Laboratory 4 – Analog (continuous-time) filters: design and analysis

(Deadline: March 30, 2017)

Introduction:

The objectives of this lab are to:

1. Build several different analog (continuous-time domain) filter circuits;
2. Experimentally investigate the time-domain output response of the analog filters using the oscilloscope;
3. Learn and plot the frequency response of different continuous-time filter circuits;

There are **4** exercises in this lab.

Filter classification

An ideal frequency-selective filter is a system that passes a pre-specified range of frequency components without any attenuation but completely rejects the remaining frequency components. The range of input frequencies that is left unaffected by the filter is referred to as the pass band of the filter, while the range of input frequencies that are blocked from the output is referred to as the stop band of the filter. Fig. 1 shows an ideal frequency-selective filter, where *A* is the magnitude of the filter.
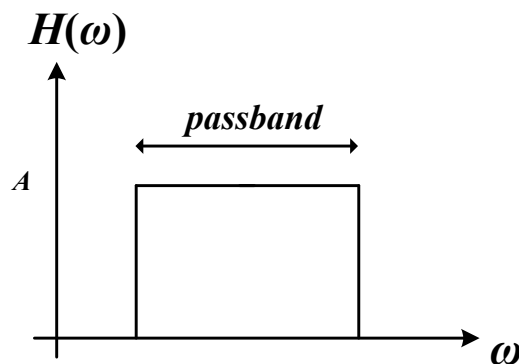

Fig. 1

The magnitude of the transfer function of the frequency filter, changes between *A* and zero as a function of ω. The magnitude of the filter $|H(\omega)|$, which is *A* in Fig. 1, is typically set to one within the pass band, while $|H(\omega)|$ is zero within the stop band. Depending upon the range of frequencies within pass and stop bands, an ideal frequency-selective filter is categorized in four different categories: (1) low-pass, (2) high-pass, (3) band-pass, and (4) band-stop. In this lab, you will build several analog filter circuits, classify them and investigate their time-domain output responses and their frequency response characteristics.

Laboratory exercise 1.

The gain and phase responses of a RC circuit as shown in Fig. 2 has been briefly highlighted in the lecture. The objective of this exercise is to experimentally investigate the frequency response of a RC circuit as shown in Fig. 2. You will need to create a plot for $y(f)/x(f)$. Perform the following steps:

1. Build the circuit in Fig. 2 on a breadboard, with $R = 1k\Omega$, $C = 1\mu F$.

2. Supply a sinusoidal input signal with a peak-to-peak value of 2V and a frequency of 20Hz (have TAs to check your circuit) from the waveform generator provided by the oscilloscope and observe both the input voltage signal ($x(t)$) and the output voltage signal ($y(t)$) on the oscilloscope (set channel 1 to $x(t)$ and channel 2 to $y(t)$). [_NOTE:_ to generate the input waveform, press the "AFG" button on the front panel of the oscilloscope, under "Waveform", select "Sine"]

3. Measure the following 3 quantities and record them:

    a. peak-to-peak values for both $x(t)$ and $y(t)$ on the oscilloscope,

    b. phase difference between $x(t)$ and $y(t)$.

To obtain the above measurements using the oscilloscope, perform the following steps:

   1) On the front panel of the oscilloscope, choose "Wave inspector"→ "measure"→ "Add Measurement".
   2) To measure the phase difference between $x(t)$ and $y(t)$, under "source", select "2". Under "Measurement Type", select "Phase". Then under "Phase to", select 1. Then select "OK Add Measurement".
   3) To measure the peak-to-peak value, repeat 1), under "Measurement Type", select "peak-peak". Then select "OK Add Measurement".

4. Record the above measurements for the following frequencies as well: 20Hz, 50Hz, 100Hz, 200Hz, 500Hz, 800Hz, 1kHz, 2kHz, 5kHz, 8kHz, 10kHz, 20kHz

5. Now adjust the frequency such that the peak-to-peak value of $y(t)$ is ½ of the maximum peak-to-peak value of $y(t)$ that you obtained from step 4. Record this frequency, which is also called the cut-off frequency, is described by (1) for a RC circuit.

$$f_{cut-off} = \frac{1}{2\pi RC} \qquad (1)$$

6. Based on the data that you obtained from steps (3) and (4), using the "**subplot**" function in MATLAB, create the magnitude and phase plots for $y(f)/x(f)$ vs frequency. To obtain the magnitude plot, calculate the ratio: [peak-to-peak of $y(t)$]/ peak-to-peak of $x(t)$].

    The magnitude plot should be located on the top and the phase on the bottom. Remember to multiply the frequency-vector by $\log_{10}$ in MATLAB to create the plots. Label the x-axis as "$\log_{10}$(frequency)". Comment on the plots. What type of filter is the RC circuit? Explain.
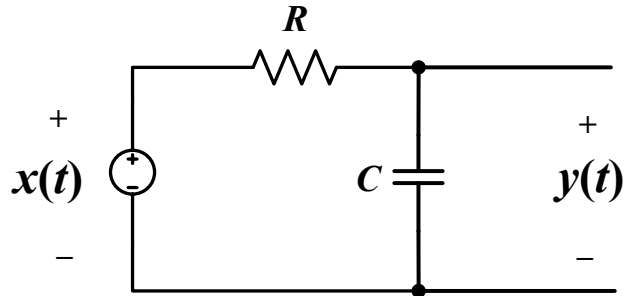
Fig. 2

Laboratory exercise 2.

Very similar to exercise 1, except this time you will experimentally investigate the frequency response of a RL circuit as shown in Fig. 3. You will then need to create the magnitude and phase plots for $y(f)/x(f)$ for the RL circuit. Perform the following steps:

1. Build the circuit in Fig. 3 on a breadboard, with $R = 1k\Omega$, $L = 100mH$.

2. Supply a sinusoidal input signal with a peak-to-peak value of 2V and a frequency of 20Hz (have TAs to check your circuit) from the waveform generator provided by the oscilloscope and observe both the input voltage signal ($x(t)$) and the output voltage signal ($y(t)$) on the oscilloscope (set channel 1 to $x(t)$ and channel 2 to $y(t)$).

3. Measure the following and record them:

    c.   peak-to-peak values for both $x(t)$ and $y(t)$,

    d.   phase difference between $x(t)$ and $y(t)$.

4. Record the above measurements for the following frequencies as well: 20Hz, 50Hz, 100Hz, 200Hz, 500Hz, 800Hz, 1kHz, 2kHz, 5kHz, 8kHz, 10kHz, 20kHz

5. Based on the data that you obtained from steps (3) and (4), plot the gain and phase responses of the RL circuit (see step 5 in exercise 1). Comment on the plots. What type of filter is the RL circuit? Explain.
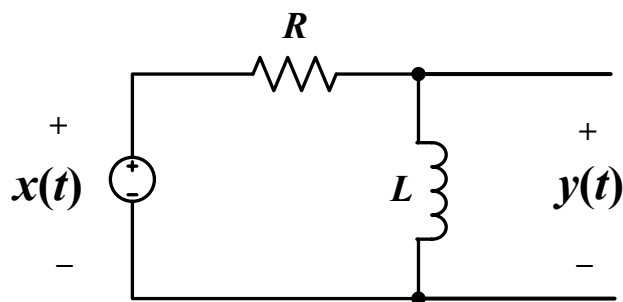

Fig. 3

Laboratory exercise 3.

This time you will experimentally investigate the characteristics of an analog filter with a series RLC circuit as shown in Fig. 4. Perform the following:

1. Build the circuit shown in Fig. 4 on a breadboard, with $R = 500\Omega$ (i.e. parallel the two $1k\Omega$ resistors), $L = 10mH$, $C = 1\mu F$.

2. Supply a sinusoidal input signal with a peak-to-peak value of 2V and a frequency of 100Hz (have TAs to check your circuit) and observe both the input voltage signal ($x(t)$) and the output signal ($y(t)$) on the oscilloscope (set channel 1 to $x(t)$ and channel 2 to $y(t)$)

3. Now adjust the frequency continuously from 100Hz to 5kHz and observe how the phase angle between $x(t)$ and the output signal $y(t)$ varies. Adjust the frequency until the phase difference is almost equal to zero. Record this frequency. You should see that at this frequency, $y(t)$ and $x(t)$ have approximately the same amplitude and they are in phase with each other. This frequency is called the center-frequency of the series LCR filter circuit.

4. Next, you will need to obtain the required data to plot the gain and phase responses of the series RLC filter circuit. You should be able to complete this step based on the procedures outlined in the previous exercises. Comment on the plots. What type of filter is the series RLC circuit? Explain.
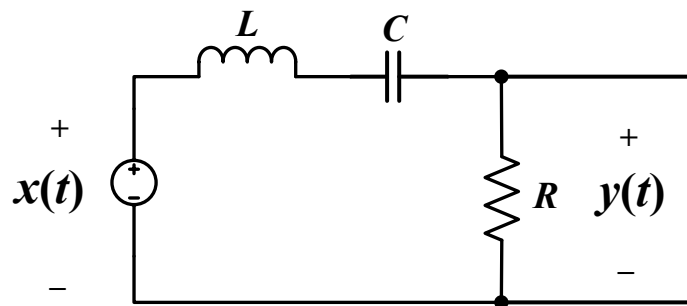

Fig. 4

Laboratory exercise 4.

The last exercise will have you to design a filter for an application in the area of electro-cardiology. Electro-cardiology is the study of the electric signals produced by the heart. These signals maintain the heart's rhythmic beat, and they are measured by an instrument called an electrocardiograph. This instrument must be capable of detecting periodic signals whose frequency is about 1Hz. The instrument must also be able to operate in the presence of sinusoidal noise consisting of signals from the surrounding electrical environment, whose fundamental frequency is 60Hz (i.e. frequency at which electric power is supplied).

Your task is to design and build a filter circuit such that the resulting circuit could be used in an electrocardiograph *to filter out any noise above 10Hz* and *pass the electric signals from the heart at or near 1Hz*. The attenuated magnitude of the component at 60Hz should be reduced by a factor of at least 3.

Based on the available components that we provided, design this filter and verify its performance by plotting its gain and phase responses (i.e. similar to the previous exercises). Draw the resulting filter circuit with all the values included. Obtain all the required data with the aid of the oscilloscope.

Submitting your files using the EECS submit service:

You can submit your files and report to eecs2602@gmail.com or hardcopy report.

Files to be submitted:

1. M-file: the M-file contains your scripts for the graphs in exercise 1 – 4.
2. The lab write-up report (follow the format on the course website under "Labs")