**Experiment #4: Filters**

## 4.1 Introduction:

Filters are frequency-selective networks that permit signals whose frequencies fall within a certain range (called the *passband*) to pass from the input to the output relatively unchanged, while impede the passage of signals whose frequencies are within other ranges (called the *stopbands*). Filters are used in a wide range of electrical systems such as radio, telephone, television, power supplies, computer circuits, industrial machinery – just to name but a few.

Filters are classified by the location of their passband: A lowpass filter passes signals whose frequencies are below a certain “cutoff” frequency, while a high-pass filter passes signals whose frequencies are above a desired cutoff frequency. On the other hand, a band-pass filter has a passband within a given range: $\omega_L < \omega < \omega_H$, where $\omega_L$ and $\omega_H$ are the lower and higher cutoff frequencies. Finally, a notch (bandstop) filter impedes any unwanted signal frequencies (or bands) from passing from the input to the output.

Filter realizations that consist of only passive elements (R, L, and C) are called the passive filters. Such filters work well at high-frequency applications (above 100kHz). For low-frequency applications, such as the audio range, it is desirable to avoid the use of inductors, as the required inductors are usually large, physically bulky, and their characteristics are quite non-ideal. Filter realizations that avoid the use of inductors, and utilize Op-Amps instead, are called active filters.

This experiment examines the frequency-selective characteristics of a second-order low-pass passive filter and a second-order band-pass active filter. In addition, it investigates the effects of the quality factor (Q) variations on their frequency response.

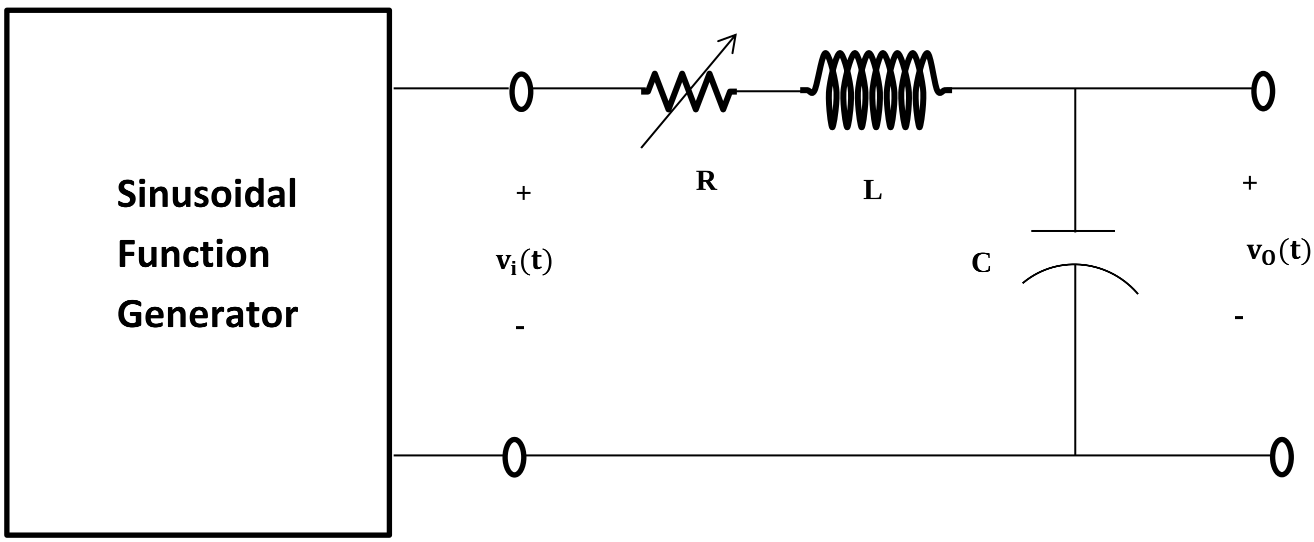
## 4.2 Objectives:

- To measure the magnitude- and phase-frequency responses of a second-order lowpass passive filter.
- To measure the magnitude- and phase-frequency responses of a second-order bandpass active filter.
- To investigate the effects of Q variations on the frequency responses of the lowpass and band pass filters.

## 4.3 Prelab Assignment (3 marks in total, 1.5 marks for each step):

**Step 1:** The circuit shown in Fig (4.1) is a second-order lowpass passive filter.

**Fig (4.1)**




a) Show that the voltage-transfer function of the filter circuit has the form:

$$H(S) = {}^{V_o}/_{V_i} = \frac{\omega_0^2}{[S^2 + \frac{\omega_0}{Q} S + \omega_0^2]}$$

Find the expressions for $\omega_0$ and Q in terms of R, L, and C.

b) Let L = 0.1H and C = 0.01μF. Select the value of R that will set Q at 0.707. Under this condition, the circuit is said to be a Butterworth (or maximally-flat) lowpass filter.

Determine the value of Q when the value of R is:

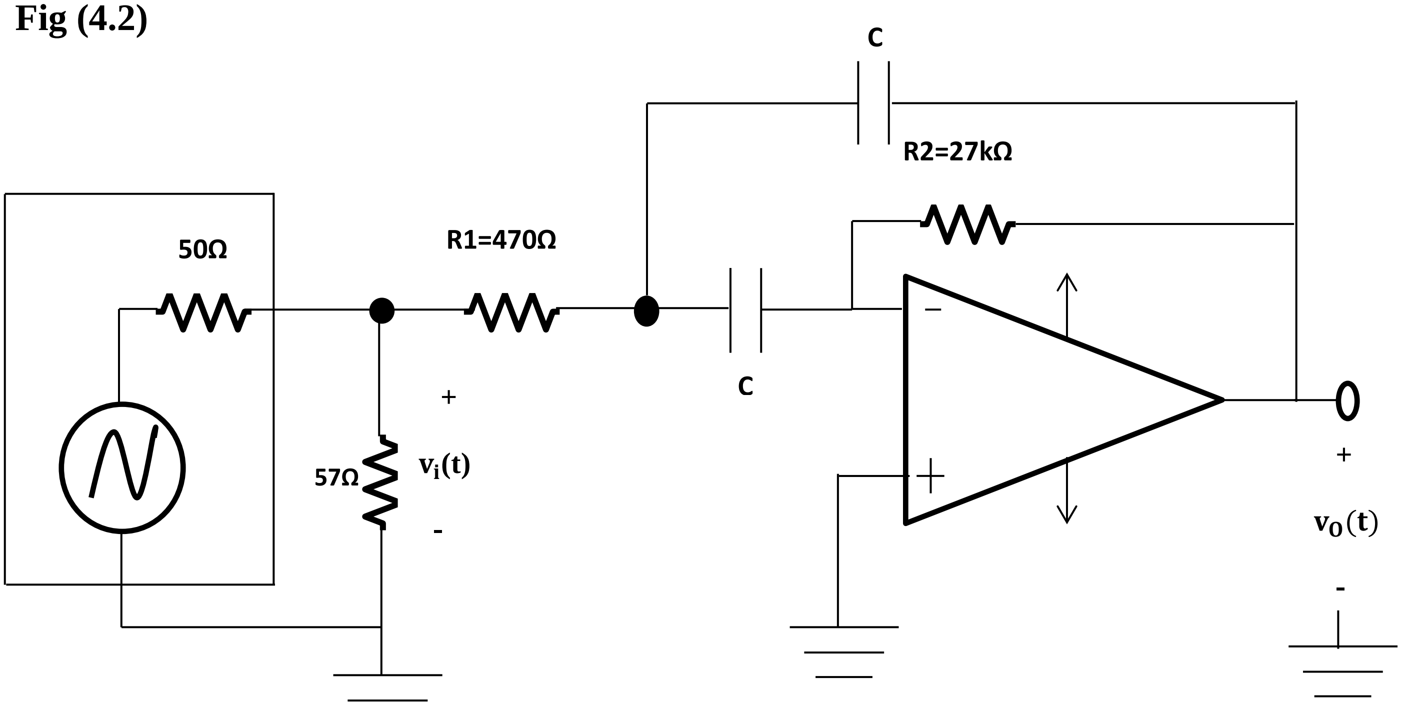
i) R = 1kΩ
ii) R = 10kΩ

c) Use Multisim to plot the magnitude (in dB) and phase (in degrees) of [ ${}^{V_o}/_{V_i}$ ] for the three Q-values of part b), over the frequency range 100Hz to 50kHz.
Use "AC Sweep" for "Analyses and Simulation" and set the "Start frequency (FSTART)" to 100Hz and "Stop frequency (FSTOP)" to 50kHz.

Under the Output tab of the AC Sweep setting, add label of $V_o$ to the "Selected variables for analysis" since $H(S) = {}^{V_o}/_{V_i} = V_o$.
Components for Fig (4.1) are: Function generator ($V_p$ = 1V) with GROUND as a reference to the COM port, RESISTOR_RATED, CAPACITOR_RATED, and INDUCTOR_RATED.

**Step 2:** The circuit shown in Fig (4.2) is a second-order bandpass active filter.

**Fig (4.2)**




a) Show that the voltage-transfer function of the filter circuit has the form:

$$H(S) = {}^{V_o}/_{V_i} = \frac{A \cdot S}{[S^2 + \frac{\omega_0}{Q} S + \omega_0^2]}$$

Find the expressions for A, $\omega_0$ and Q in terms of C, $R_1$, and $R_2$.

b) Let C = 0.01µF. Find the values of $|H(S{=}j\omega_0)|$ in dB, $\omega_0$, and Q when:

i) $R_1$ = 470Ω and $R_2$ = 27kΩ
ii) $R_1$ = 1kΩ and $R_2$ = 12kΩ

c) Use Multisim to plot the magnitude (in dB) and phase (in degrees) of [ $V_o/V_i$ ] for the two cases of part b), over the frequency range 500Hz to 50kHz.

Use “AC Sweep” for “Analyses and Simulation” and set the “Start frequency (FSTART)” to 500Hz and “Stop frequency (FSTOP)” to 50kHz.

Components for Fig (4.1) are: Function generator (set $V_p$ = 1V with “Offset”= 0 V so that the + port is providing $1\angle 0^o$V to the filter, use a GROUND as the reference for the COM port, UA741CD Op-Amp power with two 15V DC_POWER, RESISTOR_RATED, and CAPACITOR_RATED.

Add a voltage probe at $v_o(t)$ to measure magnitude and phase.

## 4.4 Procedure:

**Part I: The Frequency Responses of the Lowpass Passive Filters**

**Step 1:** Construct the circuit shown in Fig (4.1): Set L = 0.1H, C = 0.01μF, and R = 4.5kΩ [the value of R for a Butterworth (Q = 0.707) lowpass filter].

Connect Channels (A) and (B) of the oscilloscope to display the input voltage and output voltage respectively, with the trigger source at Channel (A) rising edge. Set both channels to AC coupling. Set the controls of the function generator to provide a **sinusoidal** input voltage of 6V (peak) at a frequency of 5kHz.

**Step 2:** Use "Interactive Simulation" to run your experiment. Use the oscilloscope displays to measure the phase angle $\angle H(\omega)^o$ in degrees, and use both DMMs to measure the dB-values of the input and output voltage, and evaluate the magnitude $|H(\omega)|$ in dB as:

$$|H(\omega)| \text{ (in dB)} = [V_o\text{(in dB)} - V_i\text{(in dB)}]$$

Record your results in Table (4.1).

**Step 3:** Repeat as in Step 2 for each frequency setting in Table (4.1). Use Graph (4.1) to plot the magnitude $|H(\omega)|$ in dB and phase $\angle H(\omega)^o$ in degrees versus frequency in Hz.

Note: Make sure you re-adjust the input voltage to 6V (peak) when you change the frequency.

Use your plots to find the location of the low-cutoff frequency $f_o$.

$f_o$ = ………………….

**Step 4:** Demonstrate the correct operation of your experiment setup to your TA via ZOOM.

**Part II: The Frequency Responses of the Bandpass Active Filters**

**Step 5:** Connect the circuit shown in Fig (4.2), with $R_1$ = 470Ω and $R_2$ = 27kΩ.

Connect Channels (A) and (B) of the oscilloscope to display the input and output voltage respectively, with the trigger source at Channel (A) rising edge. Set both channels to AC coupling. Set Channel (B) on *inverting* by pressing the '-' button, as the polarity of the output voltage [in Fig (4.2)] is inverted w.r.t. that of the input voltage. Set the controls of the function generator to provide a sinusoidal input voltage of 0.5V (peak-to-peak) at a frequency of 5kHz.

**Step 6:** Use "Interactive Simulation" to run your experiment. Use the oscilloscope displays to measure the phase angle $\angle H(\omega)^o$ in degrees, and use both DMMs to measure the dB-values of the input and output voltages, and evaluate the magnitude $|H(\omega)|$ in dB. Record your results in Table (4.2).

**Step 7:** Scan the frequency spectrum to locate the central frequency $f_o$, the low-cutoff frequency $f_L$, and the high-cutoff frequency $f_H$, **as defined by their phase values in Table (4.2).** Record the corresponding voltage and $|H(\omega)|$.

**Step 8:** Repeat Step 6 for each frequency setting in Table (4.2). Use Graph (4.2) to plot the magnitude $|H(\omega)|$ in dB and phase $\angle H(\omega)^o$ in degrees versus frequency in Hz. Double check your input voltage when you change the frequency.

**Step 9:** Demonstrate the correct operation of your experimental setup to your TA via ZOOM.