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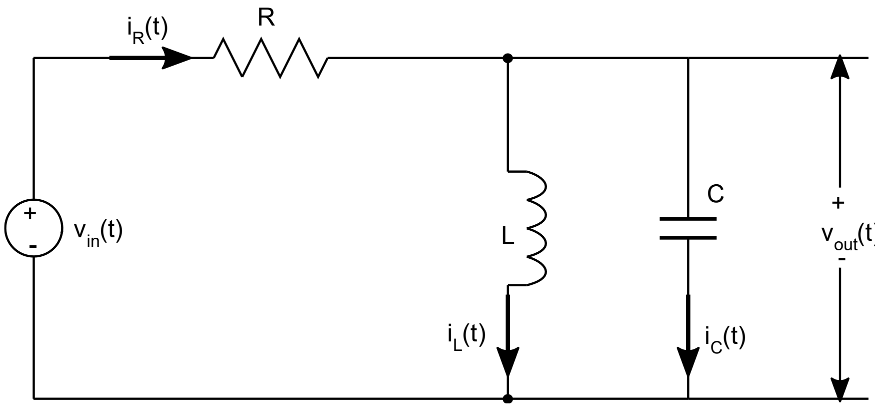
| AGH | Faculty of Mechanical Engineering and Robotics<br><br>Dept. of Robotics and Mechatronics | R&M |
| Mechatronic system identification | | |
| Lab 5: Non-parametric identification | | |

Ver. 1.1

**Aim -** The aim of this laboratory is to gain proficiency in tools used for non-parametric system identification. This laboratory is a theoretical introduction to following laboratory in which experimental signals will be processed. During the classes you will build a Simulink model and you will acquire input and output time domain signals. Next you will process these signals to obtain spectral transmittance, which will be compared against the build in functions. These results will be used to perform non-parametric identification. These tools will be used during the next laboratories to process experimental data.

## 1. Impulse response of a RLC

In this task, you have to model the RLC system using the transfer function of the system. The system consists of a resistor with resistance R, a capacitor with capacitance C and an inductor with inductance L. The input voltage is v_in (t) and the output voltage v_out (t) is measured on the capacitor.




### Ex. 1.1

For the circuit shown above, determine the relationship between v_out (t) and v_in (t) in the form of an analytic equation in the time domain. Use the following properties of electrical circuits:

I st Kirchhoff's law:

- $i_R(t) = i_L(t) + i_C(t)$

II Kirchhoff's law:

- $v_{in}(t) = i_R(t)R + v_{out}(t)$

Parallel connection of $L$ i $C$:

- $v_{out}(t) = v_C(t) = v_L(t)$

Voltage and current equation for RLC components

| Element | voltage – current | Current - voltage |
|---|---|---|
| Resistor | $v_R(t) = Ri_R(t)$ | $i_R(t) = \frac{1}{R}v_R(t)$ |
| Capacitor | $v_C(t) = \frac{1}{C}\int_0^t i_c(\tau)d\tau$ | $i_C(t) = C\frac{dv_C(t)}{dt}$ |
| Coil | $v_L(t) = L\frac{di_L(t)}{dt}$ | $i_L(t) = \frac{1}{L}\int_0^t v_L(\tau)d\tau$ |

Based on the obtained analytical equations, determine the transmittance of the system. Create Bode plots for the given RLC assuming the parameters R=10 Ω, C=1 μF, L=4 μH. Use the build in bode(SYS) function in Matlab, where SYS is the transmittance object created with the function:

```
SYS=tf(num,den);
```

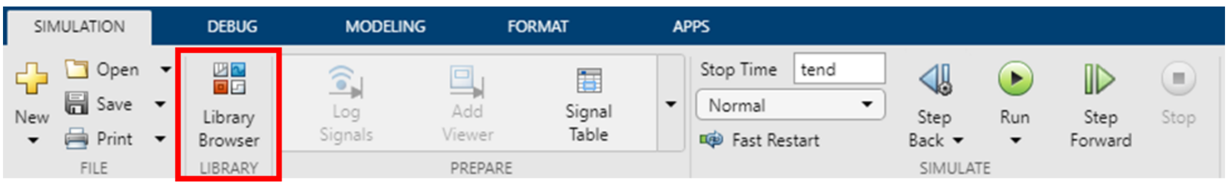
where Num and Den are the numerator and denominator of the transmittance, respectively. You will notice that the circuit under test is a band-pass filter.

Find the resonance frequency of the system. Look up equations determining resonance of RLC systems. Compare the result to the value from plot.

What should be the sampling frequency of a signal to obtain the bandwidth presented in the bode plot?

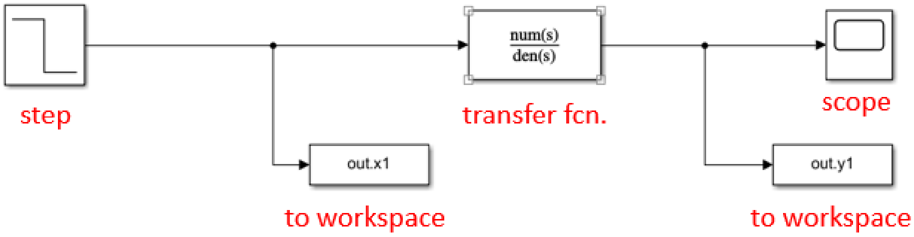
## Ex. 1.2

Create a model of the RLC system in Simulink. Search for the relevant items in the Simulation - Library Browser tab:

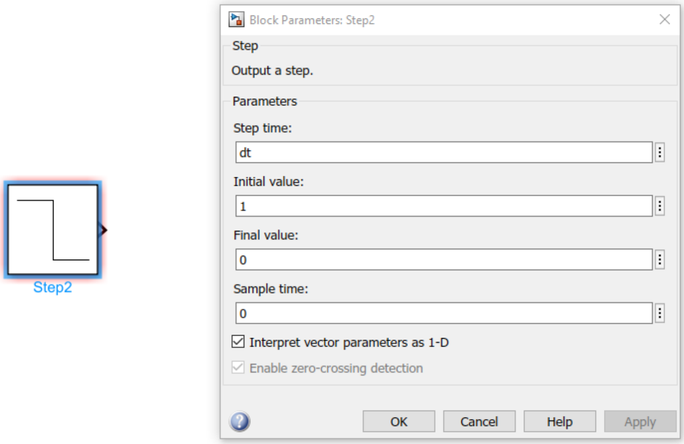



Model the RLC system using the transfer fcn block, which assumes the transfer function coefficients of the system. Also use the step block to generate a pulse signal, assuming a start value of 1, an end value of 0, and a step time equal to the simulation step. To export signals to the Matlab workspace, use the To Workspace blocks.

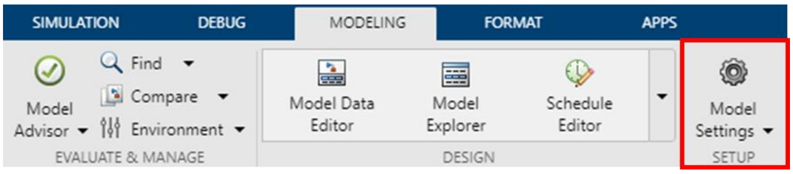
The Simulink model should look like this:

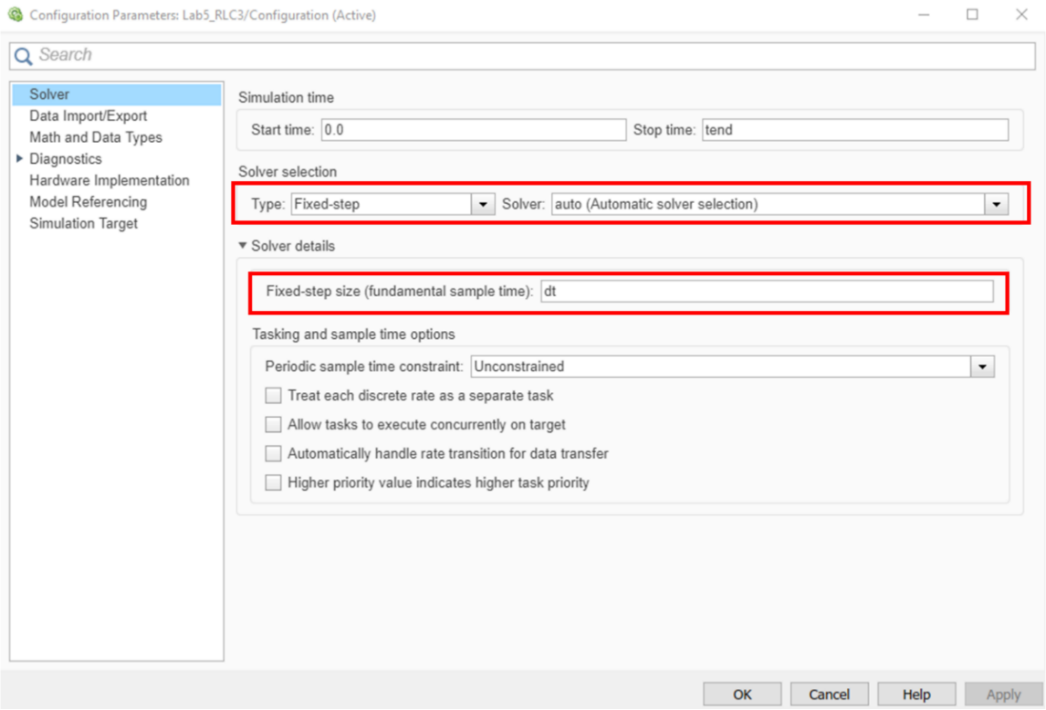



Step block parameters:




Select the appropriate time step (the model may require a very small time step), the simulation time (Start Time and Stop Time) and select the default solver with a fixed time step (Fixed - step). The time step and solver should be selected in the Modeling - Model Settings tab. Display the received impulse response on the graph.






The simulink model can be parameterized and run from a Matlab script. The function used to run the model in the simulink is given below. The out variable contains all the results saved from the To Workspace blocks.

```
out=sim('Lab5_RLC.slx');
```

## Ex. 1.3

Write your own script to obtain a Bode plot based on the Fourier transform of the impulse response obtained from the Simulink model. Use the definition of spectral transmittance directly:

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

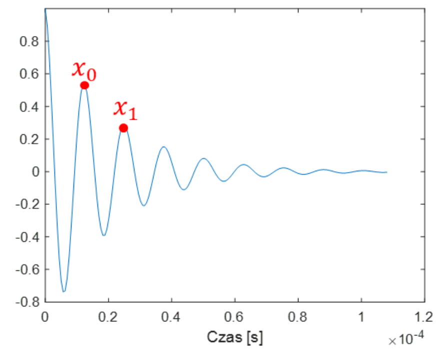
where V(ω) and Y(ω) are the Fourier transforms of the input and output signals, respectively. Compare the result to the plot obtained using function bode.

## Ex. 1.4

On the basis of the impulse response graph, calculate the dimensionless damping factor using the logarithmic method, and on the basis of the amplitude-frequency characteristics, using the half-power method (decrease by -3dB). The formulas are given in the image below:

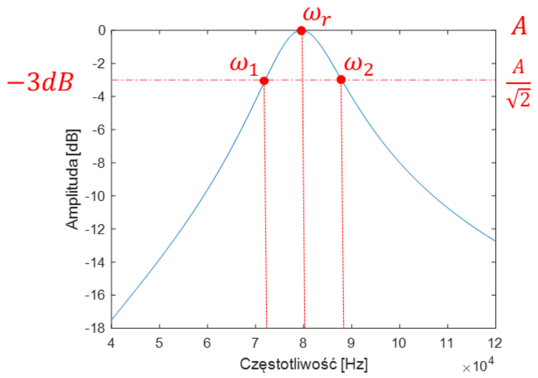
- Methods to estimate damping:
  - logarithmic damping decrement :

$$\xi = \frac{\ln(\frac{x_0}{x_1})}{2\pi}$$




  - Half power method:

$$\xi = \frac{\omega_2 - \omega_1}{2\omega_r}$$



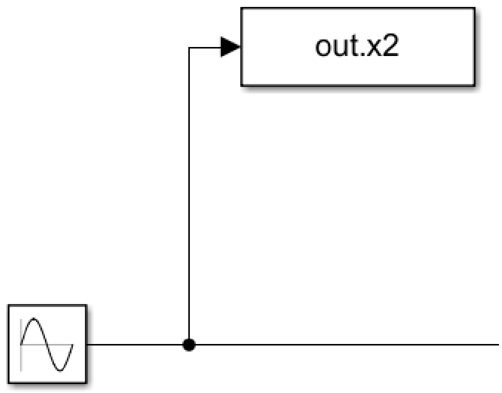

Ex. 1.5

Create Bode plots for resistance values R=5 Ω and R=100 Ω using the Simulink model. Read the filter bandwidth for the new R values. For each model, calculate the attenuation using one of the previously used methods and describe how the value of R affects the attenuation. For what approximate value of R does the system achieve critical damping?

The report should include an analytical equation showing the relationship between v_out (t) and v_in (t), the transmittance of the system, the length of the step used in the simulation, a graph showing the impulse response, and Bode plots for the given resistance values. The effect of resistance on the filter bandwidth and attenuation should be described in the comments. For what value of parameter R does the system achieve critical damping?

## 2. Sine excitation

Modify the created model by changing the excitation signal to a sinusoidal excitation (Sine Wave block) with an amplitude of 1. Assume the set of parameters R=10 Ω, C=1 µF, L=4 µH.



## Ex. 2.1

Perform the simulation assuming the excitation frequency:

- 70 kHz
- 80 kHz
- 90 kHz

In separate graphs, display the system's response to each of the above extortions. Read the amplitude of the output signal and the phase shift between the input signal and the output signal. Check that these values agree with the Bode plot for each frequency. To do this, calculate the relationship between the time shift and the phase shift using the equation $d\phi=360*dt/T$, where $d\phi$ is the phase shift $dt$ time shift and $T$ is the period of the wave.

## Ex 2.2

In a Matlab script, create a sine wave with a frequency of 70 kHz and an amplitude of 1. Convolve this signal with the system's impulse response from Problem 1.1 to get the system's response. Compare the obtained result with the result of the simulation from task 2.1.

The report should include graphs with the system's responses to individual excitation frequencies. A separate graph should include a comparison of the response to the 70 kHz signal obtained from the Simulink simulation and after the convolution in the Matlab script. In the comments, describe the obtained results - amplitudes and phase shifts - and compare them with the Bode plots.