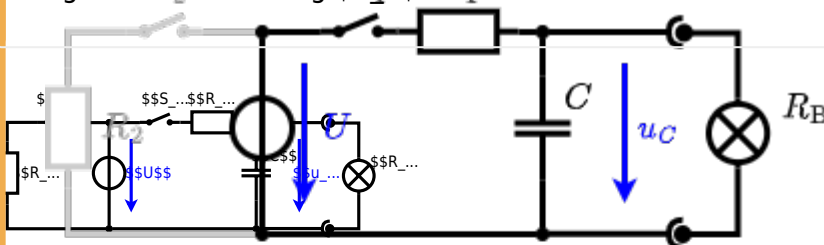
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit (see below) also consists of a resistor $R_1 = 20 \text{ } \Omega$ and a capacitor $C = 100 \text{ } \mu\text{F}$. 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 Hint: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

Solution The ideal voltage source $U = 12 \text{ V}$ is in series with the resistor $R_1 = 20 \text{ } \Omega$. The voltage u_C is independent of this series combination.

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 S_2 .

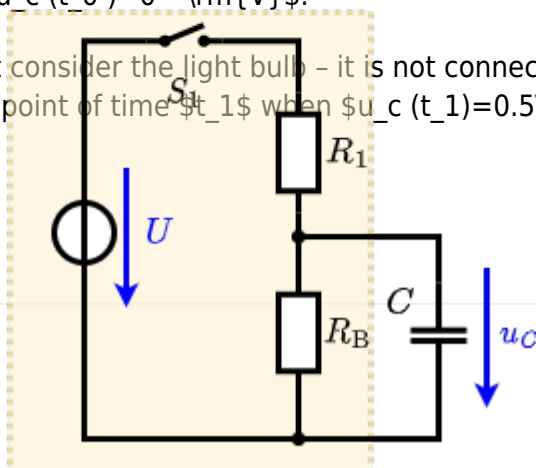


The circuit contains a voltage source $U = 12 \text{ V}$, a switch S_1 , a resistor of $R_1 = 20 \text{ } \Omega$ and a capacitor of $C = 100 \text{ } \mu\text{F}$.

The switch S_2 to an additional consumer R_2 will be considered to be open for the first tasks. 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



An equivalent linear voltage source can be given with U_s , R_1 , and 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 ($= 0 \Omega$, short-circuit).

$$R_i = R_1 \parallel R_B = 10 \Omega$$

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

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 t : $(1 - e^{-t/\tau}) = 0.5$

$$e^{-t/\tau} = 0.5 \quad \ln(0.5) = -t/\tau \quad t = \tau \cdot \ln(0.5) = R_1 \cdot C \cdot \ln(0.5)$$

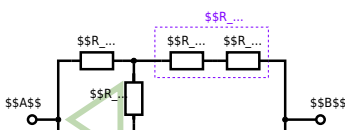
Exercise E1 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be simplified with $R_1 = 200 \Omega$, $R_2 = 100 \Omega$, $R_3 = 150 \Omega$, $R_4 = 100 \Omega$ and the voltage source $U = 10 \text{ V}$.
Result: R_B .

Solution

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

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:

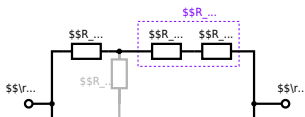
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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:

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

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