Experiment 1: Low Pass Filter and Inverting Amplifier

Aims of the experiment

You will get acquainted to the lab instruments (digital oscilloscope, wave generator, multimeters, power supplies) and you will work with fundamental electronic circuits.

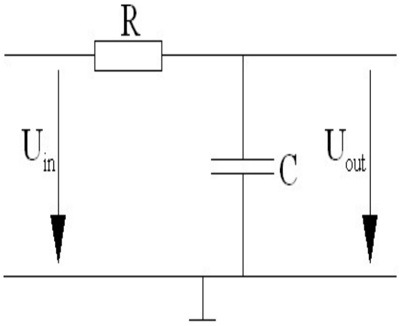
Theoretical Background

RC Low Pass Filter

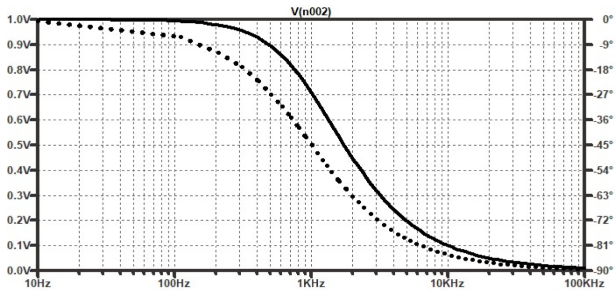
An RC low pass filter as shown in fig. 1.1 attenuates signals of frequencies higher than the cut off frequency f_{co}. The cut off frequency depends on the capacitance C and the resistance R.

$$f_{co} = \frac{1}{2\pi RC}$$

At the cut off frequency the output signal U_{out} has dropped to a value of $\frac{1}{2}\sqrt{2}$ of the original value at low frequencies.



a)



b)

Fig. 1.1 a) RC low pass filter b) Amplitude ratio A and phase φ as function of the frequency f.

Charging and Discharging of a Capacitor

The differential equation for the RC low pass as shown in fig. 1.1 is given by

$$U_{in} = \tau \cdot \frac{dU_{out}}{dt} + U_{out}$$

where τ = RC is the time constant, U_{in} the input voltage and U_{out} the output voltage.

For U_{in} = 0 the solution of the differential equation is (**discharging of a capacitor**)

$$U_{out}(t) = U_0 \cdot e^{-\frac{t}{\tau}} \qquad \text{for } t = \tau: \ U_{out} = 36{,}8\% \cdot U_0$$

where U_0 is the voltage of the capacitor at the start (U_0 is the supply voltage for a fully charged capacitor).
For $U_{in} = U_0$ the solution is (**charging of a capacitor**)

$$U_{out}(t) = U_0\left(1 - e^{-\frac{t}{\tau}}\right) \qquad \text{for } t = \tau: \ U_{out} = 63{,}2\% \cdot U_0$$

These solutions can be used to determine the time constant τ in exercise 2.

Inverting Operational Amplifier

Fig. 1.2 shows an inverting operational amplifier. The output voltage U_{out} as a function of the input voltage U_{in} is given by

$$U_{out} = -\frac{R_2}{R_1} U_{in}$$

If the frequency of U_{in} goes above the cut off frequency of the amplifier circuit, U_{out} drops below the value calculated by the above equation. At the cut off frequency the output has dropped to a value of $\frac{1}{2}\sqrt{2}$ of the original value.

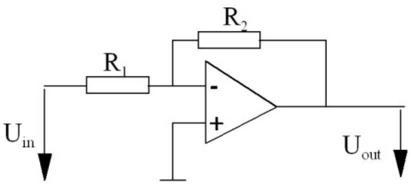


Fig 1.2 Inverting operational amplifier.

Exercise 1: Frequency Response of an RC Low Pass Filter

Build up the RC-low-pass filter as shown in fig. 1.3 with R = 10 kΩ, C = 100 nF. Connect the wave generator to the circuit and connect channel 1 of the digital storage oscilloscope (DSO) to the input and channel 2 of the DSO to the output of the low pass circuit.

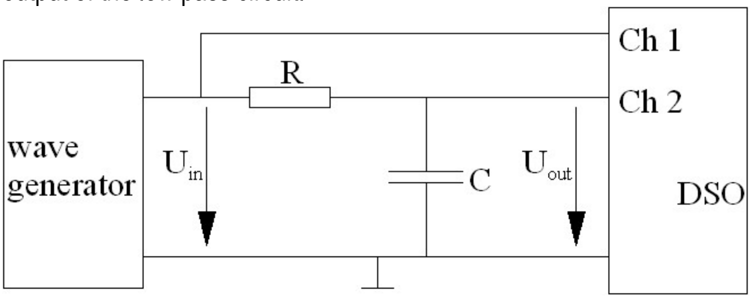


Fig. 1.3: RC low pass filter connected to the wave generator and the digital storage oscilloscope DSO.

Provide a **sine wave** of varying frequency f as input starting with a low frequency (e. g. f = 1 Hz, U_{in} = 10 Vpp). For each frequency value measure the input amplitude U_{in} and the output amplitude U_{out} and calculate the **ratio A = U_{out}/U_{in}**. Determine the **phase shift φ** between the output and the input signal both by counting divisions on the DSO-screen and by using the direct measurement tool of the DSO (not available for all DSOs in the lab). Consider that a full period of the sine wave relates to 360°. Increase the frequency to a value that you obtain a ratio A of 0.9, 0.8, … 0.1 and fill the table of the lab protocol with your measurement values.
In the lab report, draw a diagram of the ratio A and the phase φ as a function of the frequency f based on your measurement values. Determine the **cut off frequency f_{co}** and compare it to the **calculated value** according to the above equation. What is the value of the phase at the cut off frequency?

Exercise 2: Step Response of the RC Low Pass Filter

a) Instead of the sine signal apply a **positive square wave** with the amplitude U_0 = 10 V to the low pass circuit. Choose a frequency significantly **below the cut off frequency**. Measure the input signal U_{in} and the output signal U_{out} and **record the signals**. Determine **the time constant τ** on the rising and on the falling edge of the signal and compare it to the calculated time constant τ. Include the recorded signals into your lab report.

b) Now apply a positive square wave with a frequency significantly **above the cut of frequency**. Again measure the input signal U_{in} and the output signal U_{out} and record the signals (to be included in the lab report). Explain the curve.

Exercise 3: Frequency Response of an Inverting Operational Amplifier

a) Implement an **inverting OP-amplifier** as depicted in fig 1.2 with R_1 = 1 kΩ and R_2 = 1 kΩ. Supply a sine wave as input voltage U_{in} (e. g. U_{in} =2 Vpp) and measure both the input voltage U_{in} and the output voltage U_{out} with the DSO. Similar to exercise 1, determine the **ratio A** between output and input amplitude **as a function of the frequency**. Determine the **cut off frequency f_{co}.**

b) Exchange resistor R_2 with 10 kΩ (suggested U_{in} = 1 Vpp), again determine the ratio A as a function of the frequency and determine the cut off frequency f_{co}.

Acknowledgement

We thank Prof. Dr. B. Deppisch for providing the previous lab instruction material.

Names		Date of Experiment

Lab Protocol: Experiment 1: Low Pass Filter and Inverting Amplifier

Exercise 1: Frequency Response of an RC Low Pass

To be done before the lab
Calculate the cut of frequency f_{co}
for the given low pass filter.

freq. f	U_{in} [V]	U_{out} [V]	A	φ [°]
			1	
			0.9	
			0.8	
			0.7	
			0.6	
			0.5	
			0.4	
			0.2	

Determined cut off frequency f_{co}	
Phase angle φ at cut off frequency	

Exercise 2: Step Response of the RC Low Pass Filter

To be done before the lab Calculate the time constant τ from the values of the components as given in the instruction text.

chosen frequency	
Measured time constant τ on rising edge	
on falling edge	

Exercise 3: Frequency Response of an Inverting Operational Amplifier

a) $R_1 = 1\ k\Omega$, $R_2 = 1\ k\Omega$.

frequency f	U_{in} [V]	U_{out} [V]	A
			1
			0.9
			0.8
			0.7
			0.6
			0.4
			0.2

Determined cut off frequency f_{co}	

b) $R_1 = 1\ k\Omega$, $R_2 = 10\ k\Omega$.

frequency f	U_{in} [V]	U_{out} [V]	A
			10
			9
			8
			7
			6
			4
			2

Determined cut off frequency f_{co}	

Lab protocol approved