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Fakultät für Physik und Geowissenschaften
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E13He Switching Phenomena

Tasks

1. Measure the voltage drop across a capacitor (500 pF < C < 10 nF), which is discharged through a resistor with an as small as possible rating.

2. Develop a model for your observations.

3. Perform further measurements to test the model. Analyze the data quantitatively.

4. When do you observe a time constant $\tau = RC$? Make at least one measurement in this regime.

Literature

Electrodynamics and Optics, W. Demtröder, 4.3, 6.1
Physikalisches Praktikum, 14. Auflage, Hrsg. W. Schenk, F. Kremer, Elektrizitätslehre, 3.3, 4.1
https://link.springer.com/book/10.1007/978-3-658-00666-2

Accessories

Picoscope, Arduino, Breadboard, MOSFET-switch, circuit elements, cables

Introduction

The aim of this experiment is the time-resolved measurement of switch-on- and switch-off functions that appear in *RC*-, *RL*- and *RLC*-circuits. These processes are modelled with linear differential equations of first and second order that are widely used in many areas of physics.

If a capacitor with capacitance C is discharged through a resistor with resistance R, then according to the textbooks the discharge current I and the voltage V_C across the capacitor are given by:

$$I(t) = -\frac{V_K}{R}\exp\left(-\frac{t}{RC}\right), \quad V_C(t) = V\exp\left(-\frac{t}{RC}\right)$$

V_K denotes the applied voltage attained when the capacitor is fully charged.

Experimental Realization

In this HomeLab, the Picoscope is used to measure the voltage. Select reasonable values for the time constant and the voltage range on the Picoscope. Set the trigger to either “Single” or “Repeat” mode and select suitable values for the trigger level and the pre-trigger range. Reasonable values can be found by trial and error. The Picoscope only has a resolution of 8 bits. This leads to a noticeable rasterization at low voltages. However, this does not significantly affect the evaluation.

The dc voltage (3.3 V or 5.0 V) needed to charge the capacitor, is generated by the Arduino.

The experiment should be performed by using a MOSFET-switch (instead of a mechanical relay), since this yields a smooth and fast switching. The MOSFET-switch is only connected to the Arduino ground (GND) and to a digital output, a connection to a supply voltage is not necessary.
Note that the MOSFET acts as a simple switch connecting GND with V- when energized with 5 V through the digital output; Vin and V+ are always connected.

A possible sketch for actuating the MOSFET-switch might look as follows:

```
const int relais = 2;

void setup() {
  pinMode(relais, OUTPUT);
}

void loop() {
  digitalWrite(relais, HIGH);  //Relais/Switch on
  delay(5000);                 //Wait 5 s
  digitalWrite(relais, LOW);   //Relais/Switch off
  delay(5000);                 //Wait 5 s
}
```

This sketch switches the MOSFET from the conducting into the non-conducting state and back every 5 s. The switching of the MOSFET triggers the signal recording of the Picoscope.
The MOS DRIVER MODULE included in the experiment box shows a high frequency ringing, see below, which does not significantly disturb the measurement. Switching time is < 50 ns.

Eventually, you might need the CH340-driver to address the Arduino from your computer. This can be downloaded here:
https://www.az-delivery.de/products/nano-v3-mit-ch340-arduino-kompatibel

You find the software for the Picoscope here:
https://www.picotech.com/downloads

MOSFET-switch circuit

In this circuit, the charging voltage is always applied to the capacitor. The capacitor is periodically discharged through the resistor $R_{discharge}$ by operating the MOSFET-switch.

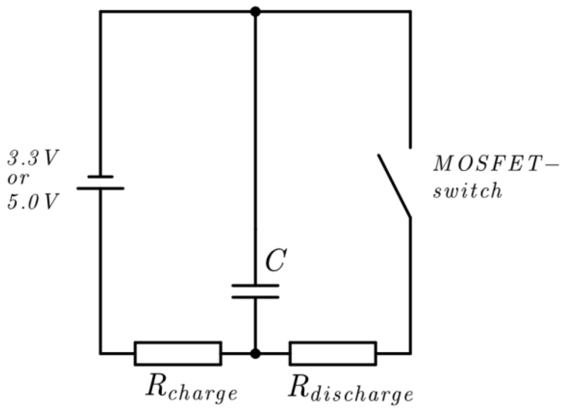

Fig. 1

MOSFET-switch discharging circuit

Charging resistance $R_{charge} \geq 1k\Omega$
The discharging resistor can be replaced by a cable.

Maker-Factory MOS module (MOSFET-switch)

This breakout board can be used to control loads with a maximum of 24 V and 5 A. To this end, a voltage of 5 V is applied to the gate of an IRF520 MOSFET via a digital output of the Arduino, which then controls the drain-source channel. The delay time when switching-on is specified as 8.8 ns and the static drain-to-source resistance as 0.27 Ω. This means that a minimum resistance of 0.27 Ω can be achieved in the discharge circuit when short-circuiting with a cable and with negligible contact resistance. The switch-on time is determined by the characteristics of the MOSFET, but also by the edge steepness of the Arduino's voltage pulse. In some test measurements, a short "ringing" (oscillating signal) could be seen after switching the MOSFET, see Fig. 2, but this did not affect the evaluation of the data.

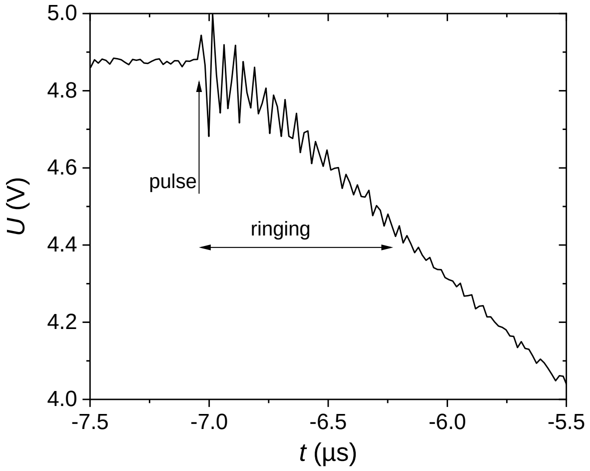

Fig. 2

Voltage drop across the capacitor as a function of time.