

Exam Winter Semester 2022

Student Group

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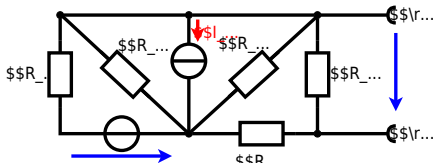
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**Exercise E1 Equivalent linear Source
(written test, approx. 14 % of a 60-minute written test, WS2022)**

The circuit in the following has to be simplified.
Result

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

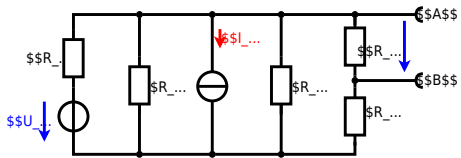
$$R_{\text{i}} = R_{\text{AB}} = 6 \text{ } \Omega$$



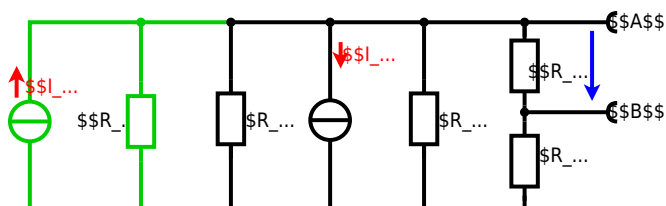
Calculated the internal resistance R_{i} and the source voltage U_{rs} of an equivalent linear voltage source on the connectors A and B .
 $R_1=5.0 \text{ } \Omega$, $U_2=6.0 \text{ V}$, $R_3= 10 \text{ } \Omega$, $I_4=4.2 \text{ A}$, $R_5=10 \text{ } \Omega$, $R_6=7.5 \text{ } \Omega$, $R_7=15 \text{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

$$U_{24} = I_{24} \cdot R_{23}$$

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

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:

$$U_{AB} = U_{24} \cdot \frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} - \left(\frac{U_2}{R_1} - I_4 \right) \cdot \frac{R_7 \cdot R_1 || R_3 || R_5}{R_6 + R_7 + R_1 || R_3 || R_5}$$

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

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

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

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

2. The graph shows the temperature dependence of the resistance of a resistor. The resistor has a resistance of $10 \text{ k}\Omega$ at 25°C . Calculate the resistance of the thermistor at -40°C .

Its temperature coefficients are: $\alpha = 0.01 \text{ K}^{-1}$ and $\beta = 71 \cdot 10^{-6} \text{ K}^{-2}$.

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

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

Resistance of the resistor R depends on the temperature T and the heat Q . Therefore, a solution is to use a heat pump 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.

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

with $\Delta T = T_{\text{end}} - T_{\text{start}}$

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

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Exercise E2 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the phasor voltage \underline{u} (in V) at $t = 30$ ms for the circuit shown in the figure. The components R and X_L shall be given.

After analysis, the following phasor voltage \underline{u} is extracted: $\underline{u} = 48.2 \angle -19.8^\circ$ V in phasor notation. Write the time-domain voltage $u(t)$ in V.

Solution
.. Calculate the physical values of the components.
Solution $R = 10 \Omega$, $X_L = 20 \Omega$, $C = 100 \mu\text{F}$

Solution
$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \angle 0^\circ}{10 + j20 - j16} = \frac{50 \angle 0^\circ}{10 + j4} = 4.68 \angle -21.1^\circ \text{ A}$$

The current and voltage are in phase since the circuit is purely resistive.
The voltage across the capacitor is $\underline{u}_C = \underline{I} \cdot \underline{Z}_C = 4.68 \angle -21.1^\circ \cdot (-j16) = -74.88 \angle -21.1^\circ = 74.88 \angle 68.9^\circ$ V.
The voltage across the inductor is $\underline{u}_L = \underline{I} \cdot \underline{Z}_L = 4.68 \angle -21.1^\circ \cdot j20 = 93.6 \angle 68.9^\circ$ V.
The total voltage is $\underline{u} = \underline{u}_C + \underline{u}_L = 74.88 \angle 68.9^\circ + 93.6 \angle 68.9^\circ = 168.48 \angle 68.9^\circ$ V.
With the complex part comes the magnitude value $u = 168.48 \cos(2\pi \cdot 15 \cdot t + 68.9^\circ)$ V.
The phase φ can be calculated as $\varphi = \arctan\left(\frac{\text{Im}(\underline{u})}{\text{Re}(\underline{u})}\right) = \arctan\left(\frac{148.2}{48.2}\right) = 71.1^\circ$.

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

2. Calculate the resulting phasor voltage \underline{u} (in V) at $t = 30$ ms for the circuit shown in the figure. The components R and X_L shall be given. The voltage source $u(t) = 3.0 \cdot \sin(2\pi \cdot 15 \cdot t)$ V is connected to a series combination of an inductor of $330 \mu\text{H}$ and a capacitor of $30.22 \mu\text{F}$, all in series.

Solution
Result
.. Draw the circuit diagram of the given circuit. Label all components, voltages, and currents.
Solution $R = 10 \Omega$, $X_L = 20 \Omega$, $X_C = 48.2 \Omega$, $Z = 19.8 \Omega$

```

\begin{align*} Z &= \frac{\hat{U}}{\hat{I}} \quad \hat{I} = \frac{\hat{U}}{Z} \\
\end{align*}
\begin{align*} Z_C &= \frac{1}{2\pi \cdot f \cdot C} \quad \omega = 2\pi \cdot 15 \\
\text{Winkel } \varphi &= \arctan\left(\frac{X_L}{X_C}\right) = \arctan\left(\frac{2\pi \cdot f \cdot L}{\frac{1}{2\pi \cdot f \cdot C}}\right) \\
\end{align*}
\begin{align*} Z &= \sqrt{R^2 + (X_L - X_C)^2} \\
\end{align*}
\begin{align*} Z_C &= \frac{1}{2\pi \cdot f \cdot C} \quad \omega = 2\pi \cdot 15 \\
&\sim \text{kHz} \cdot 330 \sim \mu\text{H} \\
\end{align*}
\begin{align*} \underline{Z} &= R + j \cdot \underline{Z}_L - j \cdot \underline{Z}_C \quad \underline{Z} = R + j \cdot (\underline{Z}_L - \underline{Z}_C) \\
|\underline{Z}| &= \sqrt{R^2 + (\underline{Z}_L - \underline{Z}_C)^2} \\
\end{align*}

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Exercise E3 Impedances at different Frequencies (written test, approx. 18 % of a 60-minute written test, WS2022)

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_2 and C_2 combined is given by

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

Since R_2 and X_{C2} are perpendicular to each other, the resulting current of the parallel circuit is given as:

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

Back to the first formula:

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Exercise E4 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 diameter of $d = 0.357 \text{ mm}$ and a length of $l = 3.57 \text{ m}$ is used for heating. The power dissipation ($P = 40 \text{ W}$) is necessary. Calculate the resistance R of the heating element.

Solution

$R = 10.3 \text{ }\Omega$

Solution

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

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

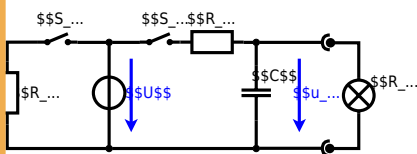
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Exercise E5 Charging Capacitors
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit (with the real battery) also takes into account the internal resistance R_1 of the battery and the capacitor C is initially charged to $U_0 = 20 \text{ V}$. The voltage across the capacitor is again U_0 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 is in series with the internal resistance R_1 and the external resistor R_2 . The voltage across the capacitor is $u_c(t) = U \cdot (1 - e^{-t/\tau})$, where $\tau = R_1 \cdot C$.
 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 .

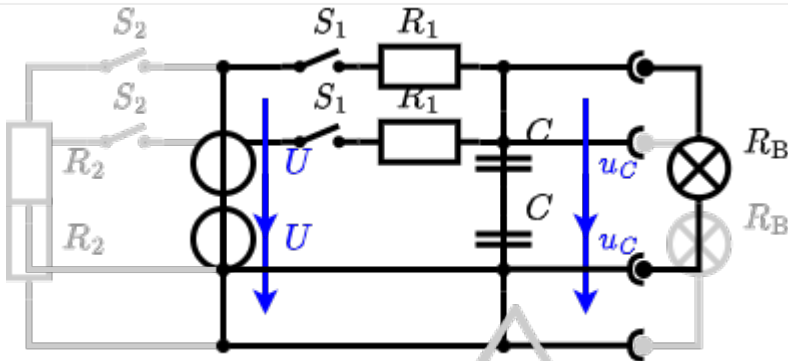


The circuit contains a voltage source $U = 12 \text{ V}$, a switch S_1 , a resistor of $R_1 = 20 \text{ } \Omega$ and a capacitor of $C = 100 \text{ } \mu\text{F}$.

The switch S_2 to an additional consumer R_2 will be considered to be open for the first asks. At the moment $t_0 = 0 \text{ s}$ the switch S_1 is closed, the voltage across the capacitor is $u_c(t_0) = 0 \text{ V}$.

- 1. First do not consider the light bulb - it is not connected to the RC circuit.
- 2. 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 $(1 - e^{-t/\tau}) = 0.5 \Rightarrow e^{-t/\tau} = 0.5 \Rightarrow -t/\tau = \ln(0.5) \Rightarrow t = \tau \cdot \ln(0.5) = R_1 \cdot C \cdot \ln(0.5)$



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: $U_s = U \cdot \frac{R_B}{R_1 + R_B} = 1/2 \cdot U$ The internal resistance is given by substituting the ideal voltage source with its resistance ($= 0 \Omega$, short-circuit).
 $R_i = R_1 \parallel R_B = 10 \Omega$

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

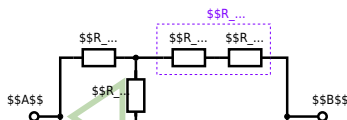
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Exercise E6 Pure Resistor Network Simplification
 (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be solved at 0°C. On the left, $R_1 = R_2 = 1.5 \text{ k}\Omega$ and the source $U = 10 \text{ V}$.
 Result: $I = 1 \text{ mA}$.

Solution

R_{eq} between A and B



Since $R_2=R_3$ and based on the equations for the transformation, the transformed R_Y is given as:

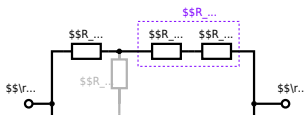
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

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

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

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:

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

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

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

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

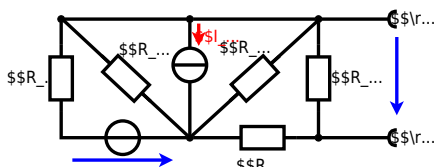
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Exercise E3 Equivalent linear Source
(written test, approx. 14 % of a 60-minute written test, WS2022)

The circuit in the following has to be simplified.
 Result

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

$$R_{\text{i}} = R_{\text{AB}} = 6 \Omega$$



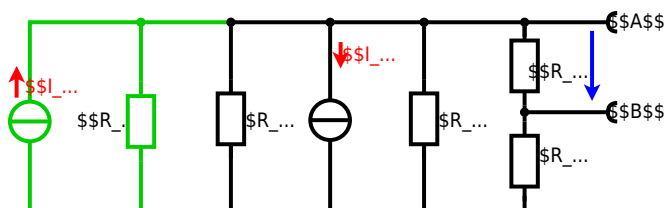
Calculated the internal resistance R_{int} and the source voltage U_{oc} of an equivalent linear voltage source on the connectors A and B . $R_1=5.0 \Omega$, $U_2=6.0 \text{ V}$, $R_3= 10 \Omega$, $I_4=4.2 \text{ A}$, $R_5=10 \Omega$, $R_6=7.5 \Omega$, $R_7=15 \Omega$ Use equivalent sources in order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

$$I_{24} = I_2 - I_4$$
 The resulting circuit can again be transformed:



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

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

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:

$$U_{AB} = U_{24} \cdot \left(\frac{R_7}{R_6 + R_7 + R_1 || R_3 || R_5} \right) - \left(\frac{U_2}{R_1} - I_4 \right) \cdot \left(R_1 || R_3 || R_5 \right)$$

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

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

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

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

2. The graph shows the temperature dependence of the resistance of a resistor. The resistor has a resistance of $10 \text{ k}\Omega$ at 25°C . Calculate the resistance of the thermistor at -40°C .

Its temperature coefficients are: $\alpha = 0.01 \text{ K}^{-1}$ and $\beta = 71 \cdot 10^{-6} \text{ K}^{-2}$.

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

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

Resistor transfer resistor R and R_0 are in the circuit and ΔT is the temperature difference between the refrigeration system and the resistor.

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

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

with $\Delta T = T_{\text{end}} - T_{\text{start}}$

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

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Exercise E5 Analyzing complex Impedances (written test, approx. 14 % of a 60-minute written test, WS2022)

2. Calculate the phasor voltage \underline{u} (in V) at $t = 30$ ms for the circuit shown in the figure. The components R and X_L shall be given.

After analysis, the following phasor voltage \underline{u} shall be extracted and given in magnitude $|\underline{u}|$ and phase φ (in degrees):

Solution
.. Calculation of physical values of the components.
Solution $R = 10 \Omega$, $X_L = 20 \Omega$, $X_C = 10 \Omega$

Solution
$$\underline{I} = \frac{\underline{U}}{\underline{Z}} = \frac{50 \angle 0^\circ}{10 + j20 - j10} = \frac{50 \angle 0^\circ}{10 + j10} = 4.47 \angle -45^\circ \text{ A}$$

The current and voltage are in phase since the circuit is purely resistive.
The voltage across the capacitor is $\underline{u}_C = \underline{I} \cdot X_C = 4.47 \angle -45^\circ \cdot 10 \angle -90^\circ = 44.7 \angle -135^\circ \text{ V}$
The voltage across the inductor is $\underline{u}_L = \underline{I} \cdot X_L = 4.47 \angle -45^\circ \cdot 20 \angle 90^\circ = 89.4 \angle 45^\circ \text{ V}$
The voltage across the resistor is $\underline{u}_R = \underline{I} \cdot R = 4.47 \angle -45^\circ \cdot 10 \angle 0^\circ = 44.7 \angle -45^\circ \text{ V}$
The total voltage is $\underline{u} = \underline{u}_R + \underline{u}_L + \underline{u}_C = 44.7 \angle -45^\circ + 89.4 \angle 45^\circ + 44.7 \angle -135^\circ = 50 \angle 0^\circ \text{ V}$
With the complex part comes the magnitude $|\underline{u}| = 50 \text{ V}$ and phase $\varphi = 0^\circ$.
The phase φ can be calculated as $\varphi = \arctan\left(\frac{\text{Im}(\underline{u})}{\text{Re}(\underline{u})}\right) = \arctan\left(\frac{0}{50}\right) = 0^\circ$

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Exercise E7 Complex Impedance Circuit (written test, approx. 15 % of a 60-minute written test, WS2022)

2. Calculate the resulting phasor voltage \underline{u} (in V) at $t = 30$ ms for the circuit shown in the figure. The components R and X_L shall be given. The voltage source $u(t) = 3.0 \cdot \sin(2\pi \cdot 15 \cdot t) \text{ V}$ is a sinusoidal source with a frequency of $f = 15 \text{ Hz}$.

Solution
This linear source is connected with an inductor of $330 \mu\text{H}$ and a capacitor of $30.22 \mu\text{F}$, all in series.
Result

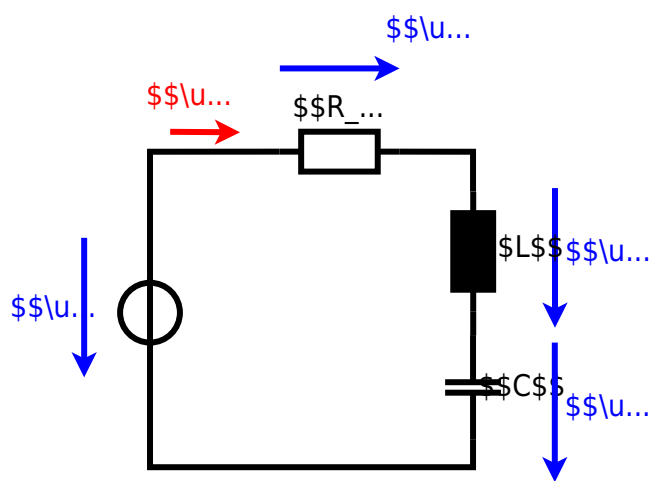
.. Draw the circuit diagram of the given circuit.
Label all components, voltages, and currents.

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\begin{align*} Z &= \frac{\hat{U}}{\hat{I}} \quad \hat{I} = \frac{\hat{U}}{Z} \\
\end{align*}
\begin{align*} Z_C &= \frac{1}{2\pi f C} \quad \omega = 2\pi \cdot 15 \\
\text{Winkel } \varphi &= \arctan\left(\frac{X_L}{X_C}\right) = \arctan\left(\frac{30}{19.28}\right) \\
\end{align*}
\begin{align*} Z_C &= \frac{1}{2\pi \cdot 15 \cdot 330 \cdot 10^{-6}} \\
\end{align*}
\underline{Z} = R + j \underline{Z}_L - j \underline{Z}_C \quad \underline{Z} = R + j(\underline{Z}_L - \underline{Z}_C) \\
|\underline{Z}| = \sqrt{R^2 + (\underline{Z}_L - \underline{Z}_C)^2}

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Exercise E6 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_1 and R_2 combined is given by $Z_{R1+R2} = R_1 + R_2$
 Parallel circuit means that the voltage is the same on R_1 and R_2
 The resulting current of the parallel circuit is given as:
 $I_{R1+R2} = I_{R1} + I_{R2}$
 Back to the first formula: $I_{R1+R2} \cdot Z_{R1+R2} = I_{R1} \cdot R_1 + I_{R1} \cdot R_2$
 $I_{R1+R2} \cdot (R_1 + R_2) = I_{R1} \cdot (R_1 + R_2)$
 $I_{R1+R2} = I_{R1}$

Solution

$R_1 = 1.00 \cdot \Omega$

$R_2 = 10.0 \cdot \Omega$

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 $Z_{R1+R2} = R_1 + R_2$
 Parallel circuit means that the voltage is the same on R_1 and R_2
 The resulting current of the parallel circuit is given as:
 $I_{R1+R2} = I_{R1} + I_{R2}$
 Back to the first formula: $I_{R1+R2} \cdot Z_{R1+R2} = I_{R1} \cdot R_1 + I_{R1} \cdot R_2$
 $I_{R1+R2} \cdot (R_1 + R_2) = I_{R1} \cdot (R_1 + R_2)$
 $I_{R1+R2} = I_{R1}$

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

The heating element is used to heat the wire with a temperature of 1800 K .
 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 $1.10 \cdot 10^{-6} \cdot \Omega \cdot \text{m}$.

The heating element is 3 m long and has a diameter of 3.57 mm .
 Calculate the resistance R of the heating element.

Solution

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

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

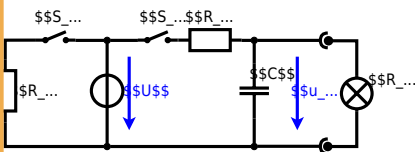
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Exercise E4 Charging Capacitors
(written test, approx. 16 % of a 60-minute written test, WS2022)

The circuit (with the real battery) also takes into account the internal resistance R_1 of the battery and the capacitor C is initially charged to $U_0 = 20 \text{ V}$. The voltage across the capacitor is again U_0 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 is in series with the internal resistance R_1 and the external resistor R_2 . The voltage across the capacitor is $u_c(t) = U \cdot (1 - e^{-t/\tau})$, where $\tau = R_1 \cdot C$.
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 .

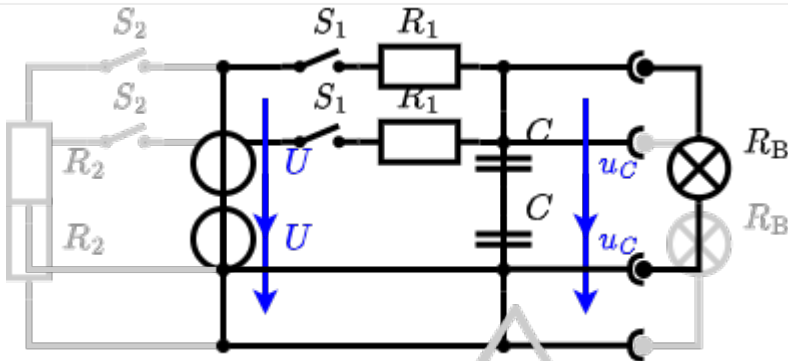


The circuit contains a voltage source $U = 12 \text{ V}$, a switch S_1 , a resistor of $R_1 = 20 \text{ } \Omega$ and a capacitor of $C = 100 \text{ } \mu\text{F}$.

The switch S_2 to an additional consumer R_2 will be considered to be open for the first asks. At the moment $t_0 = 0 \text{ s}$ the switch S_1 is closed, the voltage across the capacitor is $u_c(t_0) = 0 \text{ V}$.

- 1. First do not consider the light bulb - it is not connected to the RC circuit.
- 2. 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 $(1 - e^{-t/\tau}) = 0.5$

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



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

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

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

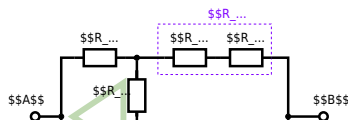
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Exercise E3 Pure Resistor Network Simplification
 (written test, approx. 13 % of a 60-minute written test, WS2022)

The following shall be solved at 0°C. On the left, $R_1 = R_2 = 1.5 \text{ k}\Omega$ and the voltage source $U = 10 \text{ V}$. The result is given in R_B .

Solution

$R_2 = R_3 = 100 \Omega$



Since $R_2 = R_3$ and based on the equations for the transformation, the transformed R_Y is given as:

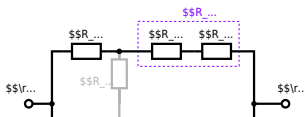
$$R_Y = \frac{R_2 \cdot R_2}{R_2 + R_2} = \frac{(100 \Omega)^2}{3 \cdot 100 \Omega} = \frac{1}{3} \cdot 100 \Omega = 33.33 \Omega$$

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

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

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:

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

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