Non-ideal capacitors (10 points)

This experiment is designed to investigate the properties of capacitors.

Capacitor's capacitance (which always means differential capacitance in this text) can be found based on its charging graph of its voltage $U(t)$ via the resistor R_1. Depending on the circuit, it is necessary to find the relation of capacitor's charging current vs voltage $I(U)$ and use it to determine capacitance:

$$C(U) = \frac{\mathrm{d}q}{\mathrm{d}U} = \frac{I\mathrm{d}t}{\mathrm{d}U} = \frac{I(U)}{\mathrm{d}U/\mathrm{d}t}. \tag{1}$$

The electric circuit implemented in this experiment is shown in Fig. 1.1. Switch S1 on the board can be used to switch between capacitors C1 and C2. The middle position of the switch does not play any role in this experiment and should never be used.

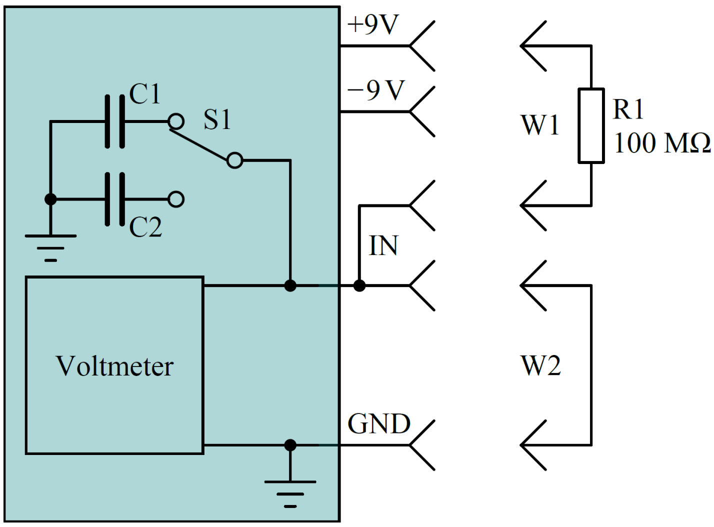

Figure 1.1. Electric circuit for the experiment.

Caution: one of the sample capacitors contains a dielectric with dielectric permittivity that depends on the capacitor voltage change rate. To keep this rate as stable as possible, when measuring at the positive voltages, the capacitor should be charged from 9 V down to –9 V, while measurements at the negative voltages should be done when capacitor is charged from –9 V towards 9 V. The measured capacitance can be influenced by the previous state of the capacitor, thus capacitor should be kept at the starting voltage for at least 10 s before the measurement.

Part A. Capacitors at room temperature (4.0 points)

Measure and graph the capacitance of the capacitors C1 and C2 versus the voltage at room temperature (draw all graphs together on the same axes).

A.1	Measure and graph $C_1(U)$ and $C_2(U)$ in range from –7 V to 7 V. In the answer sheet write C_1 and C_2 values at 0 V, 3 V, and 6 V. Write down the formula used for calculating capacitance from raw measurements. Also write Board ID and room temperature.	2.3pt

A.2	Find the voltage $U_{\text{max change}}$, at which the capacitance of capacitor exhibits the fastest relative change versus the voltage $\left(\frac{\mathrm{d}C(U)}{C(U)\mathrm{d}U}\right)$. In the answer sheet write, which capacitor (C1 or C2) exhibits the fastest change and the voltage, at which it is observed.	0.5pt

A.3	What are the charges q_1 and q_2 of capacitors C1 and C2 at 6 V?	1.2pt

Part B. Calibrating NTC thermistor (1.0 point)

Measure the NTC (Negative Temperature Coefficient) thermistor voltage at a known room temperature (from examination hall thermometer). The formula (1) for its resistance vs temperature and it's circuit is show in "Experimental Examination - Overall Guide G1".

B.1	Find the NTC thermistor constant R_0.	1.0pt

Part C. Capacitors at different temperatures (3.0 points)

C.1	Measure and graph $C_1(U)$ and $C_2(U)$ in range from –7 V to 7 V at temperatures of 40 °C, 65 °C and 85 °C.	1.3pt

C.2	Graph $C_1(T)$ and $C_2(T)$ at 0 V and 6 V versus temperature from room temperature up to 85 °C.	0.5pt

C.3	In the answer sheet write the ratio $C(85\,°\mathrm{C})/C(40\,°\mathrm{C})$ for both capacitors C1 and C2 at 0 V and 6 V.	1.2pt

Part D. Sources of measurement errors (2.0 points)

The previous tasks in this experiment were done in conditions of long initial charge. When looking at shorter recharging times (0.1 - 10 s) there can be multiple sources of errors:

1. Leakage current.

2. Polarization properties of the capacitor's dielectric media that can be expressed as the dielectric permittivity that depends on process time scale.

Caution: heat-insulating material may absorb air moisture and become conductive. Remove it when doing leakage measurements.

Determine the main source of error for measuring C1 and C2, since capacitor leakage and voltmeter input currents depend on the voltage, estimate these errors at voltage close to 9 V. Decide, which auxiliary measurements and under what conditions should be taken in order to answer these questions. In your answers to the following D.1 and D.2 questions, you might indicate the conditions of your measurements, which quantities you measure and what conclusions you make based on your measurements, as exemplified in the tables below.

Note: these are just the examples how to describe schematically your measurements; you need determine the relevant conditions of your measurements by yourself.

Examples of how answers to questions D.1 and D.2 should be written:

Example 1.
Showing that voltage change rate of C1 connected to the measuring circuit is faster at 9 V than at 0 V.
Possible S1 positions: C1, C2
Possible IN connection: +9V, -9V, GND, Free
Initial settings:

S1 position	IN connection
C1	9V

Process:

Step number	S1 position	IN connection	Duration, s	Measured variable
1	C1	Free		$\lvert \mathrm{d}uC(t)\rvert/\mathrm{d}t$
2	C1	GND		
3	C1	Free		$\lvert \mathrm{d}uC(t)\rvert/\mathrm{d}t$

Verification: $\lvert \mathrm{d}uC(t)\rvert/\mathrm{d}t\rvert_1 > \lvert \mathrm{d}uC(t)\rvert/\mathrm{d}t\rvert_3$

Example 2.
Showing that voltage change rate of C1 at 9 V is larger than the average voltage change rate starting at 0 V over 1000 seconds.
Possible S1 positions: C1, C2
Possible IN connection: +9V, -9V, GND, Free
Initial settings:

S1 position	IN connection
C1	9V

Process:

Step number	S1 position	IN connection	Duration, s	Measured variable
1	C1	Free		$\lvert \mathrm{d}uC(t)\rvert/\mathrm{d}t$
2	C1	GND		
3	C1	Free		uC
4	C1	Free	1000	
5	C1	Free		uC

Verification: $\lvert \mathrm{d}uC(t)\rvert/\mathrm{d}t\rvert_1 > (uC\rvert_3 - uC\rvert_5)/1000$

D.1	What is the main source of error for measuring $C_1(9\,\mathrm{V})$? Write the measurement steps in the tables.	1.0pt

D.2	What is the main source of error for measuring $C_2(9\,\mathrm{V})$? Write the measurement steps in the tables.	1.0pt

Light Emitting Diodes (LEDs) (10 points)

This experiment is designed to investigate the electrical and thermal properties of LEDs. For the temperature measurements of the PCB you should use coefficients, obtained in Experiment-1 B.1 section. The electric circuit used in this experiment is shown in Fig. 2.1. For equipment guide see description for question 1.

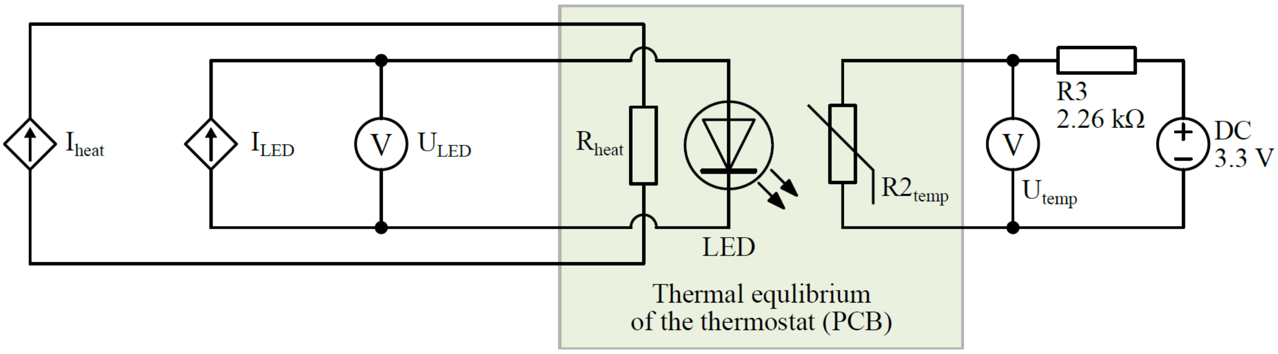

Figure 2.1. Experimental setup of the LED investigation experiment. LED is driven by the constant current (continuous or pulsed mode) and forward voltage measured by high impedance voltmeter. Heating and temperature measurement parts are the same as in Experiment 1. Thermal equilibrium is maintained between all components on printed circuit board (PCB).

The LEDs typically are driven by the constant current in contrast to constant voltage used for incandescent lamps. The measured voltage of the LEDs depends on set current and temperature of the semiconductor die. The mathematical expression of volt-ampere characteristics is complicated and depends on physical and technological parameters, which are usually not known. Therefore, in this experiment the two-dimensional dependence of the voltage vs LED current and LED die temperature T_J will have to be investigated:

$$U_{LED} = \text{function}(I_{LED},\ T_J).$$

The thermal resistance between the LED semiconductor die and the PCB is related to electrical power P as follows (at several values of the current (I_{LED})):

$$\frac{\Delta T}{P} = \frac{(T_J - T_{PCB})}{P}.$$

Caution: LED can be driven at continuous current or short current pulses. In the latter case it is assumed that the duration of the pulse is short enough to avoid the LED self-heating (for example 1 ms pulse duration with measurements spaced at least 100 ms apart), and to assume that $T_J = T_{PCB}$ at such driving regime. During the continuous operation $T_J > T_{PCB}$ and thermal resistance $\frac{\Delta T}{P}$ can be calculated.

Part A. Volt-ampere characteristics at different temperatures (5.0 points)

The physical mechanisms of the heating in both Experiment 1 and 2 are the same. Hence, you can use the result you obtained earlier in Experiment 1 to relate thermistor voltage with its temperature. Alternatively, you can use this explicit approximate relation:

$$T(U) = \frac{3500}{9.9 - \ln(\frac{1}{U} - 0.3)},$$

where T is temperature of the thermistor, expressed in kelvins, and U is voltage on the thermistor, expressed in volts.

Measure and graph the Current vs Voltage of the LED at temperatures ranging from room temperature to 80 °C in pulsed mode.

A.1	Measure and graph $I_{\text{LED\_pulsed}}(U_{\text{LED\_pulsed}}, T)$ dependence in the range from 3 mA to 50 mA at the room temperature, and 40, 60, and 80 °C. Draw all curves on the same graph.	2.5pt

A.2	In the answer sheet, fill the table with $U_{\text{LED\_pulsed}}$ values at 3, 10, 20, and 40 mA driving currents $I_{\text{LED\_pulsed}}$ at room temperature, 40, 60, and 80 °C.	1.0pt

A.3	Graph main points of $U_{\text{LED\_pulsed}}(I_{\text{LED\_pulsed}}, T)$ (those listed in question A.2) and calculate (approximate graphically) the linear voltage dependence on the temperature coefficient ($\Delta U(I)/\Delta T$) at 3, 10, 20, and 40 mA.	1.5pt

Part B. Measurement of the LED volt-ampere characteristics at continuous driving current (3.5 points)

B.1	Measure and graph the $I_{\text{LED\_continuous}}(U_{\text{LED\_continuous}})$ dependence in the range from 3 mA to 50 mA with the heater turned off in the continuous driving regime. In the answer sheet, also write down the values of $U_{\text{LED\_continuous}}$, PCB (thermostat) temperature T_{PCB}, and the difference $\Delta U = U_{\text{LED\_pulsed}} - U_{\text{LED\_continuous}}$ at 3, 10, 20, and 40 mA.	1.5pt

B.2	Since the resistance of the LEDs is not constant (depends on current), the term Dynamic Resistance is used and expressed as $\frac{\mathrm{d}U}{\mathrm{d}I}$. Using graph (B.1), estimate the reciprocal of the LED dynamic resistance $1/(\frac{\mathrm{d}U}{\mathrm{d}I}) = \frac{\mathrm{d}I}{\mathrm{d}U}$. In the answer sheet, write the values of $\frac{\mathrm{d}I}{\mathrm{d}U}$ at 3, 10, 20, and 40 mA. Draw tangents $\frac{\mathrm{d}I}{\mathrm{d}U}$ at these points on the graph.	0.5pt

B.3	Calculate and graph the difference $\Delta T(P)$between the temperature of continuously operating semiconductor die (T_{J}) and temperature of the PCB (T_{PCB}) as a function of electrical power (at 3, 10, 20, and 40 mA). Calculate (approximate graphically) the linear LED thermal resistance $\frac{\Delta T}{P}$, and write it in the answer sheet. *Note*: Assume that all electrical energy consumed by LED is converted into the heat and the energy emitted as light can be ignored.	1.5pt

Part C. Calculation of the LED current drift due to the temperature (1.5 points)

In the Introduction, it was mentioned that LEDs are typically driven by the constant current, but not constant voltage. Assume that one decided to drive the LED at nominal current value of 20 mA with constant voltage value you have measured for 20 mA current in the task B.1.

C.1	Using the LED characteristics calculated in section B, estimate the actual current flowing through LED, if voltage is kept constant (voltage measured in B.1, $U(20\mathrm{mA})$), but PCB temperature is at 0 °C and 40 °C.	1.5pt