Jacobs University Bremen

Lab Report 3 - Filters

Spring Semester 2023

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Conducted on: **March 16, 2023**

1. Introduction

The objective of the experiment is to show the behavior of simple passive RC circuits acting as filters, one low pass and one high pass, with a sinusoid of different frequencies as an input signal. We measure the properties of these circuits, and we analyze the result of the measurements and how they are represented.

A filter is a network used to select a frequency or range of frequencies while rejecting all others. Usually, they are constructed using active components like transistors or operational amplifiers, however we can also see similar behavior in passive networks of resistors, capacitors, and inductors. There are four general types. High Pass, Low Pass, Band Pass, and Notch Filters.

In our experiment, we analyze Lo-Pass and Band-Pass filters which are simple in nature, only using passive components such as inductors, capacitors, and resistors.

Furthermore, we will use the Bode plot to analyze the frequency response of these filters, and we will use the Nyquist plot to describe the parametric plot of the frequency response of the filters.

1.1 Lo-Pass

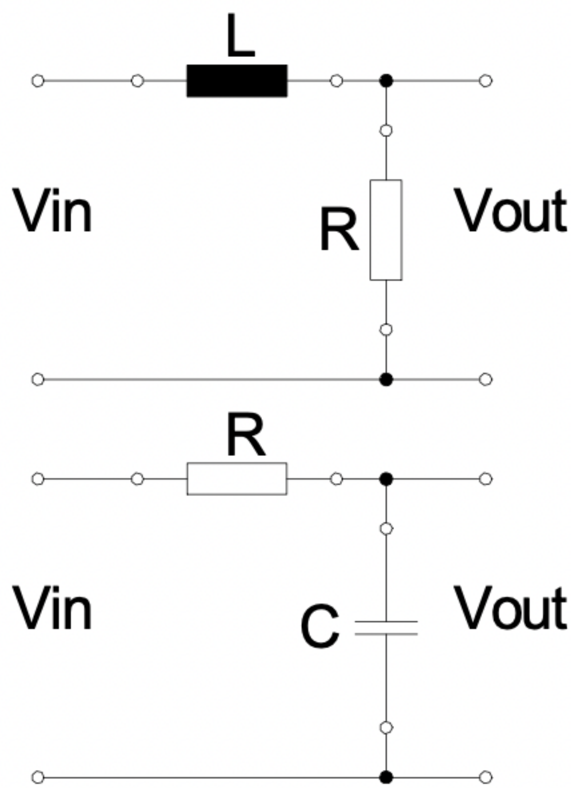

Figure 1.1: Low Pass Filter

A low pass filter allows low frequencies to pass, while it hinders higher frequencies. With high frequencies, the phase shift of the output signal becomes negative relative to the input signal.

It can be designed using a resistor and a capacitor, or an inductor and a resistor. In general, we can get the amplitude ratio of the output signal to the input signal by using the following equation:

For an RC circuit, which is what we design in the experiment:

$$\underline{A} = \frac{V_{out}}{V_{in}} = \frac{1}{1 + j\omega RC} \tag{1.1}$$

To obtain the cutoff frequency, we can use the following equation:

$$\underline{f_c} = \frac{1}{2\pi RC} \tag{1.2}$$

To obtain the amplitude and phase of the output signal, we use the following equations:

$$|\underline{A}| = \frac{1}{\sqrt{1 + (\omega RC)^2}} \text{ and } \phi = -\arctan(\omega RC) \tag{1.3}$$

1.2 Band-Pass

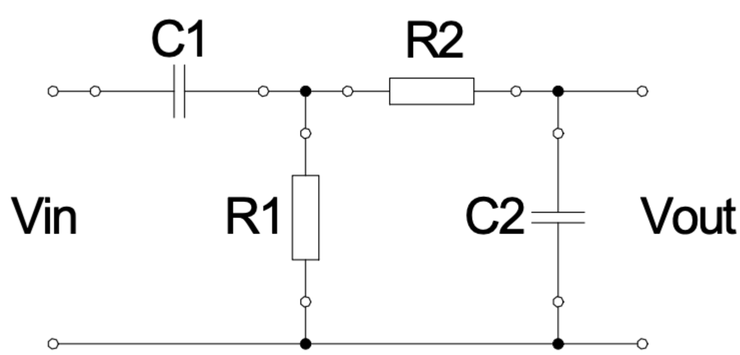

Figure 1.2: Band Pass Filter

A simple band pass filter is simply a combination of a high and low pass filter. It passes through frequencies within a certain range, and attenuates frequencies outside of it. The formula for the amplitude ratio is the same as the low pass filter, but we have to take into account the high pass filter as well. The formula for the cutoff frequency is also the same as the low pass, and high pass filter (1.2).

1.3 Obtaining the characteristic output of a filter

To describe the frequency response of these kinds of networks, we use the Bode plot. We plot the amplitude to frequencies over several decades, and the ratio is calculated. The unit of the result is **decibels**, or **dB**. **dB** is a logarithmic value used for such purposes. It is defined as:

$$A = 20 \cdot \log_{10} \frac{V_{out}}{V_{in}} \tag{1.4}$$

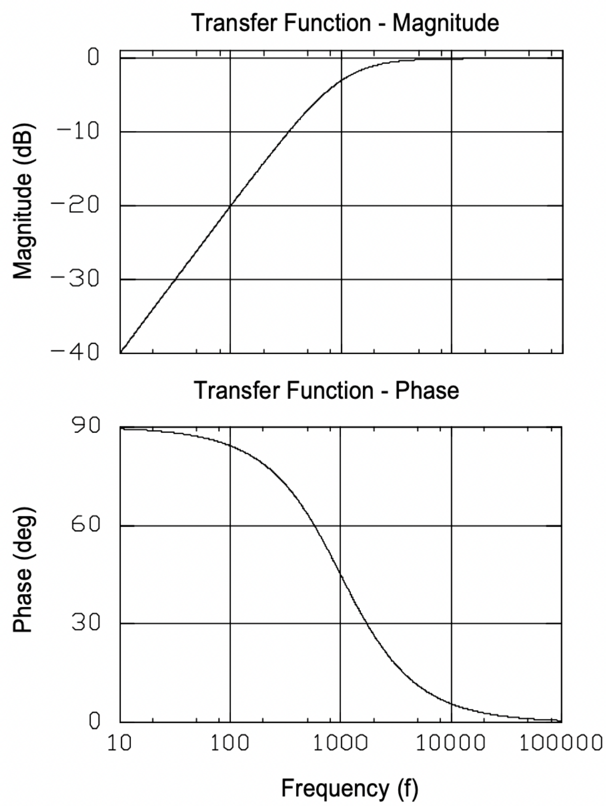

Figure 1.3: A bode plot, showing the magnitude plotted against the frequency, and the phase shift plotted against the frequency.

The other quantity measured is the phase shift ϕ between the input and output signal, taken relative to the input signal. When the output signal is ahead the input, the phase shift ϕ is positive, otherwise it is negative.

A **Nyquist plot** is a parametric plot of a frequency response. In Cartesian coordinates, the real part of the transfer function is plotted on the X axis. The imaginary part is plotted on the Y axis. The frequency is swept as a parameter, resulting in a plot per frequency.

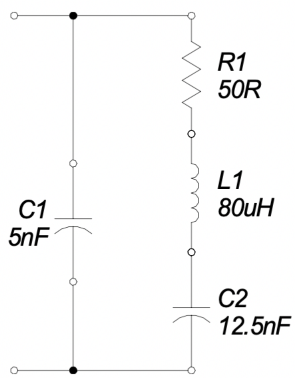

Figure 1.4: An RLC circuit with a capacitor in parallel.

We wish to find how the complex conductance changes when ω changes, given that the impedance for the RLC series circuit is

$$\underline{Z_S} = R_1 + j(\omega L_1 - \frac{1}{\omega C_2})$$

and with the parallel capacitor the admittance is

$$\underline{Y_{all}} = j\omega C_1 + \frac{1}{\underline{Z_S}}$$

When varying ω, a Nyquist plot is generated. The right plot is $\frac{1}{Y_{all}}$

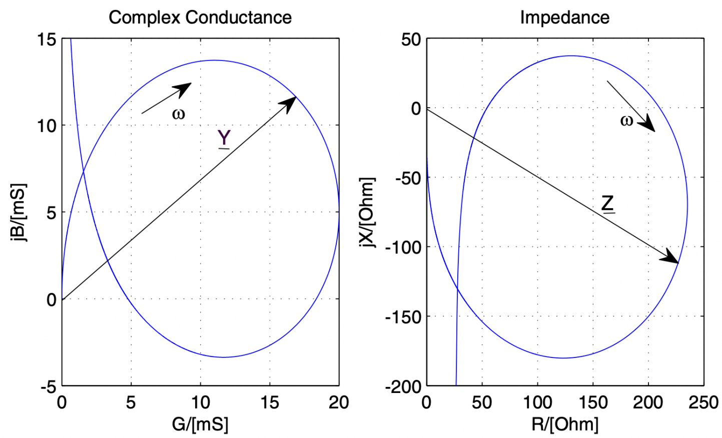

Figure 1.5: The nyquist plot of the RLC circuit.

2. Execution

Equipment: Oscilloscope, Function Generator, BNC-to-Kleps cable.

2.1 Part 1 : Lo-Pass

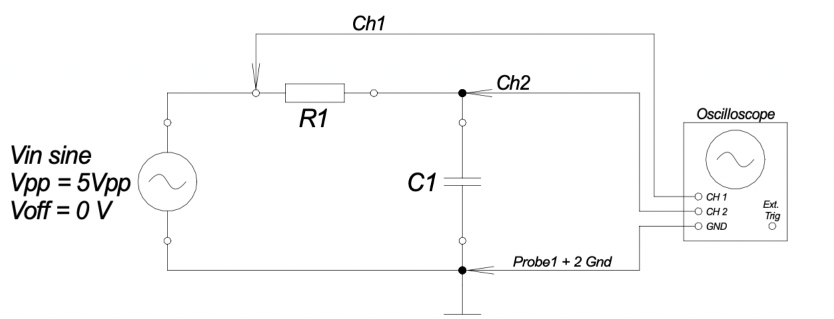

Figure 2.1: $C_1 = 1.5\text{nF}$ and $R_1 = 22\text{K}\Omega$

The signal generator is connected via the BNC-To-Kleps cable. The CH1 channel is used for the input, and the CH2 channel is used for the output. The frequency at the signal generator is then varied in steps of 1, 2, 5, 10 steps up to 100KHz.

Input Amplitude(in V)	Output Amplitude(in V)	Phase(in deg)	Frequency(in Hz)	Amplitude(in dB)
10.1	10	-0.36	50	20.00
10.1	10	-0.36	100	20.00
10.1	10	-2.59	200	20.00
10.2	10	-6.49	500	20.00
10.4	10.1	-11.8	1000	20.09
10.9	10	-23	2000	20.00
12.2	8	-47.4	5000	18.06
11.8	5.04	-64	10000	14.05
12.4	2.8	-75.3	20000	8.94
11.8	1.14	-82.8	50000	1.14
11.8	0.596	-84.6	100000	-4.50

Table 2.1: The effect of the frequency on the output amplitude is shown in the table above.

What we see is that the phase shift goes from positive to negative the further we increase the frequency, and that the output amplitude gets smaller and smaller. This is expected as we have built a low-pass filter.

2.2 Part 2 : Band-Pass

To determine the properties of a band-pass filter, we had two possible RC combinations. One combination would lead to a high pass filter, and the other would lead to a low pass filter.

We had two resistors, one of 82KΩ and one of 10.0KΩ. We also had two capacitors, one of 1.5nF and one of 100nF.

To determine the right combination, we used the formula for the cutoff frequency of a high and low pass filter:

$$f_c = \frac{1}{2\pi RC} \tag{2.1}$$

And plugging in the values for R=82KΩ and C=1.5nF, we get:

$$f_c = \frac{1}{2\pi \cdot 82K\Omega \cdot 1.5nF} = 12939.42\text{Hz} \tag{2.2}$$

Which is the low pass filter, as the cutoff frequency is the greatest out of all the other combinations.

And plugging in the values for R=10KΩ and C=100nF, we get:

$$f_c = \frac{1}{2\pi \cdot 10K\Omega \cdot 100nF} = 159.15\text{Hz} \tag{2.3}$$

Which is the high pass filter, as the cutoff frequency is the smallest out of all the other combinations.

We use a sine signal with a 5Vpp amplitude without an offset at the function generator. We vary the frequency of the generator from 50Hz all the way to 100kHz. We use the oscilloscope to measure the input and output amplitude, and we record the following values:

Input Amplitude(in V)	Output Amplitude(in V)	Phase(in deg)	Frequency(in Hz)	Amplitude
10.4	2.92	73.4	50	9.31
10.4	5.2	53	100	14.32
10	7.68	38.8	200	17.71
10	9.44	16.5	500	19.50
10.4	10	4.32	1000	20.00
10.9	10.5	-4.04	2000	20.42
11.6	10.5	-19.4	5000	20.42
11.6	9.12	-37.7	10000	19.20
11.6	6.4	-55	20000	16.12
11.6	2.92	-73.4	50000	9.31
12.4	1.54	-80.5	100000	3.75

Table 2.2: The effect of the frequency on the output amplitude is shown above. We see what we expect: Between certain frequencies the output amplitude is greater, while when going up to 100kHz or down to 50Hz we notice a significant decline.

3. Evaluation

3.1 Part 1

Below are the results of the low pass filter. The measured frequencies and amplitudes are then plotted on a bode plot.

Input Amplitude(in V)	Output Amplitude(in V)	Phase(in deg)	Frequency(in Hz)	Amplitude(in dB)
10.1	10	-0.36	50	20.00
10.1	10	-0.36	100	20.00
10.1	10	-2.59	200	20.00
10.2	10	-6.49	500	20.00
10.4	10.1	-11.8	1000	20.09
10.9	10	-23	2000	20.00
12.2	8	-47.4	5000	18.06
11.8	5.04	-64	10000	14.05
12.4	2.8	-75.3	20000	8.94
11.8	1.14	-82.8	50000	1.14
11.8	0.596	-84.6	100000	-4.50

Table 3.1: The measured frequencies and amplitudes from the low pass filter.

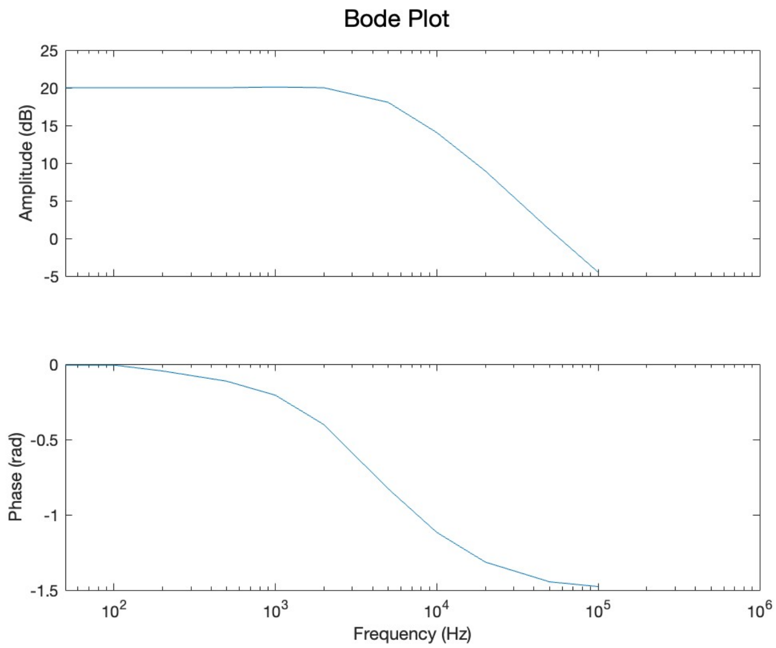

Figure 3.1: Bode plot of measured frequencies, amplitudes and phase shifts of the low pass filter.

The calculated cutoff frequency can be obtained by the following relation for the low pass filter circuit:

$$f_{-3dB} = \frac{1}{2\pi RC} \tag{3.1}$$

3.2 Part 2

4. Conclusion

5. References