

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.

Tasks

Exercise E2 Resistivity and temperature dependent Resistance (written test, approx. 7 % of a 60-minute written test, SS2023)

The resistivity of a dielectric material is given by the formula $\rho(T) = \rho_0 \exp\left(\frac{A}{T} + B T^2\right)$ where ρ_0 is a constant, A and B are material constants. The resistivity of the material is $\rho(20^\circ\text{C}) = 10^{17} \Omega\cdot\text{m}$ and $\rho(55^\circ\text{C}) = 80 \Omega\cdot\text{m}$. The temperature coefficients in the range 20°C to 55°C are given as $\alpha = -0.048 \text{ K}^{-1}$ and $\beta = +0.00057 \text{ K}^{-2}$. Calculate the resistivity of the material at $T = 35^\circ\text{C}$.

Solution
The resistivity of the dielectric material is $\rho(T) = \rho_0 \exp\left(\frac{A}{T} + B T^2\right)$.

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

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

Calculate the resistance for the dielectric material for 20°C .

Solution

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

[electrical_engineering_and_electronics:task_kyt15w11e3sempb2_with_calculation](#)
resistivity, power, exam ee1 ss2023

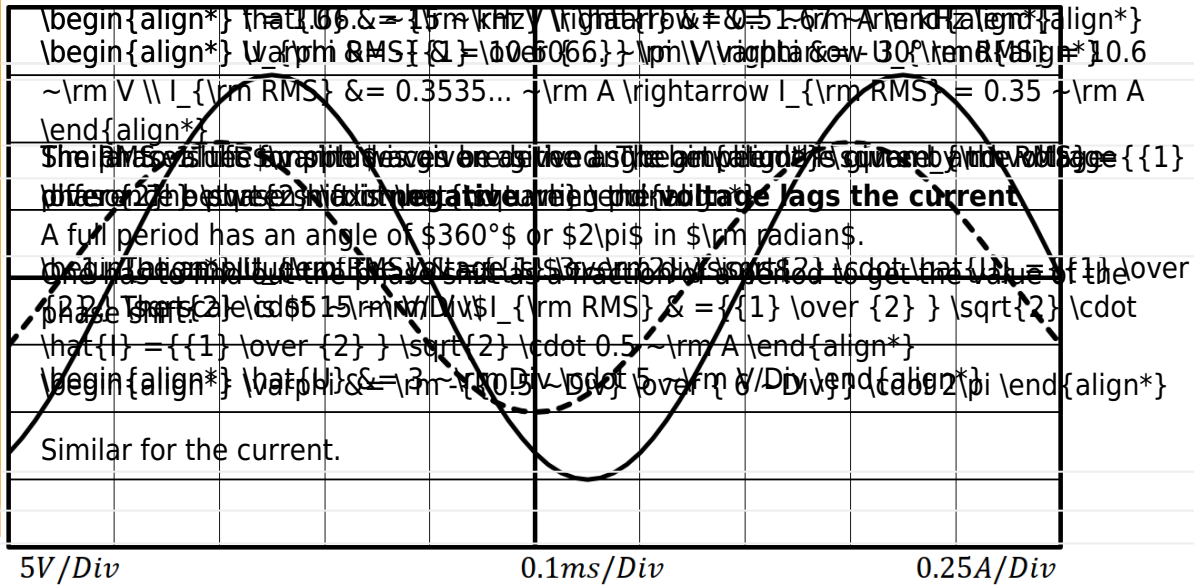
Exercise E11 Analyzing a Scope Plot
(written test, approx. 12 % of a 60-minute written test, SS2023)

Result: calculate the RMS value of the voltage (and current and degree)?

The measured current curve shall be visible as a dashed line.

The continuous line shows the voltage.

Solution



Use the correct symbols and units in your answers!

1. Calculate the frequency f of the periodic signals.

Solution

Frequency f is given by the period T . The period can be measured in the image of the scope.

1. The sine waves repeat after $6 \sim \text{rm divisions}$ (e.g. from falling turning point to falling turning point of one curve)
2. The scale is $0.1 \sim \text{rm ms/Div}$

$$f = \frac{1}{T} \quad T = 6 \sim \text{rm Div} \cdot 0.1 \sim \text{rm ms/Div}$$

$$\rightarrow f = \frac{1}{6 \sim \text{rm Div} \cdot 0.1 \sim \text{rm ms/Div}}$$

electrical_engineering_and_electronics:task_1m3izw2szosswtto_with_calculation
exam ee1 ss2023

Exercise E12 Complex voltage dividers

(written test, approx. 16 % of a 60-minute written test, SS2023)

1. Calculate the two impedances Z_1 and Z_2 in the following circuit. The resulting phase shift between impedance Z_1 and Z_2 is 45° . Choose an appropriate scaling factor and write it down.

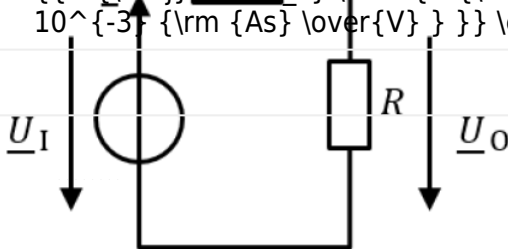
Result $R = 1.1 \text{ k}\Omega$

$$\underline{U} = \underline{U}_0 \cdot \frac{\underline{Z}_L}{\underline{Z}_L + R} \quad \underline{U}_0 = 0.5 \text{ V} - j \cdot 1.5 \text{ V}$$

- $f_0 = 150 \text{ kHz}$

The formula to start with is the (complex) voltage divider:
$$\underline{U} = \underline{U}_0 \cdot \frac{\underline{Z}_L}{\underline{Z}_L + R}$$

At the off-frequency the absolute values of impedances $\underline{Z}_L$ is equal to $\underline{Z}_L = R$. This leads to
$$\frac{|\underline{U}|}{|\underline{U}_0|} = \frac{R}{R + R} = \frac{1}{2}$$



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

Solution

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

electrical_engineering_and_electronics:task_c9f1si7l797eques_with_calculation
impedance, phasor, cutoff, exam ee1 ss2023

Exercise E13 Pure Resistor Network Simplification (written test, approx. 12 % of a 60-minute written test, SS2023)

The circuit below is given. Calculate the voltage U_K , when switch S is closed.

Result

The values in the circuit are

Solution

- $R_1 = 60 \text{ }\Omega$

The circuit is a pure resistor network. When switch S is closed, the circuit is simplified to a voltage divider.

$$R_1 = 60 \text{ }\Omega, R_2 = 40 \text{ }\Omega, R_3 = 10 \text{ }\Omega$$

The voltage divider U_K has the same proportionality as the voltage

divider $U_0 = 10 \text{ V}$. Therefore, the potential of U_K is the same as for U_0 . 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:

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

[electrical_engineering_and_electronics:task_cgeyprm6oboukcci_with_calculation_network_simplification, exam ee1 ss2023](#)

Exercise E14 Pure Resistor Network Simplification I (written test, approx. 14 % of a 60-minute written test, SS2023)

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

Solution

$$I_{\text{AB}} = \frac{U_{\text{AB}}}{R_{\text{eq}}} = \frac{60 \text{ V}}{50 \Omega} = 1.2 \text{ A}$$

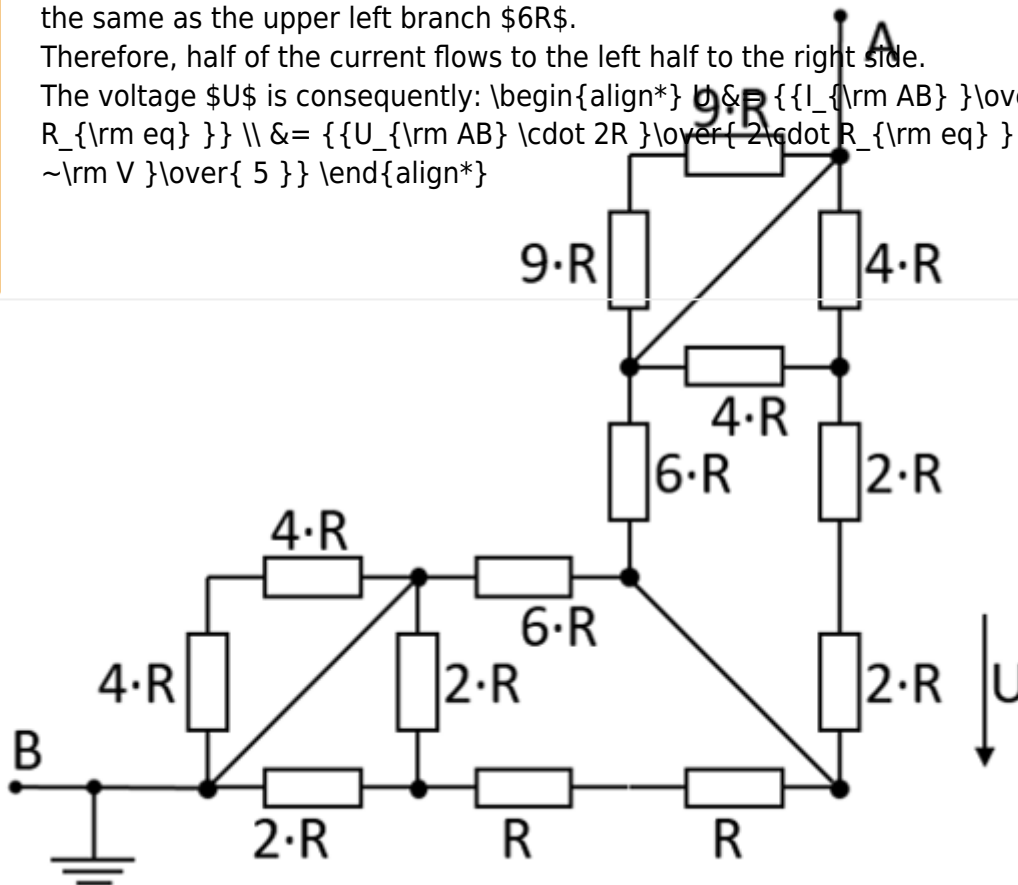
The current through the circuit is given as $I_{\text{AB}} = U_{\text{AB}} \cdot R_{\text{eq}}$.

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.

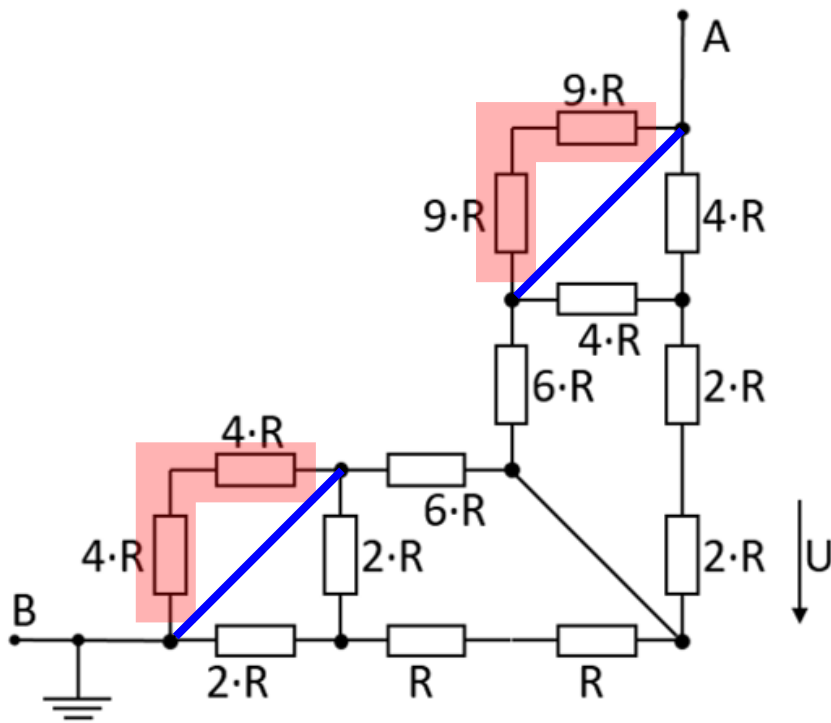
The voltage U is consequently:
$$U = I_{\text{AB}} \cdot (2R_{\text{eq}} + 2R_{\text{eq}}) = \frac{60 \text{ V}}{5}$$



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:
$$R_{\text{eq}} = (2R \parallel 2R + R +$$

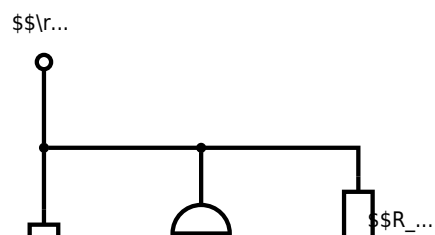
$$R) \parallel 6R \text{ \&\&+ } 6R \parallel (2R + 2R + 4R) \parallel 4R \text{ \&\&= } (R + R + R) \parallel 6R \text{ \&\&+ } 6R \parallel (2R + 2R + 2R) \text{ \&\&= } 3R \parallel 6R \text{ \&\&+ } 6R \parallel 6R \text{ \&\&= } \frac{\{3R \cdot 6R\}}{\{3R+6R\}} \text{ \&\&+ } 3R \text{ \&\& \end{align*}}$$

electrical_engineering_and_electronics:task_erlctd760zmvox0t_with_calculation
network simplification, exam ee1 ss2023

Exercise E15 Equivalent Linear Source (written test, approx. 10 % of a 60-minute written test, SS2023)

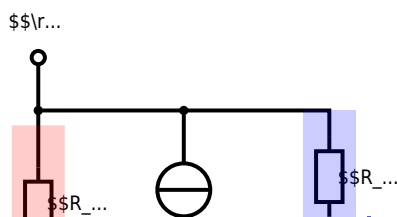
The circuit below has to be simplified. Use equivalent linear sources for simplification.
Calculate the internal resistance R_{i} and the source voltage U_{s} of an equivalent linear voltage source.

- $R_1 = 5 \text{ } \Omega$
- $U_{\text{AB}} = 1.11 \text{ V}$
- $R_2 = 10 \text{ } \Omega$
- $I_3 = 0.5 \text{ A}$
- $R_4 = 10 \text{ } \Omega$
- $U_5 = 4 \text{ V}$



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 $R_{124} = R_{12} || R_4$.

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

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:

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

[electrical_engineering_and_electronics:task_lefxcuaxiu8ewcr9_with_calculation](#)
network simplification, equivalent sources, exam ee1 ss2023

Exercise E16 (Dis)Charging Capacities

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

The circuit diagram shows a circuit with a voltage source $U = 10 \text{ V}$, a capacitor $C = 200 \text{ nF}$, and resistors $R_1 = 8 \text{ k}\Omega$, $R_2 = 17 \text{ k}\Omega$, and $R_3 = 25 \text{ k}\Omega$. The switch S_1 is initially open and is closed at $t = 0$. What is the time constant τ of the circuit?

- $C = 200 \text{ nF}$

Solution: $\tau = 8.0 \text{ ms}$

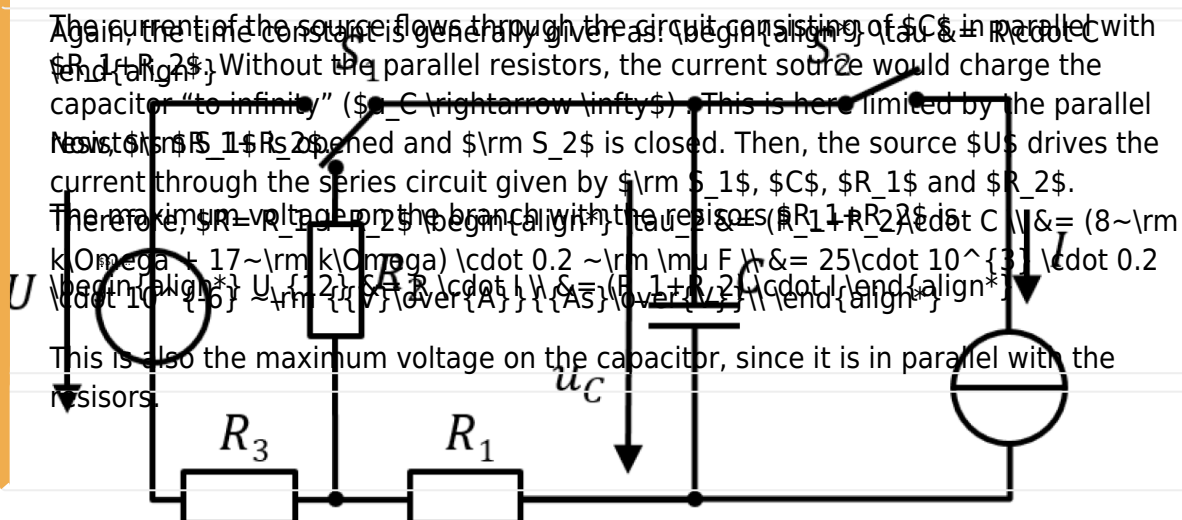
Solution: $\tau = 8.0 \text{ ms}$

$$\begin{aligned} U_C(t) &= U_C(0) + (U_C(\infty) - U_C(0)) \cdot e^{-t/\tau} \\ U_C(0) &= 0 \text{ V} \quad U_C(\infty) = 10 \text{ V} \end{aligned}$$

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" ($C \rightarrow \infty$). 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 U , C , R_1 and R_2 .

$$\begin{aligned} U_C &= U \cdot \frac{R_1 \parallel R_2}{R_1 \parallel R_2 + C} = 10 \text{ V} \cdot \frac{8 \text{ k}\Omega \parallel 17 \text{ k}\Omega}{8 \text{ k}\Omega \parallel 17 \text{ k}\Omega + 200 \text{ nF}} = 10 \text{ V} \cdot \frac{5.71 \text{ k}\Omega}{5.71 \text{ k}\Omega + 200 \text{ nF}} = 10 \text{ V} \cdot 0.96 = 9.6 \text{ V} \end{aligned}$$

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



Before $t_0 = 0 \text{ s}$ all switches are switched as shown and the capacitor is fully discharged. At $t_0 = 0 \text{ s}$ 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 ($1 - e^{-x}$).

[electrical_engineering_and_electronics:task_p8yrdjr60k6bvc4n_with_calculation_charging_capacities_exam_ee1_ss2023](#)

Exercise E17 Impedances at Frequencies

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

At an inductor with $X_{L1} = 60 \sim \text{m}\Omega$ and $\omega = 15.9 \sim \text{kHz}$, the voltage $U = 3.6 \sim \text{V}$ is applied. The result is a current $I = 0.3 \sim \text{A}$.
 1. An inductor with $X_{L1} = 60 \sim \text{m}\Omega$ and $\omega = 15.9 \sim \text{kHz}$.

Solution

Solution

$$f = 15.9 \sim \text{kHz} \quad \omega = 2\pi f = 2\pi \cdot 15.9 \sim \text{kHz}$$

$$X_{L1} = 60 \sim \text{m}\Omega \quad X_{L2} = \omega L = 2\pi f L = 2\pi \cdot 15.9 \sim \text{kHz} \cdot L = 60 \sim \text{m}\Omega$$

electrical_engineering_and_electronics:task_uzbbnoz8abe6201d_with_calculation
 exam ee1 ss2023

Exercise E18 Efficiency**(written test, approx. 14 % of a 60-minute written test, SS2023)**

1. A battery with an internal resistance $R_i = 0.05 \sim \Omega$ and a nominal voltage $U_N = 3.6 \sim \text{V}$ is connected to a load with a resistance $R_L = 3 \sim \Omega$. The battery shall provide energy for a duration of $t = 10 \sim \text{h}$. The battery shall provide energy for a duration of $t = 10 \sim \text{h}$.
 Result: What is the lowest possible efficiency?

Solution: The device with a load resistance of $R_L = 3 \sim \Omega$ is connected to the battery. The device with a load resistance of $R_L = 3 \sim \Omega$ is connected to the battery.
 Solution: The device with a load resistance of $R_L = 3 \sim \Omega$ is connected to the battery.

$$U_N = 3.6 \sim \text{V} \quad R_i = 0.05 \sim \Omega \quad R_L = 3 \sim \Omega \quad t = 10 \sim \text{h}$$

Solution: The device with a load resistance of $R_L = 3 \sim \Omega$ is connected to the battery.

$$P_{\text{eff}} = I^2 R_L \quad P_{\text{tot}} = I^2 (R_i + R_L) \quad \eta = \frac{P_{\text{eff}}}{P_{\text{tot}}} = \frac{R_L}{R_i + R_L}$$

lowest efficiency for highest internal resistance R_i and lowest load resistance R_L

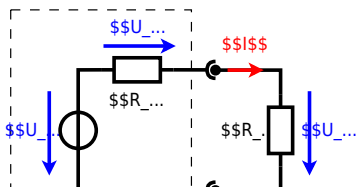
.. Efficiency of a circuit diagram with the internal resistance and an external load.

label: voltage and current: $U = 3.6 \sim \text{V}$ and $I = 0.3 \sim \text{A}$

$$P_{\text{eff}} = I^2 R_L = (0.3 \sim \text{A})^2 \cdot 3 \sim \Omega = 0.27 \sim \text{W}$$

$$P_{\text{tot}} = I^2 (R_i + R_L) = (0.3 \sim \text{A})^2 \cdot (0.05 \sim \Omega + 3 \sim \Omega) = 0.27 \sim \text{W}$$

$$\eta = \frac{P_{\text{eff}}}{P_{\text{tot}}} = \frac{0.27 \sim \text{W}}{0.27 \sim \text{W}} = 1$$



electrical_engineering_and_electronics:task_w3wf215v2u98ty07_with_calculation
efficiency, charges, power, exam ee1 ss2023

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