HÁSKÓLI ÍSLANDS **Eðlisfræðiskor**
Raunvísindadeild **Eðlisfræði I**

Oscilloscope and electric measurements

References

1. Young & Freedman: *University Physics*, ch. 26.4.
2. Benson: *University Physics*, ch. 28.4

1 Introduction

In this lab exercise the student will get to know the oscilloscope and multimeters, connect a simple electric circuit following a circuit diagram and carefully record data. The exercise is divided into two parts. The first part is about getting to know the oscilloscope, making simple measurements with it and comparing with results from a multimeter. In the second part we explore discharge of a capacitor and compare the results with a model of such discharge.

2 First inspection - without recording data

Instruments used are the oscilloscope, a function generator, digital multimeter, a variable resistor and a capacitor. Descriptions of the oscilloscope and the function generator are in the *appendix* under „Sveiflusjá-lýsing" and „Sveiflugjafi-lýsing". *Read these descriptions before you start the experiment.*

- Set the function generator to a sine wave, around 1000 Hz frequency and a voltage of $\frac{1}{2}$ to 1 V.
- Connect channel 1 of the oscilloscope to the output of the function generator, choose to view CH1 (#4) and make sure to trigger on CH1 (#5). Numbers refer to Fig. 2 in „Sveiflusjá lýsing".
- Try to achieve a steady picture of the wave on the screen by adjusting the trigger voltage (#1).
- Change the frequency and the voltage on the function generator and observe what happens. Also try changing to a square wave.
- Change the voltage amplification and try shifting the picture up and down on the screen.
- Change the speed the ray traces across the screen.
- Change teh *cal* settings (#13, #14 and #17) to see how they work but leave them in their original positions.
- Change #4 to *alt* and observe both channels simultaneously - the voltage on channel 2 is probably zero.
- Move the trace to the right (#16) so the beginning of the trace is on the screen. Adjust the trigger voltage (#1) and observe how the trace is triggered at different places. With the *SLOPE* button you choose whether the trace is triggered on a rising or a falling voltage.

3 Exercise with oscilloscope

This part is about learning to use the equipment: the oscilloscope and multimeter. You complete the *ready made forms* and sketch your setup on them.

3.1 Measuring AC voltage

- Set the function generator to 1 - 2 kHz and the voltage between $\frac{1}{2}$ and 1 V.
- Adjust the oscilloscope until an acceptable (size) trace is obtained, i.e. one that utilizes most of the screen.
- Measure the amplitude and the period of the wave on the screen.
- Connect a multimeter set to V_{rms} to the output of the function generator (along with the oscilloscope, it shouldn't have any effect). Measure the voltage output of the function generator.
- Compare these two voltage readings (reading off oscilloscope and multimeter) and two frequency values (reading off function generator and measurement from screen).
- Repeat this for higher frequency, e.g. 30 - 40 kHz. Multimeters don't all handle high frequency very well.

Note: AC meters measure V_{rms} that relates to the AC voltage amplitude as $V_{rms} = V_0/\sqrt{2}$. This must be taken into account during comparison.

3.2 Line frequency, or "house electricity"

The so-called "line voltage", supplied by the power plant, (230 V_{rms} i.e. oscillates between + and - 325 V) is too high to observe directly on an oscilloscope. Therefore we use a doorbell transformer to convert to a lower voltage.

- Observe and measure the output voltage of the transformer and the frequency of the power line (same as frequency at output of the transformer).
- Connect the function generator to the free channel on the oscilloscope and set it to a similar frequency as the one you measured at the transformer output.
- Observe both at channels simultaneously (set #4 to *Alt* or *Chop*) and set the output voltage of the function generator or the amplification on the oscilloscope so the amplitudes of the two signals, or waves, are similar.
- Next observe them in xy-mode (#18), fine tune the frequency at the function generator to obtain a stable picture.
- Increase the frequency n=2,3,4... times at the function generator and sketch the pictures you observe. These are named after a French mathematician Jules-Antonie Lissajous who first observed them with sand falling from a coupled pendulum.

4 Time constant of RC-circuit

This is the main part of the lab session. We shall measure the voltage change across a resistor in an RC-circuit as a function of time. The we process the data and compare it with a model for the voltage drop (across the resistor) in such a circuit.

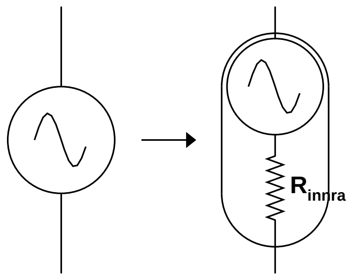
4.1 Output impedance (internal impedance) of a function generator

Before we can start our measurements on the RC-circuit we must take a closer look at the function generator. In general we can consider any power supply (function generator, battery etc.) as two "things" connected in series. The first is an ideal power supply that always delivers the requested voltage (EMF) and then a resistor, called the output resistance (or more generally output impedance, or internal resistance/impedance) through which all the current must flow.

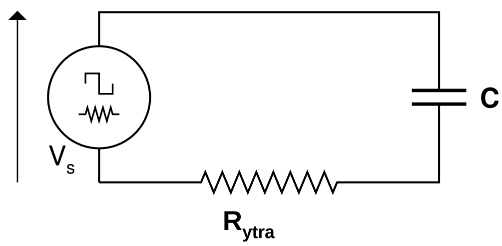
If no current flows from the power supply there is no voltage drop in this output impedance and the output voltage equals the EMF og the ideal power supply. When current flows however there will be a voltage drop over the output impedance and the output voltage therefore drops. If we connect our power supply to a variable resistor and adjust it such that the output voltage is exactly half the EMF then we know the output impedance (resistance in this case) equals the value of the external resistor.

Measurement of output impedance of function generator

- Set the function generator to sine wave, $V = \frac{1}{2} - 1\ V_{rms}$ and $f = 500$ Hz.
- Connect the multimeter to the function generator's output and record the EMF.
- Connect the variable resistor to the function generator output and adjust the resistance value to obtain exactly half the EMF as the output voltage. Record the value of the required resistance.



Mynd 1: Function generators have output resistance R_{innra}. A simplified picture of this assumes the function generator is an ideal resistanceless function generator with a resistor (internal) in series.



Mynd 2: RC-circuit

4.2 RC circuit - introduction

Figure 2 displays an RC circuit connected to a function generator with a square wave output. The student should be familiar with the RC circuit from prior studies and should review the relevant material (see references). When the function generator jumps from high to low voltage currents will flow from the capacitor. The current will decrease exponentially with time. The current is controlled by the size of the capacitor and the total resistance in the circuit $R_{alls} = R_{innra} + R_{ytra}$. The current can be described by

$$I = I_0 \cdot e^{-\kappa t} \tag{1}$$

where the time constant κ

$$\kappa = \frac{1}{R_{alls} \cdot C}$$

Using Ohm's law we can rewrite Eq. (1) as

$$V_R = V_{R0} \cdot e^{-\kappa t} \tag{2}$$

We can observe this exponential function with the oscilloscope and measure the time constant κ.

Measurement of time constant of RC circuit

- Connect the RC circuit shown in Fig. (2). Use a the capacitor supplied (about 0.1 μF) and set the variable resistor to R = 1kΩ
- Set the function generator to a square wave output at a frequency of about 500 Hz
- Observe the voltage across the resistor V_R. Ohm's law ($V_R = I \cdot R$) means the voltage must decrease exponentialy just like the current in the circuit.
- Set the scales (#15, #7 or #8) so that the trace utilizes a big part of the screen. Read 6 - 8 points $\{t, V_R(t)\}$ from the trace. The zero-ground voltage cant always be accessed by setting #11 or #12 to *gnd*. Uncertainty/error should of course be recorded simultaneously.
- Compare these data with the model as appropriate, determine the time constant $\tau = \frac{1}{\kappa} = R_{alls}C$ and compare with value obtained from value of R and C.

Suggestion for data processing: Model (2) says the voltage across the resistor decreases exponentially with time. To see if the data fit the model we can compare them graphically. We could draw a graph of $V(t)$ as function of t, then pick the „best" value for V_0 and the time constant and draw a curve according to (2) and check if it crosses through the data points. The difficulty is in how would you choose such „best" valuse and it is all but impossible to tell whether one curve fits better than another to the data points. Therefore we attempt to rewrite the model to a linear relationship between the measured quantities.

In this case is apprpriate to take the (natural) logarithm of equation (2) so that

$$\ln V_R = \ln V_{R0} - \kappa \cdot t$$

Draw a graph of $\ln V_R$ as function of t (both with error margins of course). Does the data fit a straight line model, and if so what is its slope? If the error in the slope overlaps the model value for κ we can say the measurements agree with the model (or vice versa).

Addition for more advanced students

Observe the voltage drop across each component in the RC circuit individually, the power supply (V_S), the capacitor (V_C) and the resistor (V_R). Sketch the traces observed on the oscilloscope and compare. Explain why the sum of all these quantities is zero.

Suggestion for data processing: When the voltage drop across the function generator is observed the ground is between the function generator and the resistor. To observe the voltage drop over the capacitor and the resistor we must move the ground so that it is between them. This moves the reference level on the oscilloscope.
Observe the voltage drop across the capacitor on channel 1 and the voltage over the resistor on channel 2. Here we must invert the signal on channel 2 so both signals are positive. Set the oscilloscope to *add* but note that the voltage scale on both channels must be the same. Compare the figure obtained with the figure when observing the voltage drop across the function generator.