ECE 231 Laboratory Exercise 6—Frequency / Time Response of RL and RC Circuits

OBJECTIVES
- Observe and calculate the response of first-order low pass and high pass filters.
- Gain experience in plotting Bode plots and calculating decibels.
- Test your ability to design and properly test a circuit.

EQUIPMENT REQUIRED
- ECE 231 Circuit Board (In Stock room)
- Three BNC cables (one for input ac voltage and two for input/output voltage to oscilloscope)
- One lot of clip leads and/or jumper wires
- Two-channel Oscilloscope

BACKGROUND
Both capacitors and inductors have reactances that are frequency dependent.

\[ X_C = \frac{1}{2\pi f C} = \frac{1}{\omega C} \quad X_L = 2\pi f L = \omega L \quad (1) \]

When measuring the capacitance and inductance of a component it is very important that you know the frequency at which the measuring instrument is using. All components R, C, and L consist of all three. The frequency at which they are operating is a predictor of which ones can be ignored in calculations. This laboratory experiment will not examine these characteristics of R, C, and L. Capacitors and inductors as received from manufacturers usually have high tolerances. For example it is not uncommon for a capacitor to have a tolerance of ± 20%; therefore, measure the values of your components on the protoboards using an RLC meter.

The voltage transfer function (voltage gain) of a filter is expressed as eq. (2)

\[ H_V(j\omega) = \frac{V_{out}(j\omega)}{V_{in}(j\omega)} \quad (2) \]

The method used to calculate \( V_{out} \) is the voltage divider rule. The only difference is that resistances are replaced by reactances which are complex vectors. Complex impedance is shown in equation (3).

\[ Z = \sqrt{R^2 + (X_L - X_C)^2} \arctan \left( \frac{X_L - X_C}{R} \right) \quad (3) \]
The transfer function will have to be plotted on semi log paper with the vertical axis in dB and the horizontal axis in a logarithmic scale. The definition of dB is shown in eq. (4).

$$\text{dB} = 20 \log \frac{V_{\text{out}}}{V_{\text{in}}}$$  \hspace{1cm} (4)

The corner frequency of the filters occurs when $R=X_L$ or $X_C$. This is also called the -3dB corner frequency, or ½ power frequency, eq. (5).

$$f_{\text{frequency\_corner}} = \frac{1}{2\pi RC} = \frac{R}{2\pi L}$$  \hspace{1cm} (5)

A negative slope on a Bode plot also functions as an integrator and a positive slope also functions as a differentiator. This makes these circuits useful in signal conditioning as well as filtering.

**PROCEDURE**

1. Construct the four circuits shown in Figure 1. Select components for a corner frequency between 1 KHz and 5 KHz. Show all of your calculations. That is, design four circuits that operate within the capabilities of the equipment in the laboratory.

![Figure 1. Low Pass and Hi Pass filter schematics. These same circuits can function as integrators or differentiators.](image)

The circuit simulations for low-pass and hi-pass circuits are shown in Figures 2 and 4. Notice that the corner frequencies are approximately 1591 Hz.

Note
You cannot view the waveforms shown in Figures 2 and 4. You have to plot these by hand or with the assistance of Excel. You can see the waveform shown in Figures 3 and 5 when the same circuits are functioning as integrators and differentiators.
Figure 2. Low Pass circuit simulation using National Instruments Multisim Software. At frequencies above the corner frequency the circuit behaves as an integrator. Input a high frequency square wave and you should see a triangular wave on the oscilloscope.

Figure 3 is a plot of an integrator where the input square wave frequency is about 10 times the corner frequency.

![Oscilloscope-XSC1](image)

Figure 3. Low-Pass circuit functioning as an integrator when the input frequency is above the corner frequency. Input is 10 KHz square wave and output is a triangular wave.

2. Connect your signal generator to the input and channel 1 of the oscilloscope. Select a reasonable input such as 5 volts peak. Sweep the frequency from about two decades below the corner frequency to two decades above the corner frequency. You will know you are at the corner frequency when the voltage output is 0.707 (-3 dB) lower than the input voltage. Observe the output on channel 2 of the oscilloscope. Plot the output seen on channel 2 as the input frequency is varied. We do not have Bode plotters as shown in Figure 2 in the lab so the plots must be performed by hand. Record and tabulate all of your settings and readings. The low-pass and hi-pass curves
cannot be observed on the oscilloscope as shown in Figures 2 and 4. The phase shift between the input and output can be read on the oscilloscope using the soft keys.

3. Make plots of each low-pass filter shown in Figure 1. One plot with a capacitor/resistor and one with an inductor/resistor. You can plot the phase shift on the same Bode plot by adding a separate vertical scale for the phase.

4. While one of the low-pass filters (you choose) is still connected change the input (channel 1) to a high frequency square wave and observe that the output (channel 2) is a triangular wave. The circuit is now functioning as an integrator. See Figure 3.

5. Make plots of each hi-pass filter shown in Figure 4.

6. While one of the hi-pass filters is still connected change the input (channel 1) to a low frequency triangular wave and observe the output (channel 2) is a square wave. The circuit is now functioning as a differentiator. The slope of the triangular wave is proportional to the height of the square wave. See Figure 5. You can copy your oscilloscope trace and paste it in your report.

Draw the schematic of the circuit used for your curves. Make sure the reader can tell which schematic goes with which curve.

The Bode Plots of your data for the low-pass and hi-pass filters must be plotted on semi-log graph paper. The vertical axis shall be in dBs and the horizontal axis shall be log frequency. You can download semi log graph paper off the internet or buy it at the bookstore. Use two vertical scales. One for dBs and one for phase.
Figure 4. Hi Pass circuit simulation using National Instruments Multisim Software. At frequencies below the corner frequency the circuit behaves as a differentiator. Input a low frequency triangular wave and you should see a square wave on the oscilloscope.
Figure 5. Hi-pass filter acting as an integrator. The input is a low frequency (100 Hz) triangular wave and the output is a square wave.

7. Write a professional comprehensive lab report using a word processor. Show your results and include a comprehensive conclusion. There are lots of sample lab reports on the internet.

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