

Exam Summer Semester 2023

Student Group

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Exam Summer Semester 2023

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.

Only EEE1-relevant Part

This part is only for about 25 minutes !

Exercise E1 Resistivity and temperature dependent Resistance (written test, approx. 7 % of a 60-minute written test, SS2023)

The resistivity ρ of a dielectric material is temperature dependent and is described by the Arrhenius law: $\rho = \rho_0 \exp\left(\frac{A}{T}\right)$ with $\rho_0 = 10^{17} \Omega \cdot \text{m}$ and $A = 10^4 \text{ K}$. The resistivity ρ is given in $\Omega \cdot \text{m}$ and T in $^\circ\text{C}$. The temperature T is given in $^\circ\text{C}$ and ρ in $\Omega \cdot \text{m}$.

Solution: The resistivity of the dielectric material is $\rho_{\text{PP}}(20 \text{ } ^\circ\text{C}) = 10^{17} \Omega \cdot \text{m}$.

For the given material the temperature coefficients in the range of $20 \text{ } ^\circ\text{C}$ and $55 \text{ } ^\circ\text{C}$ are given as $\alpha = -0.048 \text{ } ^\circ\text{C}^{-1}$ and $\beta = +0.00057 \text{ } ^\circ\text{C}^{-2}$.

$$\begin{aligned} R(55 \text{ } ^\circ\text{C}) &= R(20 \text{ } ^\circ\text{C}) \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2 + \dots) \\ &= 80 \text{ } \Omega \cdot (1 - 0.048 \text{ } ^\circ\text{C}^{-1} \cdot (35 \text{ } ^\circ\text{C}) + 0.00057 \text{ } ^\circ\text{C}^{-2} \cdot (35 \text{ } ^\circ\text{C})^2) \end{aligned}$$

Calculate the resistance for the dielectric material for $20\text{ }^\circ\text{C}$.

Solution

$$R(20\text{ }^\circ\text{C}) = \rho \cdot \frac{d}{A} = 10^{17}\text{ }\Omega \cdot \frac{0.8 \cdot 10^{-6}\text{ m}}{1\text{ m}^2}$$

Exercise E2 Pure Resistor Network Simplification (written test, approx. 12 % of a 60-minute written test, SS2023)

Calculate the voltage across the K , when switch S is closed.

Result

The values in the circuit are

Solution

$$R_1 = 60 \, \Omega$$

$$R_2 = 40 \, \Omega$$

$$R_3 = 40 \, \Omega$$

$$R_4 = 100 \, \Omega$$

The voltage divider for node K has the same proportionality as the voltage divider for node K' . Therefore, the potential of K is the same as for K' . There will be no current flow through R_3 . The resistance does not create a voltage drop and therefore does not interfere with the circuit.

1. Calculate the voltage at node K , when switch S is open.
It might be beneficial to redraw the circuit first.

Solution

Rearranging the circuit one can get:

Once the switch S is opened, the upper part is a parallel circuit. Therefore, R_{eq} is given as:

$$R_{\text{eq}} = (R_1 + R_2) \parallel (R_1 + R_2) + R_4 \parallel \frac{1}{2} \cdot (R_1 + R_2) + R_4 = \frac{1}{2} \cdot (60 \, \Omega + 40 \, \Omega) + 100 \, \Omega$$

Exercise E3 Pure Resistor Network Simplification I (written test, approx. 14 % of a 60-minute written test, SS2023)

The circuit below should be given as $U_{\text{AB}} = 60 \, \text{V}$. What is the value for I_{AB} in the circuit?

Solution

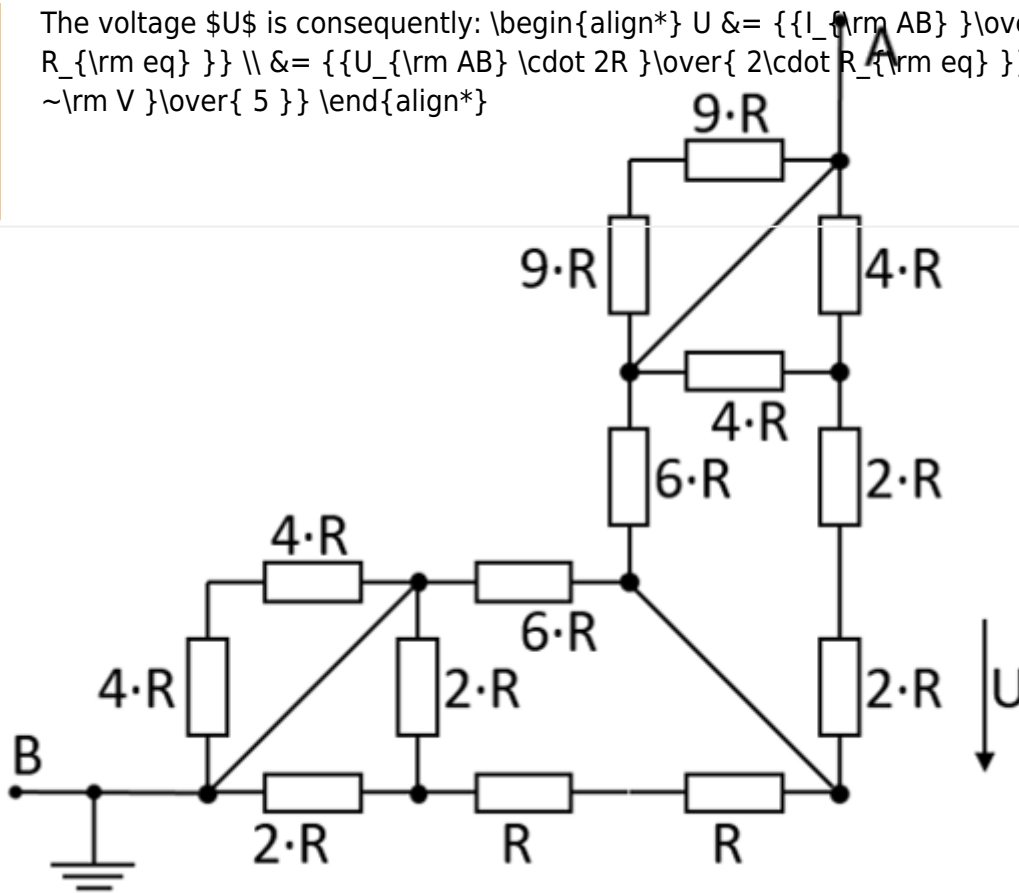
$$I_{\text{AB}} = \frac{U_{\text{AB}}}{R_{\text{eq}}} = \frac{60 \, \text{V}}{120 \, \Omega} = 0.5 \, \text{A}$$

The current through the circuit is given as $I_{\text{AB}} = \frac{U_{\text{AB}}}{R_{\text{eq}}}$.

This current has to flow in summary through parallel branches. The voltage U in question in the upper right branch given by $(4R \parallel 4R) + 2R + 2R$. Its resistance is just the same as the upper left branch $6R$.

Therefore, half of the current flows to the left half to the right side.

The voltage U is consequently:
$$U = \frac{I_{\text{arm AB}}}{2 \cdot R_{\text{eq}}} \quad \&= \quad \frac{U_{\text{AB}} \cdot 2R}{2 \cdot R_{\text{eq}}} \quad \&= \quad \frac{60 \text{ V}}{5}$$



1. What is the equivalent resistance R_{eq} ?

Solution

Part of the circuit is shorted. Here the resistors (marked in red) are shorted by the connections marked in blue:

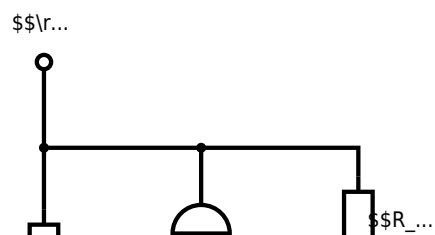
$$R) \parallel 6R \text{ \&\&+ } 6R \parallel (2R + 2R + 4R) \parallel 4R \text{ \&\&= } (R + R + R) \parallel 6R \text{ \&\&+ } 6R \parallel (2R + 2R + 2R) \text{ \&\&= } 3R \parallel 6R \text{ \&\&+ } 6R \parallel 6R \text{ \&\&= } \left\{ \frac{3R \cdot 6R}{3R + 6R} \right\} \text{ \&\&+ } 3R \text{ \&\& \end{align*}}$$

Exercise E4 Equivalent Linear Source (written test, approx. 10 % of a 60-minute written test, SS2023)

The circuit below has to be simplified. Use equivalent linear sources for simplification.

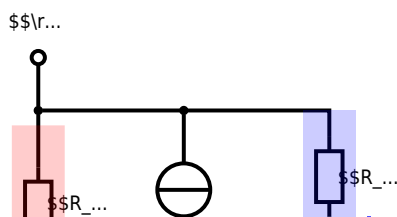
Calculate the internal resistance R_{i} and the source voltage U_{s} of an equivalent linear voltage source.

- $R_1 = 5 \text{ } \Omega$
 - $U_1 = 10 \text{ V}$
 - $R_2 = 5 \text{ } \Omega$
 - $I_3 = 0.5 \text{ A}$
 - $R_4 = 10 \text{ } \Omega$
 - $U_5 = 4 \text{ V}$
- Result: $U_{\text{s}} = U_{\text{AB}} = 1.11 \text{ V}$ $R_{\text{i}} = 5.55 \text{ } \Omega$



Solution

The principle idea here is to find parts of the circuit which are already a linear (voltage or current) source. Then this can be transformed into the equivalent other source, as shown in the next picture.



In order to get the currents one has to calculate it by $I_x = \frac{U_x}{R_x}$

$$\begin{aligned} I_0 &= \frac{U_0}{R_1} = \frac{10 \text{ V}}{5 \text{ } \Omega} = 2 \text{ A} \\ I_5 &= \frac{U_5}{R_4} = \frac{4 \text{ V}}{10 \text{ } \Omega} = 0.4 \text{ A} \end{aligned}$$

I_3 and I_0 can be combined to $I_{03} = I_0 - I_3$ facing upwards:

$$I_{03} = 1.5 \text{ A}$$

Then, the linear current source I_{03} with R_1 gets transformed into a linear voltage source with $U_{03} = R_1 \cdot I_{03}$ facing down.

$$U_{03} = 7.5 \text{ V}$$

Then, the resistors R_1 and R_2 can be combined to $R_{12} = R_1 + R_2$.

After this, the next step is to make a linear current source out of U_{03} and R_{12} . The current will be $I_{0123} = \frac{U_{03}}{R_{12}}$, facing up again.

$$I_{0123} = 0.6 \text{ A}$$

The second-last step is the sum up of the current sources I_{0123} and I_5 as $I_{01235} = I_{0123} - I_5$ and the resistors as $R_{124} = R_{12} || R_4$.

$$I_{01235} = 0.2 \text{ A} \quad R_{124} = 5.55 \text{ } \Omega$$

The final step is the back-transformation to a linear voltage source, with $U_{\text{AB}} = R_{124} \cdot I_{01235}$.

The simplest and fastest (= for exams) is to work with interim results in the calculation.

Here, there is also a full final formula given:

$$\begin{aligned} U_{\text{AB}} &= U_{\text{AB}} = I_{01235} \cdot R_{124} \quad \&= (I_{0123} - I_5) \cdot (R_{12} \parallel R_4) \quad \&= \left(\frac{U_{03}}{R_{12}} - I_5 \right) \cdot (R_{12} \parallel R_4) \\ &\quad \&= \left(\frac{R_1 \cdot I_{03}}{R_1 + R_2} - I_5 \right) \cdot (R_{12} \parallel R_4) \quad \&= \left(\frac{R_1 \cdot \left(\frac{U_0}{R_1} - I_3 \right)}{R_1 + R_2} - I_5 \right) \cdot (R_{12} \parallel R_4) \end{aligned}$$

Full Exam

These is the full exam

Full exam

Exercise E1 Resistivity and temperature dependent Resistance (written test, approx. 7 % of a 60-minute written test, SS2023)

The resistivity of a dielectric material is $\rho_{\text{PP}}(T)$ in $\Omega \cdot \text{m}$. The temperature dependence of the resistivity is described by the Arrhenius equation: $\rho_{\text{PP}}(T) = \rho_0 \cdot \exp\left(\frac{E_a}{k_B T}\right)$, where E_a is the activation energy in eV and k_B is the Boltzmann constant in eV/K. The resistivity of the dielectric material is $\rho_{\text{PP}}(20^\circ\text{C}) = 10^{17} \Omega \cdot \text{m}$ and $\rho_{\text{PP}}(100^\circ\text{C}) = 10^{15} \Omega \cdot \text{m}$. The test was performed at 20°C and 100°C .

Solution
The resistivity of the dielectric material is $\rho_{\text{PP}}(20^\circ\text{C}) = 10^{17} \Omega \cdot \text{m}$.

For the given material the temperature coefficients in the range 20°C and 55°C are given as $\alpha = -0.048 \text{ K}^{-1}$ and $\beta = +0.00057 \text{ K}^{-2}$.

$$\begin{aligned} R(55^\circ\text{C}) &= R(20^\circ\text{C}) \cdot (1 + \alpha \cdot \Delta T + \beta \cdot \Delta T^2 + \dots) \\ &= 80 \text{ G}\Omega \cdot (1 - 0.048 \text{ K}^{-1} \cdot (35 \text{ K}) + 0.00057 \text{ K}^{-2} \cdot (35 \text{ K})^2) \end{aligned}$$

Calculate the resistance for the dielectric material for $20 \text{ }^\circ\text{C}$.

Solution

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\begin{align*} R(20 \text{ }^\circ\text{C}) &= \rho \cdot \frac{d}{A} \\ &= 10^{17} \text{ } \Omega \cdot \text{m} \cdot \frac{0.8 \cdot 10^{-6} \text{ m}}{1 \text{ m}^2} \\ \end{align*}
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[electrical_engineering_and_electronics:task_kyt15w11e3sempb2_with_calculation](#)
resistivity, power, exam ee1 ss2023

Exercise E5 Analyzing a Scope Plot (written test, approx. 12 % of a 60-minute written test, SS2023)

9. What is the RMS value of a sine wave with a peak-to-peak voltage of 10 V (in radian and degree)?

Result $L = 3.5 \sim \text{mH}$

$$\underline{U}_O = \underline{U}_I \cdot \frac{Z_L}{Z_L + R} = 0.5 \sim \text{V} - j \cdot 1.5 \sim \text{V}$$

The formula to start with is the (complex) voltage divider: $\underline{U}_O = \underline{U}_I \cdot \frac{Z_L}{Z_L + R}$

At the off-frequency the absolute values of impedances $|Z_L|$ is equal to $|R|$. This leads to $\frac{|Z_L|}{|Z_L + R|} = \frac{1}{\sqrt{2}}$ (cutoff). $|Z_L| = \frac{1}{\omega L} = \frac{1}{2\pi \cdot 150 \cdot 10^3 \cdot L} = \frac{1}{2\pi \cdot 3.5 \cdot 10^{-3}}$ As $\frac{1}{V}$



1. Calculate the impedance $\underline{Z}_L$.

Solution

$$\underline{Z}_L = j \cdot \omega \cdot L = j \cdot 2\pi \cdot 150 \sim \text{kHz} \cdot 3.5 \sim \text{mH}$$

electrical_engineering_and_electronics:task_c9f1si7l797equs_with_calculation
impedance, phasor, cutoff, exam ee1 ss2023

Exercise E2 Pure Resistor Network Simplification (written test, approx. 12 % of a 60-minute written test, SS2023)

Calculate the voltage divider $\underline{U}_K$, when switch S is closed.

Result

The values in the circuit are

Solution

• $R_1 = 60 \sim \Omega$
 The circuit is a pure resistor network. The voltage divider $\underline{U}_K$ is the same as for $\underline{U}_I$.
 $R_3 = 40 \sim \Omega$
 The voltage divider $\underline{U}_K$ has the same proportionality as the voltage divider $\underline{U}_I$. Therefore, the potential of $\underline{U}_K$ is the same as for $\underline{U}_I$. There will be no current flow through R_3 . The resistance does not create a voltage drop and therefore does not interfere with the circuit.

1. Calculate the voltage at node K , when switch S is open.
It might be beneficial to redraw the circuit first.

Solution

Rearranging the circuit one can get:

Once the switch S is opened, the upper part is a parallel circuit. Therefore, R_{eq} is given as:

$$R_{\text{eq}} = \frac{(R_1 + R_2) \parallel (R_1 + R_2) + R_4}{1} = \frac{1}{2} \cdot (R_1 + R_2) + R_4 = \frac{1}{2} \cdot (60 \, \Omega + 40 \, \Omega) + 100 \, \Omega$$

[electrical_engineering_and_electronics:task_cgcyprm6oboukcci_with_calculation_network_simplification, exam ee1 ss2023](#)

Exercise E3 Pure Resistor Network Simplification I (written test, approx. 14 % of a 60-minute written test, SS2023)

The input voltage is given as $U_{\text{AB}} = 60 \, \text{V}$. What is the value for I_{AB} in the circuit?

Solution

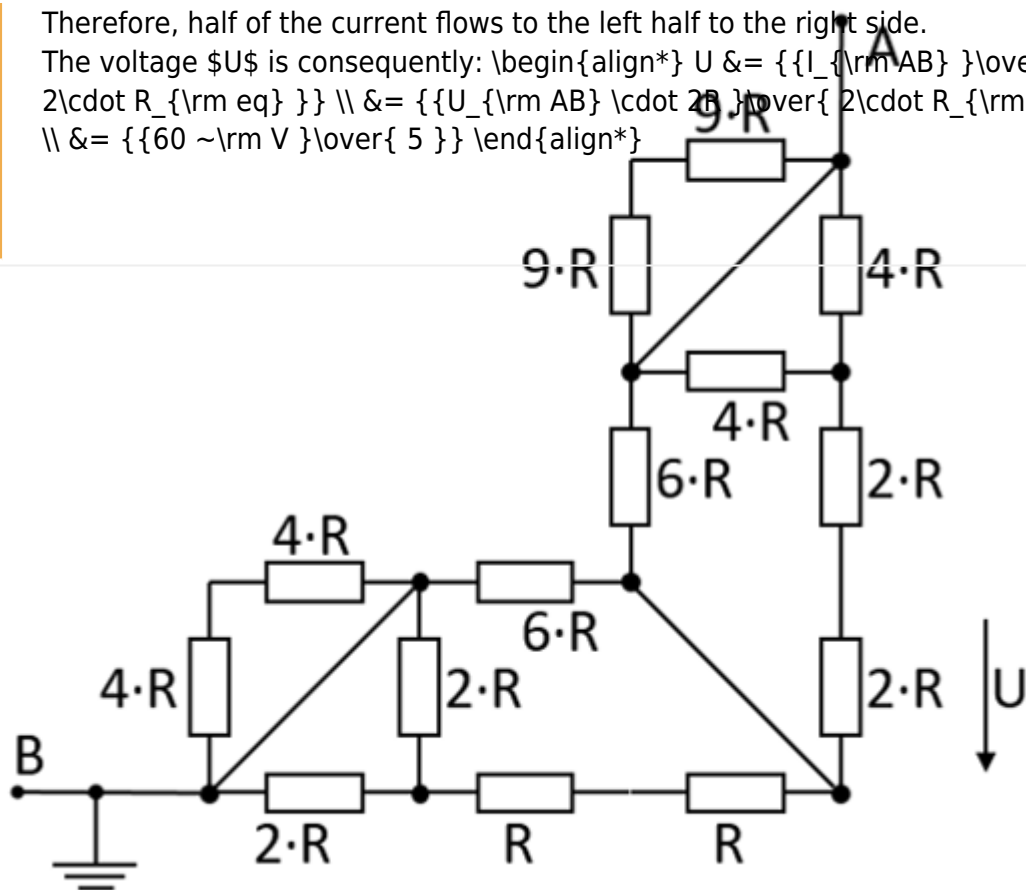
$$I_{\text{AB}} = \frac{U_{\text{AB}}}{R_{\text{eq}}} = \frac{60 \, \text{V}}{120 \, \Omega} = 0.5 \, \text{A}$$

The current through the circuit is given as $I_{\text{AB}} = \frac{U_{\text{AB}}}{R_{\text{eq}}}$.

This current has to flow in summary through parallel branches. The voltage U in question in the upper right branch given by $(4R \parallel 4R) + 2R + 2R$. Its resistance is just the same as the upper left branch $6R$.

Therefore, half of the current flows to the left half to the right side.

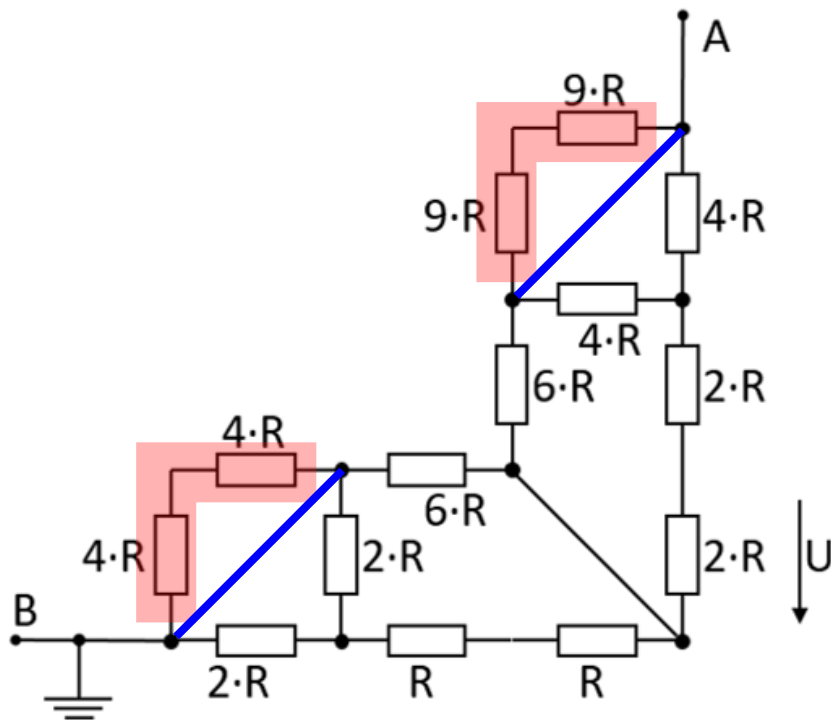
The voltage U is consequently:
$$U = \frac{I_{\text{AB}}}{2 \cdot R_{\text{eq}}} \quad \&= \quad \frac{U_{\text{AB}} \cdot 2R}{2 \cdot R_{\text{eq}}} \quad \&= \quad \frac{60 \text{ V}}{5}$$



1. What is the equivalent resistance R_{eq} ?

Solution

Part of the circuit is shorted. Here the resistors (marked in red) are shorted by the connections marked in blue:



The circuit can then be rearranged for better interpretation:

Therefore, R_{eq} is given as:
$$R_{\text{eq}} = (2R \parallel 2R + R + R) \parallel 6R + 6R \parallel (2R + 2R + 4R \parallel 4R) \parallel (R + R + R) \parallel 6R + 6R \parallel (2R + 2R)$$

$$+ 2R) \parallel \&= 3R \parallel 6R \&\&+ 6R \parallel 6R \parallel \&= \left\{ \frac{3R \cdot 6R}{3R+6R} \right\} \&\&+ 3R \parallel$$

$$\end{align*}$$

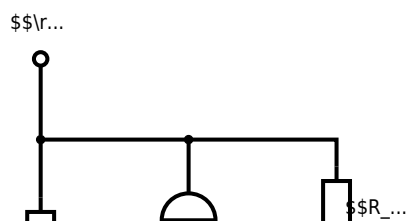
[electrical_engineering_and_electronics:task_erlctd760zmvox0t_with_calculation](#)
[network simplification, exam ee1 ss2023](#)

Exercise E4 Equivalent Linear Source

(written test, approx. 10 % of a 60-minute written test, SS2023)

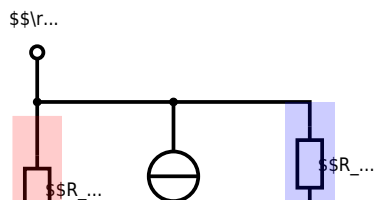
The circuit below has to be simplified. Use equivalent linear sources for simplification.
 Calculate the internal resistance R_{i} and the source voltage U_{ss} of an equivalent linear voltage source.

- $R_1 = 5 \, \Omega$
- $U_1 = 10 \, \text{V}$
- $R_2 = 10 \, \Omega$
- $R_3 = 5 \, \Omega$
- $I_3 = 0.5 \, \text{A}$
- $R_4 = 10 \, \Omega$
- $U_5 = 4 \, \text{V}$



Solution

The principle idea here is to find parts of the circuit which are already a linear (voltage or current) source. Then this can be transformed into the equivalent other source, as shown in the next picture.



In order to get the currents one has to calculate it by $I_x = \frac{U_x}{R_x}$

$$\begin{aligned} I_0 &= \frac{U_0}{R_1} = \frac{10 \text{ V}}{5 \text{ } \Omega} = 2 \text{ A} \\ I_5 &= \frac{U_5}{R_4} = \frac{4 \text{ V}}{10 \text{ } \Omega} = 0.4 \text{ A} \end{aligned}$$

I_3 and I_0 can be combined to $I_{03} = I_0 - I_3$ facing upwards:

$$I_{03} = 1.5 \text{ A}$$

Then, the linear current source I_{03} with R_1 gets transformed into a linear voltage source with $U_{03} = R_1 \cdot I_{03}$ facing down.

$$U_{03} = 7.5 \text{ V}$$

Then, the resistors R_1 and R_2 can be combined to $R_{12} = R_1 + R_2$.

After this, the next step is to make a linear current source out of U_{03} and R_{12} . The current will be $I_{0123} = \frac{U_{03}}{R_{12}}$, facing up again.

$$I_{0123} = 0.6 \text{ A}$$

The second-last step is the sum up of the current sources I_{0123} and I_5 as $I_{01235} = I_{0123} - I_5$ and the resistors as $R_{124} = R_{12} || R_4$.

$$I_{01235} = 0.2 \text{ A} \quad R_{124} = 5.55 \dots \text{ } \Omega$$

The final step is the back-transformation to a linear voltage source, with U_{rm}

$$AB\} = R_{124} \cdot I_{01235}\}.$$

The simplest and fastest (= for exams) is to work with interim results in the calculation.

Here, there there is also a full final formula given:

$$\begin{aligned} U_{\text{AB}} &= U_{\text{AB}} = I_{01235} \cdot R_{124} \parallel \&= \\ &= (I_{0123} - I_5) \cdot (R_{12} \parallel R_4) \parallel \&= \left(\frac{U_{03}}{R_{12}} - I_5 \right) \cdot (R_{12} \parallel R_4) \parallel \&= \\ &= \left(\frac{R_1 \cdot I_{03}}{R_1 + R_2} - I_5 \right) \cdot (R_{12} \parallel R_4) \parallel \&= \\ &= \left(\frac{R_1 \cdot \left(\frac{U_0}{R_1} - I_3 \right)}{R_1 + R_2} - I_5 \right) \cdot (R_{12} \parallel R_4) \parallel \end{aligned}$$

electrical_engineering_and_electronics:task_lefxcuaxiu8ewcr9_with_calculation
network simplification, equivalent sources, exam ee1 ss2023

Exercise E7 (Dis)Charging Capacities

(written test, approx. 14 % of a 60-minute written test, SS2023)

The circuit shown in the drawing is given. At $t = 0$ s, the switch S_1 is switched to the position shown in the drawing. What will be the maximum voltage across the capacitor C ?
Result: $U_C = 10$ V
Solution: $U_C = 10$ V

- $C = 200 \text{ nF}$

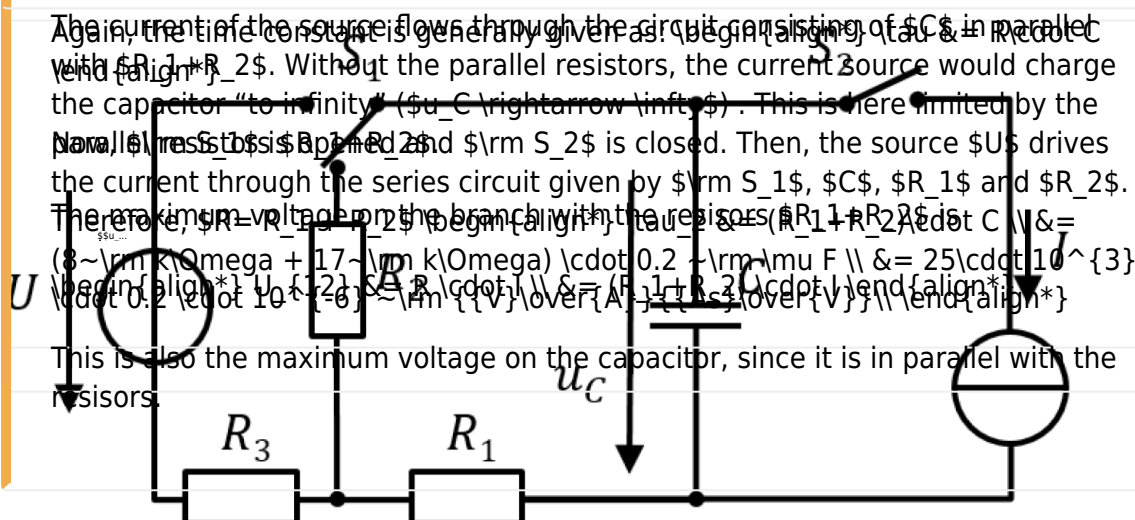
Solution: $R_1 = 8.0 \text{ k}\Omega$

Solution: $U_C = 10$ V

$$\begin{aligned} U_C &= U_C = U_0 \cdot (1 - e^{-t/\tau}) \parallel \&= 10 \text{ V} \cdot (1 - e^{-t/\tau}) \parallel \&= \\ &= 10 \text{ V} \cdot (1 - e^{-t/\tau}) \parallel \end{aligned}$$

The current of the source flows through the circuit consisting of C in parallel with R_1 and R_2 . Without the parallel resistors, the current source would charge the capacitor "to infinity" ($U_C \rightarrow \infty$). This is here limited by the parallel resistors R_1 and R_2 . Then, the source U drives the current through the series circuit given by S_1 , C , R_1 and R_2 . Therefore, the voltage on the branch with the resistors ($R_1 + R_2$) and C is $U_C = U \cdot \frac{R_1 + R_2}{R_1 + R_2 + C} = 25 \cdot \frac{10}{10 + 20} = 10$ V.

This is also the maximum voltage on the capacitor, since it is in parallel with the resistors.



Before t_0 all switches are switched as shown and the capacitor is fully discharged. At $t_0 = 0$ s the switch S_1 shall switch to the voltage source.

1. Calculate the time constant for charging the capacitor.

Solution

The time constant is generally given as:
$$\tau = R \cdot C$$

Once S_1 is closed and S_2 is open at t_0 , the source U drives the current through the series circuit given by S_1 , C , R_1 and R_3 .
Therefore, $R = R_1 + R_3$
$$\tau_1 = (R_1 + R_3) \cdot C = (8 \text{ k}\Omega + 7 \text{ k}\Omega) \cdot 0.2 \text{ }\mu\text{F} = 15 \cdot 10^3 \cdot 0.2 \cdot 10^{-6} \text{ s} = 3 \text{ ms}$$

⚡⚡...

Solution

Both courses of the voltage for charging and discharging are described with an exponential function. However, the curve for charging increases first steep and flattens out for longer time scales ($\propto (1 - e^{-x})$).

[electrical_engineering_and_electronics:task_p8yrdjr60k6bvc4n_with_calculation_charging, capacities, exam ee1 ss2023](#)

Exercise E8 Impedances at Frequencies

(written test, approx. 14 % of a 60-minute written test, SS2023)

At an inductor with $L = 50 \text{ mH}$ following harmonic voltage $u(t) = 100 \sin(314t) \text{ V}$ is applied. The resulting current $i(t) = 1.6 \sin(314t) \text{ A}$ is measured.

1. An inductor with $L_1 = 60 \text{ mH}$ and $f_1 = 15.9 \text{ Hz}$.

Solution

Solution

$$\begin{aligned} f_2 &= 318.3 \text{ Hz} \\ \omega_2 &= 6000 \text{ rad/s} \end{aligned}$$

$$\begin{aligned} X_{L2} &= \omega_2 L_2 = 3600 \cdot 0.06 = 216 \Omega \\ I_{\text{eff}} &= \frac{U_{\text{eff}}}{X_{L2}} = \frac{100}{216} = 0.463 \text{ A} \end{aligned}$$

electrical_engineering_and_electronics:task_uzbbnoz8abe6201d_with_calculation
exam ee1 ss2023

Exercise E9 Efficiency**(written test, approx. 14 % of a 60-minute written test, SS2023)**

1. A battery with an internal resistance $R_i = 0.5 \Omega$ and an open-circuit voltage $U_0 = 3.5 \text{ V}$ is connected to a load resistor $R_L = 3 \Omega$. The battery shall deliver a current $I = 1 \text{ A}$.

Calculate the efficiency η of the battery. The efficiency is defined as the ratio of the power delivered to the load to the total power supplied by the battery.

$$\begin{aligned} \eta &= \frac{P_{\text{load}}}{P_{\text{total}}} = \frac{I^2 R_L}{I^2 (R_i + R_L)} = \frac{R_L}{R_i + R_L} \end{aligned}$$

$$\eta = \frac{3}{0.5 + 3} = \frac{3}{3.5} = 0.857 = 85.7\%$$

$$\bullet \text{ Type capacitor: } C = 100 \mu\text{F} \text{ and } \omega = 1000 \text{ rad/s}$$

$$\text{lowest efficiency for highest rms voltage for } \sin(\omega t) \text{ in this case, the}$$

.. efficiency is 100% (valent circuit diagram with the internal resistance and an external

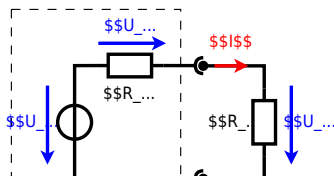
$$\text{load, both voltages and currents } Q \text{ over } q \text{ e}} \quad Q = 2.6 \text{ Ah}$$

$$\begin{aligned} \text{and } \omega = 3600 \text{ rad/s} \quad \omega = 3600 \text{ rad/s} \end{aligned}$$

$$\text{and } R_i = 0.5 \Omega \quad R_i = 0.5 \Omega$$

$$\text{and } R_L = 3 \Omega \quad R_L = 3 \Omega$$

$$\text{Result } \eta = \frac{3}{3.5} = 0.857 = 85.7\%$$



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