1 Purpose of the Exercise

- Getting to know the basic functions of the generator and oscilloscope.
- Consolidation of the method of determining the amplitude and phase characteristics using two methods.

2 Theoretical Basics

2.1 Frequency Characteristics

The basic method of determining the properties of linear systems is the determination of Bode characteristics, i.e., frequency characteristics. The frequency response describes the response of the system to a sinusoidal input with a frequency varying within a given range.
Let the input signal be determined as follows:

$$uwe(t) = Uwe \sin(2\pi ft - \varphi_{we})$$

Then the steady-state response of the linear system can be described as:

$$uwy(t) = Uwy \sin(2\pi ft - \varphi_{wy})$$

The system response is a sinusoidal signal of the same frequency but generally different in amplitude and phase. The change in the amplitude and phase of the signal after passing through the system depends on the frequency f. Amplitude characteristics $K_u = K_u(f)$ is the ratio of the amplitude of the output signal to the amplitude of the input signal as a function of frequency:

$$K_u(f) = \frac{Uwy(f)}{Uwe(f)}$$

In electronics, a logarithmic measure is often given $K_u[dB]$:

$$K_u[dB] = 20 \log_{10} K_u = 20 \log_{10} \frac{Uwy}{Uwe}[dB]$$

Phase characteristics $\varphi = \varphi(f)$ is the phase shift of the output signal with respect to the input signal as a function of frequency:

$$\varphi(f) = \varphi_{we}(f) - \varphi_{wy}(f)$$

2.2 Experimental Determination of the Amplitude and Phase Characteristics

The experimental determination of the amplitude characteristics of the system consists in applying a sinusoidal signal of constant amplitude to its input and measuring the amplitude of the signal observed at the output of the system. The quotient of the output signal amplitude to the input signal amplitude is the vertical coordinate of a single point on the amplitude characteristic plot, where the horizontal coordinate is the signal frequency.
The experimental determination of the phase characteristic consists in measuring the shift between the input and output signal. The phase shift can be measured using two methods: the classical method and the Lissajous figure method. The classical method is based on measuring the phase shift as the angle corresponding to the delay time interval between the output and input signal. The Lissajous figure method consists in determining the angle on the basis of an ellipse obtained for a given frequency.

2.3 1st Order RC Low-Pass Filter

For the 1st order RC low-pass filter, the following equations and the resulting differential equation can be written:

$$uwe(t) = uwy(t) + Ri(t)$$

$$i(t) = ic(t) = C\frac{duwy(t)}{dt}$$

$$\Rightarrow uwe(t) = uwy(t) + RC\frac{duwy(t)}{dt}$$

Applying the Laplace transform to the above equation, we get the operator transmittance of the first-order RC filter:

$$H(s) = \frac{Uwy(s)}{Uwe(s)} = \frac{1}{RCs + 1}$$

Substituting $s = j\omega$, we get the relationship describing the amplitude characteristic:

$$K_u(\omega) = |H(s = j\omega)| = \frac{1}{\sqrt{1 + (RC\omega)^2}}$$

The relationship describing the phase characteristics:

$$\varphi(\omega) = \arg(H(s = j\omega)) = \arctan(-RC\omega)$$

Knowing the dependence that describes the amplitude characteristics, the cutoff frequency ω_g of the first-order RC low-pass filter can be determined from the following equation:

$$-3dB = 20 \log_{10} K_u(\omega_g)$$

3 The Course of the Exercise

3.1 Getting to Know the Operation of the Oscilloscope and Generator

Tasks to be completed:

- Oscilloscope, generator - overview - connection of the oscilloscope to the generator.
- Channel on and off, timeline and amplitude positioning, timeline and amplitude gain, trigger, AC and DC coupling, XT mode, XY mode.
- Measurements of signal parameters, cursors, measurement of displacements, saving waveforms.

3.2 Determination of the Amplitude and Phase Characteristics

Tasks to be completed:

- Performing measurements using two methods:
  - Classic method - oscilloscope in XT mode.
  - Lissajous figure method - oscilloscope in XY mode.
- Making calculations and plotting the amplitude and phase characteristics.

3.3 Recording of Waveforms from an Oscilloscope

Observe the voltage waveforms at the input of the RC filter for different frequencies and for the following input signal shapes: sinusoidal, square, and triangle. Then input a sinusoidal waveform and record Lissajous figures for different frequencies of the input signal.

4 Report

The report should contain:

- Results of measurements and calculations.
- Sample calculations.
- Sample waveforms observed on the oscilloscope.
- RC filter frequency characteristics obtained on the basis of measurements and comparing them with theoretical characteristics.
- Interpretation of characteristics taking into account the frequency response, cut-off frequency, and steepness of the characteristic.

5 Conclusion

In this exercise, we successfully learned how to operate the generator and oscilloscope, and used these tools to determine the amplitude and phase characteristics of an RC low-pass filter. The experimental results were consistent with the theoretical expectations, validating the fundamental concepts of frequency response, amplitude characteristics, and phase characteristics. The classic method and Lissajous figure method provided reliable measurements for plotting Bode plots. This exercise reinforced our understanding of how filters affect signal amplitude and phase, which is crucial in the design and analysis of electronic circuits.

Protocol

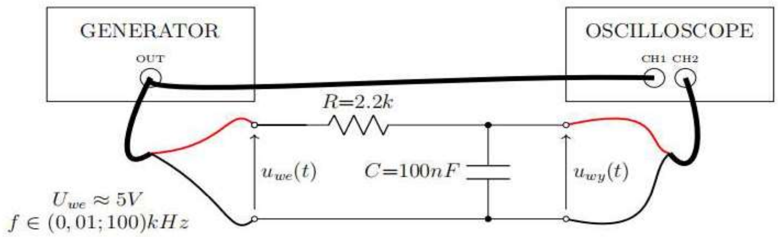
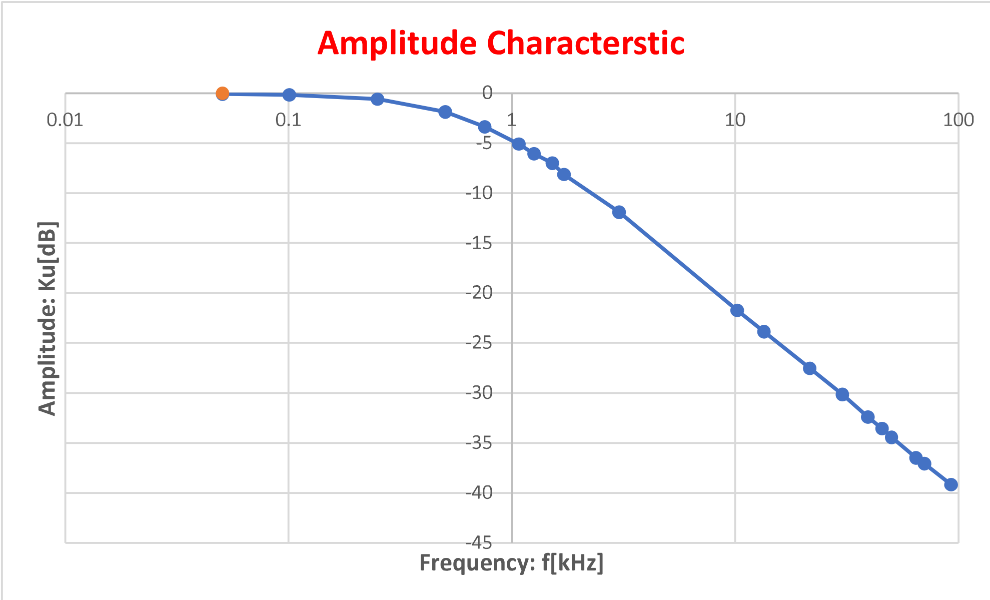


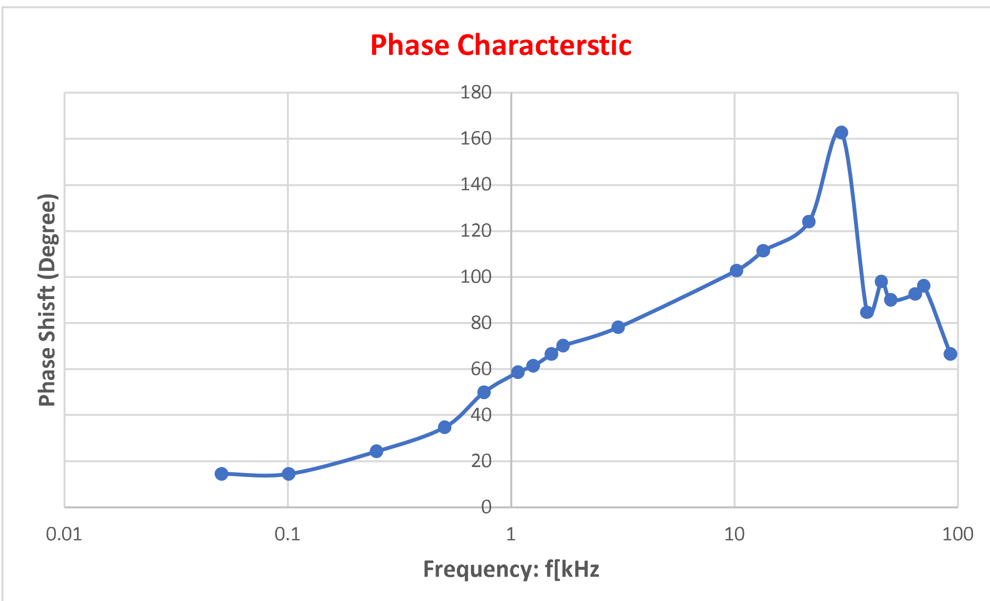
Figure 6: Scheme of the measuring system

Results of measurements and calculations: (Calcution is done Excel**)**

Measurements				**Calculation results**		
f [kHz]	U^{we}_{pp} [V]	U^{wy}_{pp} [V]	Δt [ms]	K_u [$-$]	$K_{u\,[dB]}$ [dB]	φ [°]
0.05064	-0.087	50.64	0.8	0.99	-0.087	14.58432
0.1008	-0.175	100.8	0.4	0.98	-0.175	14.5152
0.2498	-0.602	249.8	0.27	0.933	-0.602	24.28056
0.5035	-1.862	503.5	0.192	0.807	-1.862	34.80192
0.7544	-3.375	754.4	0.184	0.678	-3.375	49.971456
1.072	-5.098	1072	0.152	0.556	-5.098	58.65984
1.255	-6.055	1255	0.136	0.498	-6.055	61.4448
1.515	-6.993	1515	0.122	0.447	-6.993	66.5388
1.71	-8.134	1710	0.114	0.392	-8.134	70.1784
3.015	-11.903	3015	0.072	0.254	-11.993	78.1488
10.2	-21.723	10200	0.028	0.082	-21.723	102.816
13.44	-23.876	13440	0.023	0.064	-23.876	111.2832
21.52	-27.535	21520	0.016	0.042	-27.535	123.9552
30.13	-30.172	30130	0.015	0.031	-30.172	162.702
39.21	-32.395	39210	0.006	0.024	-32.395	84.6936
45.39	-33.556	45390	0.006	0.021	-33.556	98.0424
50.02	-34.434	50020	0.005	0.019	-34.424	90.036
64.31	-36.478	64310	0.004	0.015	-36.478	92.6064
70.32	-37.077	70320	0.0038	0.014	-37.077	96.19776
92.4	-39.172	92400	0.002	0.011	-39.172	66.528

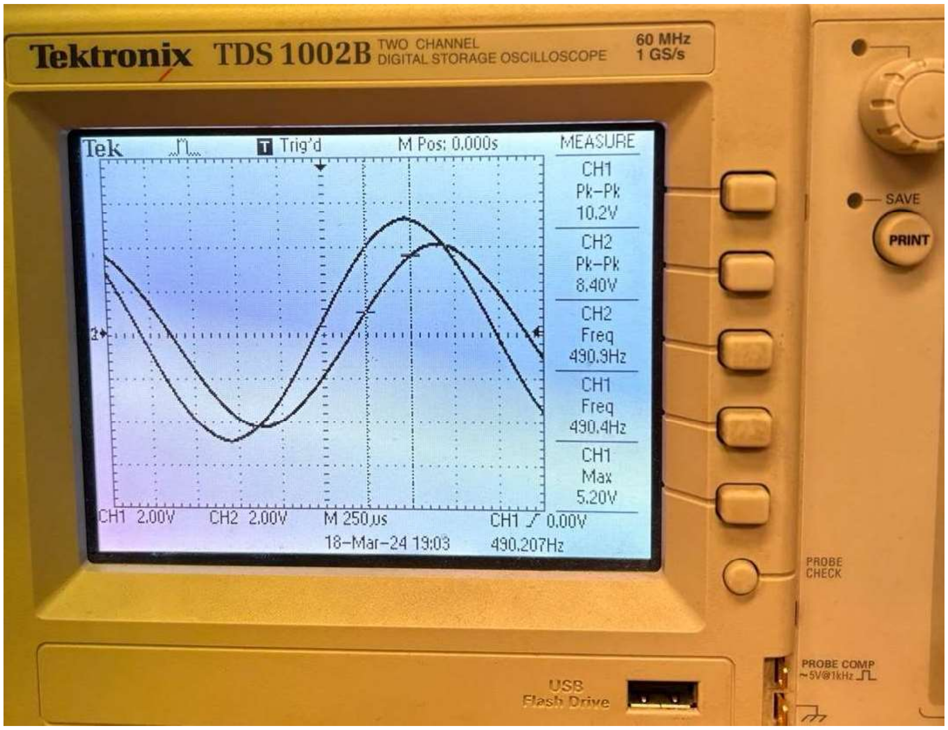


Amplitude Characterstic
Amplitude: Ku[dB]
Frequency: f[kHz]
0.01
0.1
1
10
100
0
-5
-10
-15
-20
-25
-30
-35
-40
-45

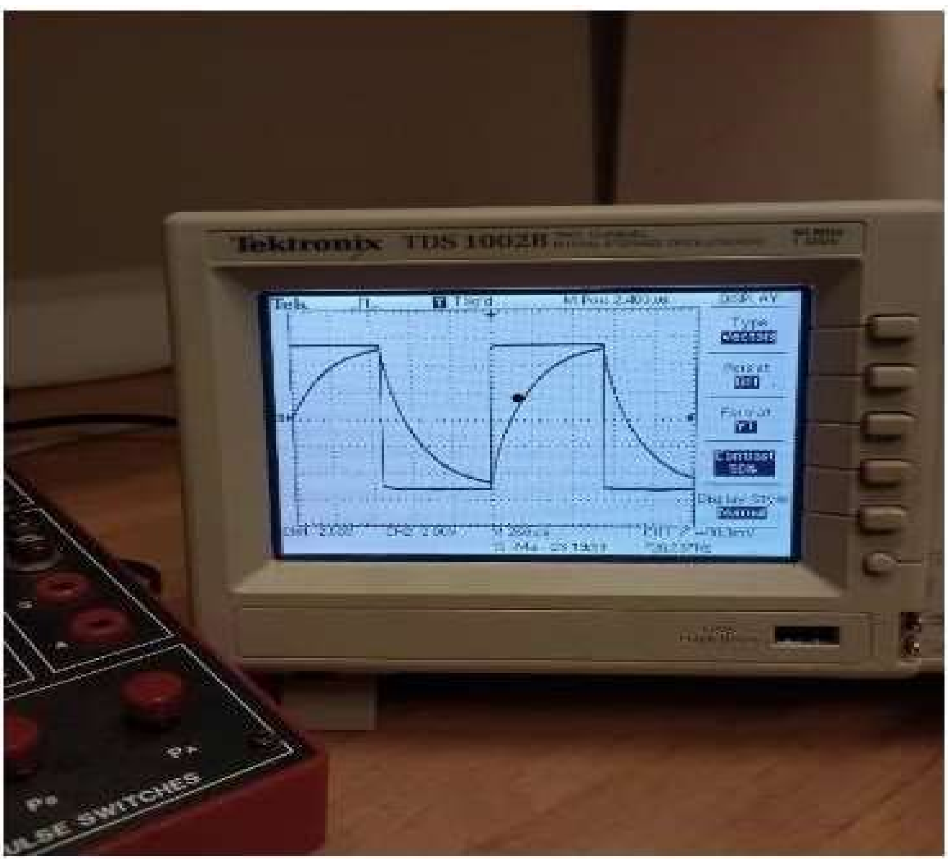


Phase Characterstic
Phase Shisft (Degree)
Frequency: f[kHz
180
160
140
120
100
80
60
40
20
0
0.01
0.1
1
10
100

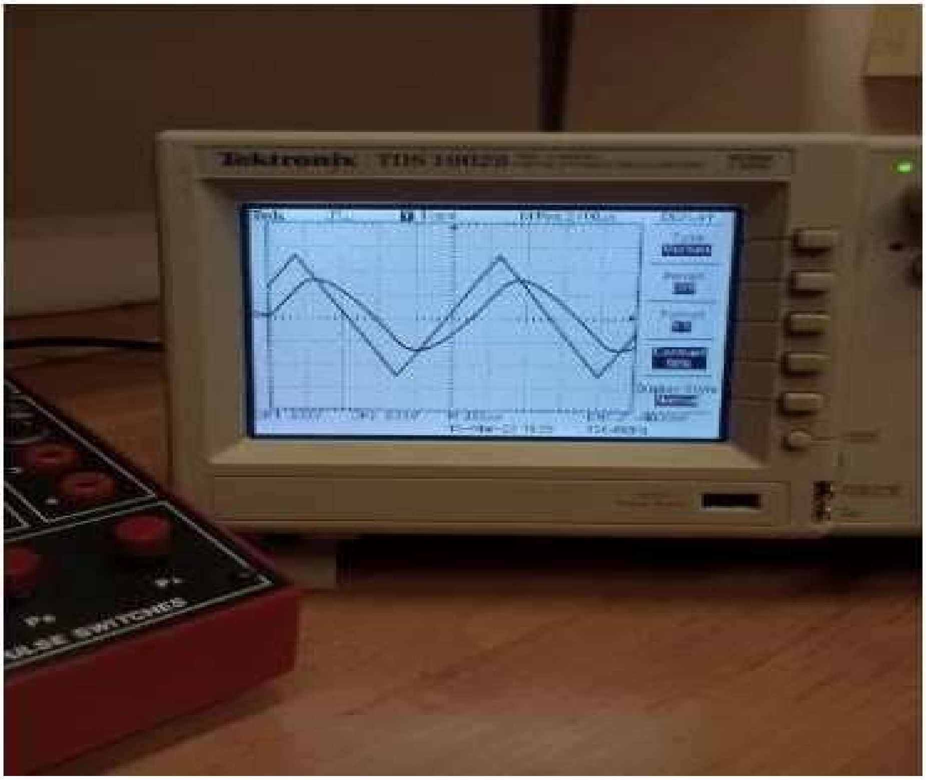
sample waveforms observed on the oscilloscope



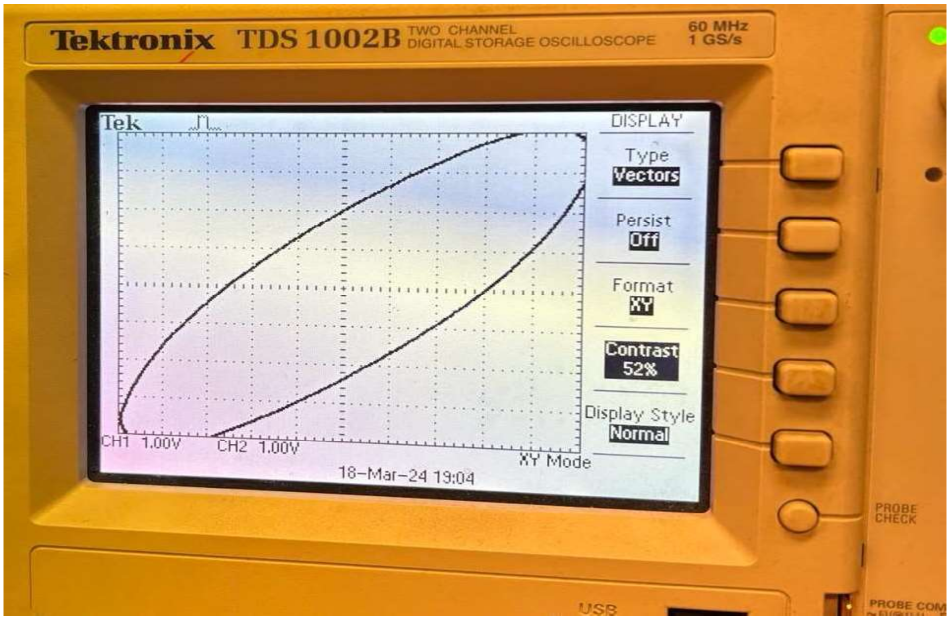
SQUARE WAVE SIGNALS



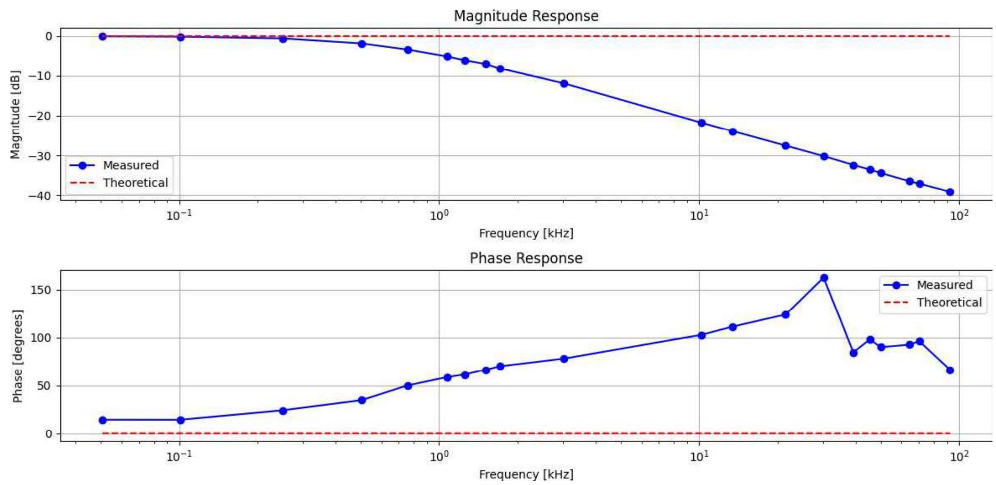
TRIANGLE WAVE SIGNAL



sample waveforms observed on the oscilloscope (Formate XY) - LISSAJOUS ELLIPSES



RC filter frequency characteristics obtained based on measurements and comparing them with theoretical characteristics



interpretation of characteristics taking into account the frequency response, cut-off fre quency and steepness of the characteristic