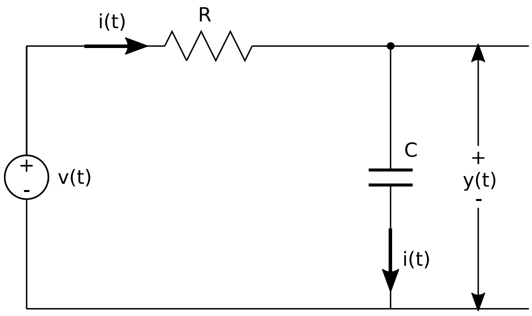
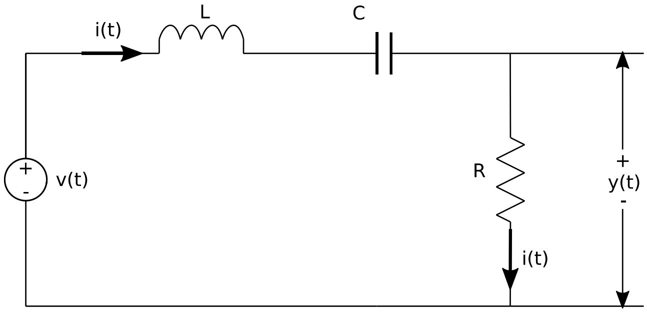
	Faculty of Mechanical Engineering and Robotics Department of Robotics and Mechatronics	
Mechatronics system identyfication		
Lab 6: Non-parametric identyfication based on experimental data		

1. Non-parametric identification of RLC filters

The laboratory measurement was carried out using two electrical circuits: the RC low-pass filter and the RLC band-pass filter. Their schemes and transmittances are shown in the figures below.



$$H(s) = \frac{Y(s)}{V(s)} = \frac{\frac{1}{R_1 C_1}}{s + \frac{1}{R_1 C_1}}$$



$$H(s) = \frac{Y(s)}{V(s)} = \frac{\frac{R_2}{L_2} s}{s^2 + \frac{R_2}{L_2} s + \frac{1}{C_2 L_2}}$$

For each of the filters, the input signal v(t) and the output signal y(t) were measured. The components of the individual systems have the following nominal values:

- RC: $R_1 = 47\ \Omega$, $C_1 = 2.2\ \mu\mathrm{F}$
- RLC: $R_2 = 220\ \Omega$, $C_2 = 4.7\ \mathrm{nF}$ i $L_2 = 1\ \mathrm{mH}$

Identification of both systems was carried out using a chirp signal and noise. For individual systems, these signals had the following parameters:

- RC system:

- chirp: frequency from 40 Hz to 150 kHz, signal length 2 seconds
- noise: frequency up to 200 kHz, signal length 2 seconds

• RLC system:

- chirp: frequency from 1 to 300 kHz, signal length 2 seconds
- noise: frequency up to 500 kHz, signal length 2 seconds

Ex. 1.1

Based on measurements using chirp excitation (file names 20210305-RC_Chirp40v150kHz_T2s.mat and 20220401-RLC_Chirp1v300kHz_T2s.mat), create Bode plots for the given filters, using the definition of spectral transmittance directly:

$$H(\omega) = \frac{Y(\omega)}{V(\omega)}$$

where V(ω) and Y(ω) are the Fourier transforms of the input and output signals, respectively. Do the following:

- compare the obtained plots with the theoretical Bode plots obtained using the bode(sys) function, where sys is the transmittance of the system; the characteristics from the bode() function can be extracted for further processing with the following code:

```
[mag,phase,w]=bode(sys);
```

- read the resonant frequency of the RLC system and determine its damping using one of the known methods; compare the values obtained from the theoretical transmittance with the measurement results.

Note 1: for experimental data from the RLC filter, there should be a decrease in the amplitude of the spectral transmittance, which results from the imperfection of the measurement system (e.g. the fact that the real coil has resistance). In this case, using the half-power method, read the -3dB drop from the maximum amplitude on the characteristic.

• determine the frequency response of the RC filter (based on the amplitude drop by -3dB) from the Bode characteristic obtained theoretically and from the experiment; compare results

Note 2: Bode plots should be displayed within the excitation frequency range, as outside this range we expect high levels of noise and therefore unreliable characteristics.

Mat files with data can be loaded by double-clicking on them, or using the Load function, for example**:**

```
load('20210305-RC_Chirp40v150kHz_T2s.mat')
```

The files contain the following datasets:

A – measured output signal y(t)
B – measured input signal v(t)
Length – the length of the signal
Tinterval - time step
Tstart – value of the first time moment
Version – the version of the acquisition software used

Signals A and B may contain invalid values due to acquisition errors. These errors cause "Inf" or "NaN" values to appear. To remove these values from the signal, the simplest solution is to assign them a value of 0:

```
A(isnan(A)) = 0;
B(isnan(B)) = 0;
A(isinf(A)) = 0;
B(isinf(B)) = 0;
```

Please note that this solution is not ideal, because it introduces additional discontinuities into the signal.

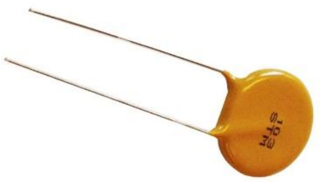
Ex 1.2

Re-plot the Bode characteristics for the RLC system, taking new component values and compensating for system imperfections. Apply the new transfer function of the system, which takes into account the resistance of the inductive choke (inductive element L_2) and other components of the system (e.g. wires or breadboard) in the form of the variable R_2L:

$$H(s) = \frac{Y(s)}{V(s)} = \frac{\frac{R_2}{L_2}s}{s^2 + \frac{(R_2 + R_{2L})}{L_2}s + \frac{1}{C_2 L_2}}$$

Using a multimeter, measure the resistance of the components R_2 and L_2, and the capacitance of the capacitor C_2. Find by trial and error the value of inductance L_2 (within the tolerance of +/- 20% from the nominal value) to obtain the best agreement between the theoretical and experimental characteristics.

Note: the resistance R_2L is the sum of the measured resistance of the choke L_2 and the resistance of other elements in the system. The resistance of the remaining elements should be estimated by trial and error, however, it should not exceed the measured resistance of the choke L_2.



Ceramic capacitor

resistor

inductor

The report should include the Bode characteristics created on the basis of the measurement with chirp excitation. They should be compared with the Bode characteristics created on the basis of the theoretical transmittance of the systems and the read properties of the systems (attenuation, frequency response, resonance frequency) should be provided. The comment should describe the differences between the individual characteristics and what may be the reason for the differences between the theoretical results and the results of the experiment.

From task 1.2, the new Bode characteristic of the RLC system should be included, taking into account the modified parameters and transmittance. Give the values of the parameters, thanks to which the theoretical and experimental characteristics were consistent.

Ex. 2

An alternative way to determine the transition function is to use estimators, e.g. the H1 estimator using the tfestimate function. This function computes the H_1 estimator using the Welch periodogram method (similar to power spectral density estimation). In the tfestimate function, it is used to calculate the eigenspectrum G_xx (ω) and the reciprocal spectrum G_xy (ω). The algorithm used here divides the signal into windows with a length in samples equal to the window variable, which can overlap each other by a number of samples equal to the value of the overlap variable. From each window, G_xx (ω) and G_xy (ω) are calculated, and then they are averaged and used to determine H_1 (ω) according to the formula:

$$H_1(\omega) = \frac{G_{xy}(\omega)}{G_{xx}(\omega)}$$

The following code shows the implementation of the tfestimate function. The variable df is the frequency resolution to be obtained after using the tfestimate function. Determine the lengths of the window and overlap variables depending on the df parameter to obtain a given frequency resolution and 50% overlap of the windows.

```
df = 1;
window = ?;
overlap = ?;
nfft = window;
[H1,F] = tfestimate(B,A,window,overlap,nfft,fs,'twosided');
```

The completed code snippet should be included in the report along with an explanation as to why such variable values give the specified resolution. An exemplary chart can be used as justification.

Ex. 3

Load the measurement data obtained with noise input (file names 20210305-RC_SzumBand200kHz_T2s.mat and 20220401-RLC_SzumBand500kHz_T2.mat). As in Task 1, the acquisition errors from vectors A and B should be removed.

Zadanie 3.1

Determine the transfer functions H(ω) of the RLC and RC filters using the formula used in Problem 1.1. Create the Bode plots corresponding to the obtained transfer functions and compare them with the theoretical Bode plots (for RLC, assume the modified transfer function from Problem 1.2).

Zadanie 3.2

Calculate the transfer functions for the RC and RLC filters using the H_1 estimator in the form of the Matlab tfestimate function, according to the code from Exercise 2. Calculate the H_1 estimators assuming resolution df equal to 1, 10 and 100. Plot the Bode plots for each of the obtained transfer functions and compare with the plot Bode for the theoretical model. What is the effect of using different df values?

The Bode characteristics created from the measurement with noise excitation should be included in the report. They should be compared with the Bode characteristics created on the basis of the theoretical transmittances of the systems. The comment should also specify the difference between the estimation of the transfer function obtained directly (using the formula from Task 1.1) and the estimation using the tfestimate function. It should also be discussed how different values of the df parameter affect the estimation result and why? Why is the estimation quality different in different frequency ranges?