

Exam Winter Semester 2022

Student Group

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Exercise E1 Resistance of a Wire by Resistivity (written test, approx. 6 % of a 60-minute written test, WS2022)

A heating element made of solid nichrome wire with a cross-section of 1.80 mm^2 is used. Electric power dissipation (= heat flow) of $P=40 \text{ W}$ is necessary.

Determine the current I linked to the operating voltage for heating elements.

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

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

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

Exercise E1 Resistance of a Wire by Resistivity (written test, approx. 6 % of a 60-minute written test, WS2022)

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

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Exercise E1 Temperature-dependent Resistance

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

2. A refrigerator, which has a temperature coefficient of performance of 2.5, has a resistance of $10 \text{ k}\Omega$ at 25°C . Your answer.

Its temperature coefficients are: $\alpha = 0.01 \text{ K}^{-1}$ and $\beta = 71 \text{ K}^{-2}$.

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

$$R = 6.5 \text{ k}\Omega$$

The power transfer resistor P is the output of the circuit and generates heat. Therefore, a solution is to use a heat sink to cool the refrigerator system.

Therefore, with constant U and increasing R the power decreases. Ten times more resistance decreases the heat flow to one-tenth.

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

Exercise E2 Temperature-dependent Resistance**(written test, approx. 6 % of a 60-minute written test, WS2022)**

2. A refrigerator, which has a temperature coefficient of performance of 2.5, has a resistance of $10 \text{ k}\Omega$ at 25°C . Your answer.

Its temperature coefficients are: $\alpha = 0.01 \text{ K}^{-1}$ and $\beta = 71 \text{ K}^{-2}$.

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

$$R = 6.5 \text{ k}\Omega$$

The power transfer resistor P is the output of the circuit and generates heat. Therefore, a solution is to use a heat sink to cool the refrigerator system.

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

Exercise E1 Pure Resistor Network Simplification

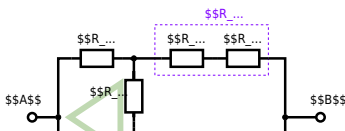
(written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall now be closed and the equivalent resistance R_{eq} between terminals A and B shall be calculated. The switch shall now be open. Calculate the equivalent resistance R_{eq} between terminals A and B.

Solution

$$R_{\text{eq}} = 133.8 \, \Omega$$

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:

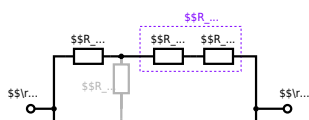
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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

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

The switch shall now be open. Calculate the equivalent resistance R_{eq} between terminals A and B.

Solution



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

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

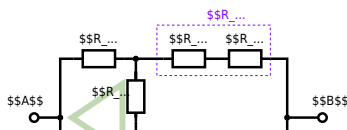
Exercise E3 Pure Resistor Network Simplification (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be solved with $R_1 = 200 \, \Omega$, $R_2 = 100 \, \Omega$, $R_3 = 150 \, \Omega$, $R_4 = 100 \, \Omega$, and the voltage source $U_{SV} = 10 \, \text{V}$.
Result given: $R_{eq} = 132.8 \, \Omega$.

Solution

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

Now a wye-delta transformation is necessary.



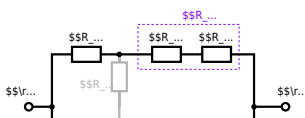
Since $R_2 = R_3$ and based on the equations for the transformation, the transformed R_Y is given as:
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2 + R_2} = \frac{(100 \, \Omega)^2}{3 \cdot 100 \, \Omega} = \frac{1}{3} \cdot 100 \, \Omega = 33.33 \, \Omega$$

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



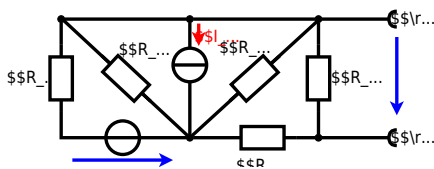
The equivalent resistor is given by a parallel configuration of resistors in series:

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

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

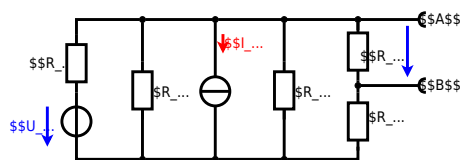
$$U_{\text{s}} = U_{\text{AB}} = 4.5 \, \text{V} \quad R_{\text{i}} = R_{\text{AB}} = 6 \, \Omega$$



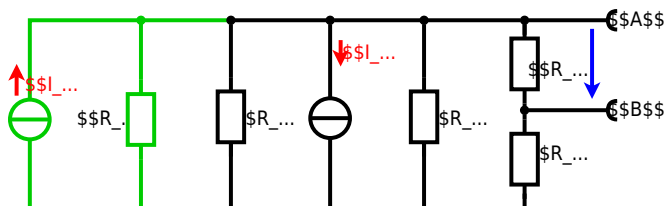
Calculate the internal resistance R_{int} and the source voltage U_{S} of an equivalent linear voltage source on the connectors A and B . $\begin{aligned} R_1 &= 5.0 \, \Omega, \quad U_2 = 6.0 \, \text{V}, \quad R_3 = 10 \, \Omega, \quad I_4 = 4.2 \, \text{A}, \\ R_5 &= 10 \, \Omega, \quad R_6 = 7.5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

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

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

The resulting circuit can again be transformed:



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

$$U_{24} = I_{24} \cdot R_{135}$$

$$U_{24} = U_{23} \cdot \frac{R_7}{R_6 + R_7 + R_1 \parallel R_3 \parallel R_5} = (U_2 - U_4) \cdot \frac{R_7}{R_6 + R_7 + R_1 \parallel R_3 \parallel R_5}$$

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:

$$U_{AB} = U_{24} \cdot \frac{R_7}{R_6 + R_7 + R_1 \parallel R_3 \parallel R_5} = (U_2 - U_4) \cdot \frac{R_7}{R_6 + R_7 + R_1 \parallel R_3 \parallel R_5}$$

For the internal resistance R_i the ideal voltage source is substituted by its resistance ($=0\Omega$, so a short-circuit):

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

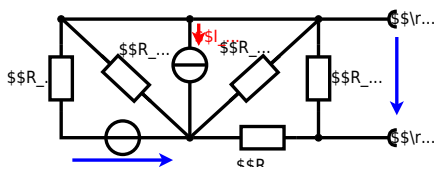
with $R_1 \parallel R_3 \parallel R_5 = 5\Omega \parallel 10\Omega \parallel 10\Omega = 5\Omega \parallel 5\Omega = 2.5\Omega$:

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

Exercise E4 Equivalent linear Source (written test, approx. 14 % of a 60-minute written test, WS2022)

The circuit in the following has to be simplified.
Result

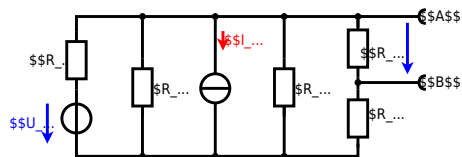
$$U_s = U_{AB} = 4.5\text{V} \quad R_i = R_{AB} = 6\Omega$$



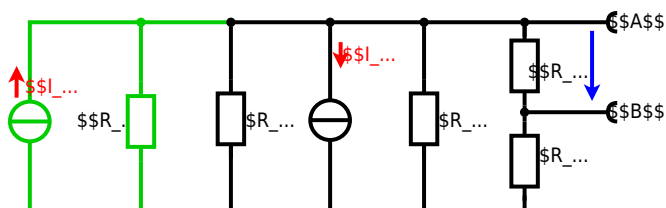
Calculate the internal resistance R_{int} and the source voltage U_s of an equivalent linear voltage source on the connectors A and B. $\begin{aligned} R_1 &= 5.0 \, \Omega, \quad U_2 = 6.0 \, \text{V}, \quad R_3 = 10 \, \Omega, \quad I_4 = 4.2 \, \text{A}, \\ R_5 &= 10 \, \Omega, \quad R_6 = 7.5 \,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

$$U_{24} = I_{24} \cdot R_{135}$$

$$I_{24} = \frac{U_{24}}{R_1 + R_3 + R_5} = \frac{6.0 \text{ V} - 4.2 \text{ V}}{5.0 \Omega + 10 \Omega + 10 \Omega} = 0.15 \text{ A}$$

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

$$U_{AB} = U_{24} \cdot \frac{R_7}{R_6 + R_7 + R_1 + R_3 + R_5} = \frac{6.0 \text{ V} - 4.2 \text{ V}}{5.0 \Omega + 10 \Omega + 10 \Omega} \cdot \frac{15 \Omega}{15 \Omega + 7.5 \Omega + 2.5 \Omega} = 1.5 \text{ V}$$

For the internal resistance R_i the ideal voltage source is substituted by its resistance ($=0 \Omega$, so a short-circuit):

$$R_{AB} = R_7 \parallel (R_6 + R_1 + R_3 + R_5) = 15 \Omega \parallel (10 \Omega + 10 \Omega + 10 \Omega) = 2.5 \Omega$$

with $R_1 + R_3 + R_5 = 5 \Omega + 10 \Omega + 10 \Omega = 25 \Omega$

$$U_{AB} = \frac{6.0 \text{ V} - 4.2 \text{ V}}{5.0 \Omega + 10 \Omega + 10 \Omega} \cdot \frac{15 \Omega}{15 \Omega + 7.5 \Omega + 2.5 \Omega} = 1.5 \text{ V}$$

Exercise E1 Charging Capacitors

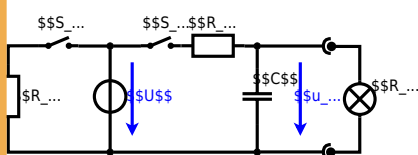
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit below is a simplified model of a power supply unit. It consists of a DC voltage source U with an internal resistance R_1 and a switch S_1 . 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.

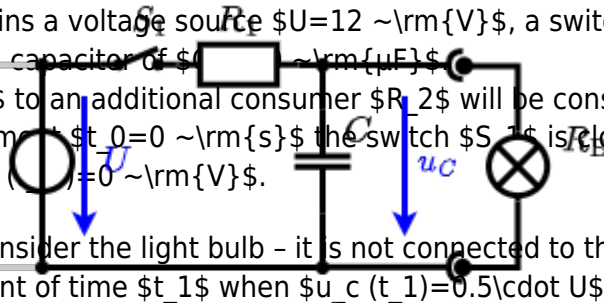
Hint: To solve this, first create an equivalent linear voltage source from U , R_1 , and R_2 .

Solution: The equivalent circuit is shown below. The ideal voltage source U_{eq} is given by $U_{eq} = \frac{U \cdot R_2}{R_1 + R_2}$ and the internal resistance R_{eq} is given by $R_{eq} = \frac{R_1 \cdot R_2}{R_1 + R_2}$.

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 .



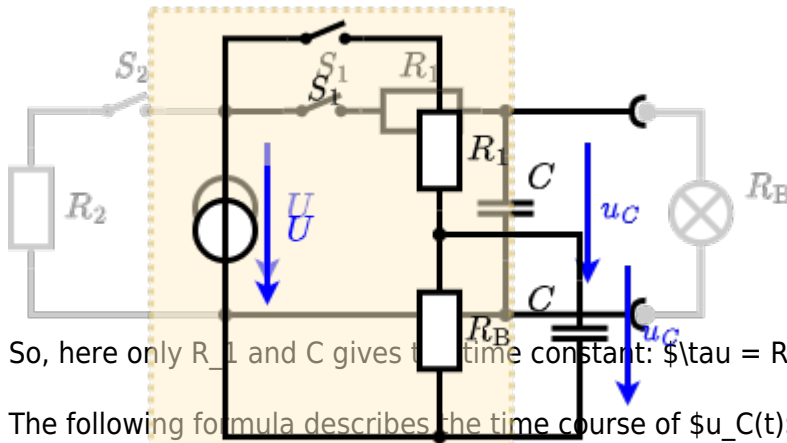
The circuit contains a voltage source $U=12\text{ V}$, a switch S_1 , a resistor of $R_1=20\text{ }\Omega$ and a capacitor of $C=100\text{ }\mu\text{F}$. The switch S_2 to an additional consumer R_2 will be considered to be open for the first task. At the moment $t_0=0\text{ s}$ the switch S_1 is closed, 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 , 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 ($=0\text{ }\Omega$, short-circuit).

$$R_i = R_1 \parallel R_B = 10\text{ }\Omega$$

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

Exercise E5 Charging Capacitors

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

The circuit (see the solution) consists of a 12 V voltage source, a $20\text{ }\Omega$ resistor, a $100\text{ }\mu\text{F}$ capacitor, and a $20\text{ }\Omega$ 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

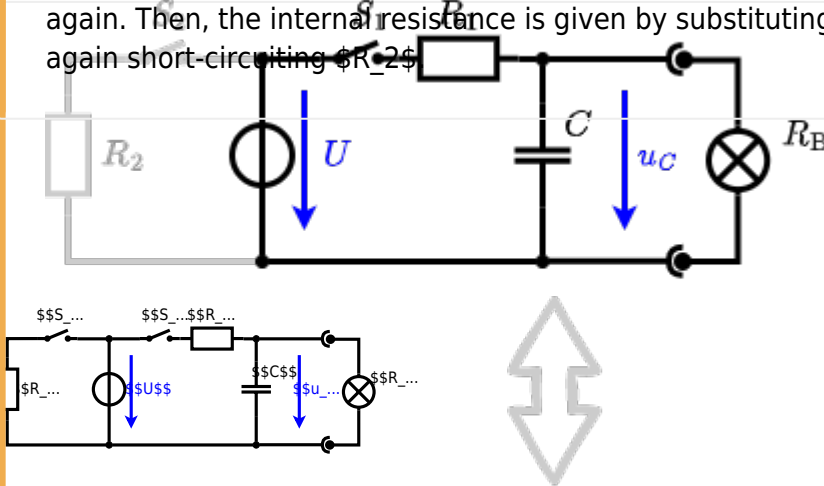
To solve this, first create an equivalent linear voltage source from U , R_1 , and R_B .

$$U_s = U \cdot \frac{R_B}{R_1 + R_B} = \frac{1}{2} \cdot U = 6\text{ V}$$

Solution

The ideal voltage source is given by $U_s = U \cdot \frac{R_1}{R_1 + R_B}$ and the internal resistance is given by $R_i = R_1 \parallel R_B$.

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 .

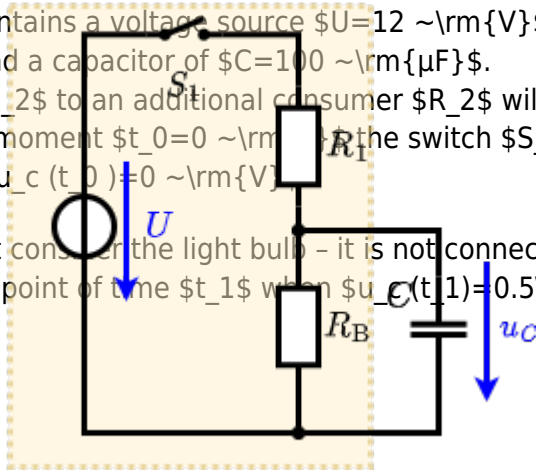


The circuit contains a voltage source $U = 12 \text{ V}$, a switch S_1 , a resistor of $R_1 = 20 \text{ }\Omega$ and a capacitor of $C = 100 \text{ }\mu\text{F}$.

The switch S_2 to an additional consumer R_2 will be considered to be open for the first tasks. At the moment $t_0 = 0$ 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 ($R_i = 0 \text{ }\Omega$, short-circuit).

$$R_i = R_1 \parallel R_B = 10 \text{ }\Omega$$

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 t :

$$(1 - e^{-t/\tau}) = 0.5 \implies e^{-t/\tau} = 0.5 \implies -t/\tau = \ln(0.5) \implies t = \tau \cdot \ln(0.5) \implies t = R_1 \cdot C \cdot \ln(0.5)$$

The absolute value of the impedance is $\sqrt{(0.24 \sim \Omega)^2 + (4.68 \sim \Omega)^2} = 4.7 \sim \Omega$.
 The phase φ is $\arctan\left(\frac{4.68 \sim \Omega}{0.24 \sim \Omega}\right) = 87.1^\circ$.
 With the complex part comes the physical value: $X_L = \omega L = 2\pi \cdot 4.7 \sim \Omega$.
 The phase φ is $\arctan\left(\frac{4.68 \sim \Omega}{0.24 \sim \Omega}\right) = 87.1^\circ$.
 The phase φ is $\arctan\left(\frac{4.68 \sim \Omega}{0.24 \sim \Omega}\right) = 87.1^\circ$.

Exercise E1 Impedances at different Frequencies

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

A series circuit means that the current is constant on every component.
 The equivalent impedance for R and L combined is given by $Z = \sqrt{R^2 + X_L^2}$.
 The equivalent impedance for R and C combined is given by $Z = \sqrt{R^2 + X_C^2}$.
 The equivalent impedance for R , L and C combined is given by $Z = \sqrt{R^2 + (X_L - X_C)^2}$.
 The equivalent impedance for R , L and C combined is given by $Z = \sqrt{R^2 + (X_L - X_C)^2}$.

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 and L combined is given by $Z = \sqrt{R^2 + X_L^2}$.

Parallel circuit means that the voltage is the same on R_1 and R_2 .
 $\frac{1}{Z} = \frac{1}{R_1} + \frac{1}{R_2}$ since $\frac{1}{Z} = \frac{1}{R_1} + \frac{1}{R_2}$ is perpendicular to R_2 this can be simplified to $\frac{1}{Z} = \frac{1}{R_1} + \frac{1}{R_2}$.

$\frac{1}{Z} = \frac{1}{R_1} + \frac{1}{R_2}$ is perpendicular to R_1 (It has to, since R_1 is perpendicular to R_2).

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

$\frac{1}{Z} = \frac{1}{R_1} + \frac{1}{R_2}$

This can be simplified to $\frac{1}{Z} = \frac{1}{R_1} + \frac{1}{R_2}$.

Back to the first formula: $Z = \sqrt{R^2 + X_L^2}$

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Exercise E7 Impedances at different Frequencies

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

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

1. Calculate the equivalent impedance Z for the circuit shown in the following diagram (of 3S) 21.B.0
 $\sim \sqrt{R} X_s \omega f B = 200 = 450 \sim \text{kHz}$ high frequency capacitor $C = 10 \sim \text{pF}$ $\sim \sqrt{R} A_s$ through
 R_3 resistor R_1 shall have the same absolute value of the impedance as a capacitor

$C_1 = 40 \sim \text{nF}$ at $f_1 = 4 \sim \text{MHz}$.

Solution: $\begin{aligned} R_1 &= 1.00 \sim \Omega \end{aligned}$

Solution: $\begin{aligned} R_2 &= 10.0 \sim \Omega \end{aligned}$

Solution

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

The equivalent impedance for R and L combined is given by $\begin{aligned} \end{aligned}$

Parallel circuit means that the voltage is the same on R_1 and R_2 $\begin{aligned} \end{aligned}$

$\begin{aligned} R_1 &= \sqrt{R_2^2 + X_{L2}^2} \end{aligned}$ Since $X_{L2} = 2\pi f \cdot L = 2\pi \cdot 450 \cdot 10^{-6} = 1.36 \sim \Omega$

$\begin{aligned} R_1 &= \sqrt{1^2 + 1.36^2} = 1.69 \sim \Omega \end{aligned}$ (It has to, since R_3 is perpendicular to X_{L2})

$\begin{aligned} R_1 &= \sqrt{R_2^2 + X_{L2}^2} \end{aligned}$ (It has to, since R_3 is perpendicular to X_{L2})

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Therefore, the resulting current of the parallel circuit is given as: $\begin{aligned} \end{aligned}$

$\begin{aligned} I_{\text{total}} &= I_{\text{R1}} + I_{\text{R2}} \end{aligned}$

This can be simplified to: $\begin{aligned} I_{\text{total}} &= \frac{U}{R_1} + \frac{U}{R_2} \end{aligned}$

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Back to the first formula: $\begin{aligned} R_3 \cdot I_{\text{total}} &= X_{C3} \cdot I_{\text{total}} \end{aligned}$

$\begin{aligned} R_3 &= X_{C3} \end{aligned}$

$\begin{aligned} R_3 &= \frac{1}{2\pi f \cdot C_3} \end{aligned}$

$\begin{aligned} R_3 &= \frac{1}{2\pi \cdot 450 \cdot 10^{-6}} \end{aligned}$

Exercise E1 Complex Impedance Circuit

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

1. Calculate the equivalent impedance Z for the circuit shown in the following diagram (of 3S) 21.B.0

$\begin{aligned} R_1 &= 1.00 \sim \Omega \end{aligned}$ Since $X_{L2} = 2\pi f \cdot L = 2\pi \cdot 450 \cdot 10^{-6} = 1.36 \sim \Omega$

$\begin{aligned} R_1 &= \sqrt{R_2^2 + X_{L2}^2} \end{aligned}$ (It has to, since R_3 is perpendicular to X_{L2})

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Solution

Result

$\begin{aligned} R_1 &= 1.00 \sim \Omega \end{aligned}$ Since $X_{L2} = 2\pi f \cdot L = 2\pi \cdot 450 \cdot 10^{-6} = 1.36 \sim \Omega$

$\begin{aligned} R_1 &= \sqrt{R_2^2 + X_{L2}^2} \end{aligned}$ (It has to, since R_3 is perpendicular to X_{L2})

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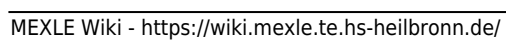
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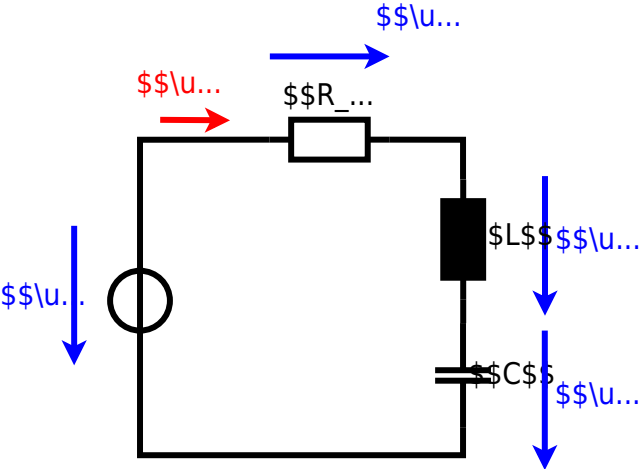
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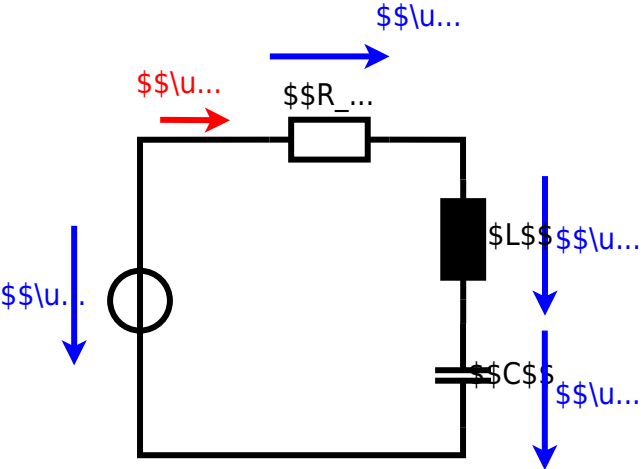
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