Ryerson University

Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

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Course Number:	ELE302
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Instructor:	S. Jassar

Assignment/Lab Number:	4
Assignment/Lab Title:	Filters

Submission Date:	Tues Nov 15, 2024
Due Date:	

Student LAST Name	Student FIRST Name	Student Number	Section	Signature*
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Toronto Metropolitan University
Department of Electrical, Computer, & Biomedical Engineering
Faculty of Engineering & Architectural Science

ELE 302
Laboratory #4

Filters

1.0 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 ω_L and ω_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.

2.0 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.

3.0 REQUIRED LAB EQUIPMENT & PARTS:

- DC Power Supply (PS), Function Generator (FG) and Oscilloscope.
- ELE202 Lab Kit and ELE302 Lab Kit: various components, breadboard, wires and jumpers.
- Digital Multimeter (DMM).

4.0 PRE-LAB ASSIGNMENT (3 marks with 1.5 marks for each step):

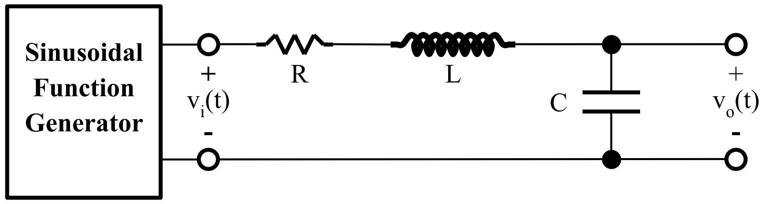


Figure 1.0: Second-Order Lowpass Passive Filter

(a) Step 1: The circuit shown in **Figure 1.0** is a second-order lowpass passive filter.

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

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

Find the expressions for ω_o and Q in terms of R, L, and C.

Pre-Lab workspace (show your analysis here)

$$H(S) = \frac{V_o}{V_i} = \frac{\omega_o^2}{\left[S^2 + \frac{\omega_o}{Q}S + \omega_o^2\right]}$$

$\omega_o = ?$

$Q = ?$

$\therefore$ the

$\omega_o \longrightarrow \omega_o = \frac{1}{\sqrt{LC}}$

$Q = \frac{\omega_o}{B}$

$B = \frac{R}{L}$

$= \frac{1/\sqrt{LC}}{\frac{R}{L}}$

$= \left(\frac{1}{\sqrt{LC}}\right)\left(\frac{L}{R}\right)$

$\therefore$ Q is

$\hookrightarrow Q = \left(\frac{1}{R}\right)\left(\sqrt{\frac{L}{C}}\right)$

ii) 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:

* R = 1kΩ
* R = 10kΩ

Pre-Lab workspace (show your analysis here)

$Q = 0.707 \quad R = ?$

$L = 0.1H$

$C = 0.01\mu F$

$$Q = \left(\frac{1}{R}\right)\left(\sqrt{\frac{L}{C}}\right)$$

$$0.707 = \frac{1}{R}\left(\sqrt{\frac{0.1}{0.01 \times 10^{-6}}}\right)$$

$$0.707 = \frac{1}{R}(3162.3)$$

$$0.707R = 3162.3$$

$$R = 4472.84$$

$$\boxed{R = 4.473k\Omega}$$

Part i) $R = 1k\Omega$

$$Q = \frac{1}{R}\left(\sqrt{\frac{L}{C}}\right)$$

$$= \frac{1}{1000}\left(\sqrt{\frac{0.1}{1 \times 10^{-8}}}\right)$$

$$\boxed{Q = 3.162}$$

Part ii) $R = 10k\Omega$

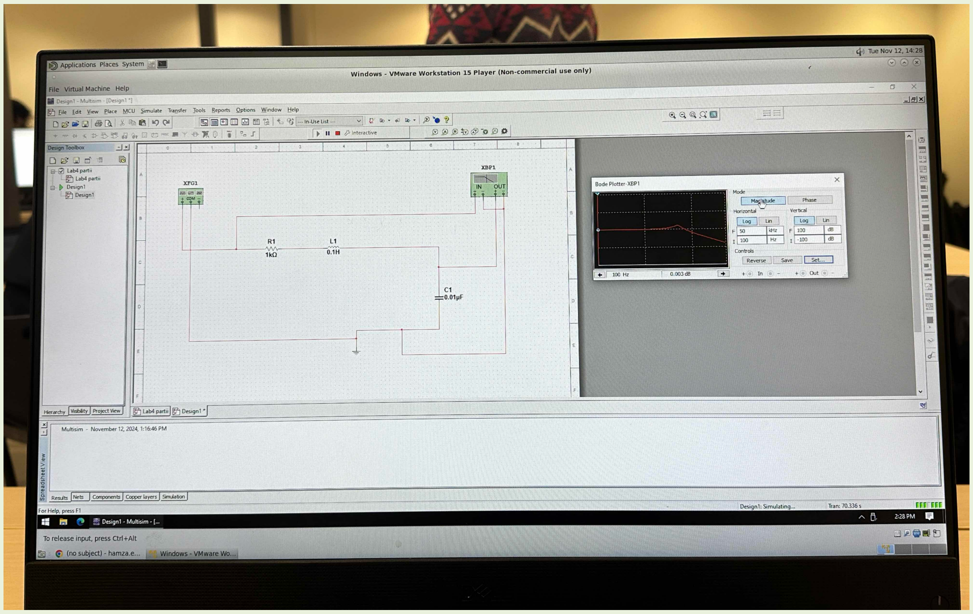
$$Q = \frac{1}{R}\left(\sqrt{\frac{L}{C}}\right)$$

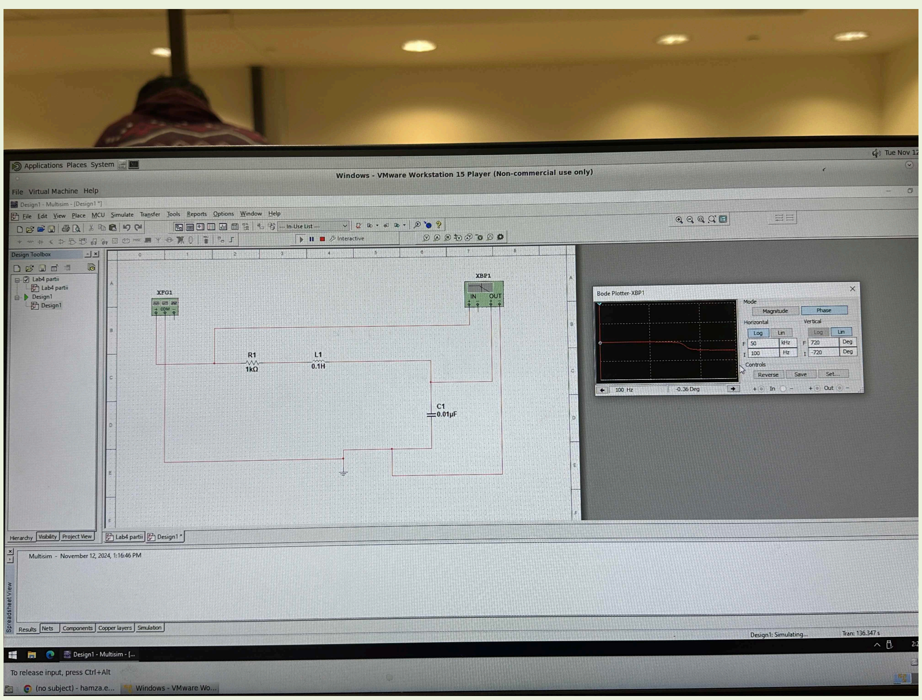
$$= \frac{1}{10000}\left(\sqrt{\frac{0.1}{1 \times 10^{-8}}}\right)$$

$$\boxed{Q = 0.3162}$$

iii) Use Multisim to plot the magnitude (in dB) and phase (in degrees) of $[V_o/V_i]$ for the three Q-values of part ii), over the frequency range 100Hz to 50kHz.

Pre-Lab workspace (show your analysis here)





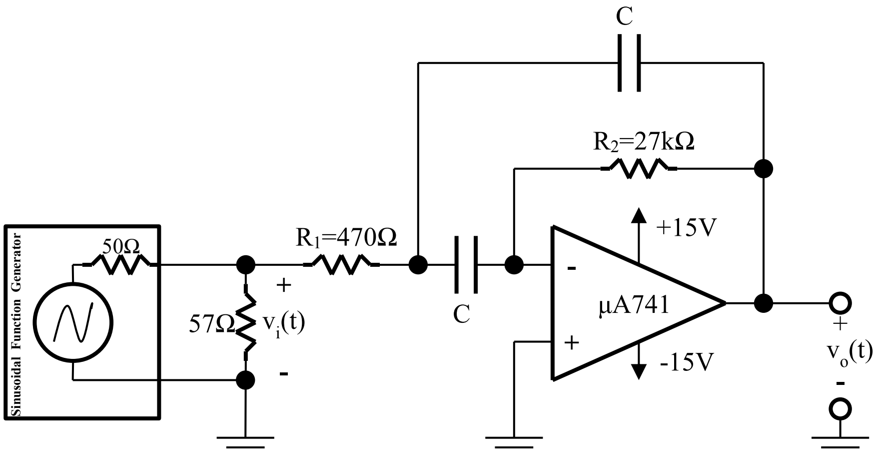


Figure 2.0: Second-Order Bandpass Active Filter

(b) Step 2: The circuit shown in **Figure 2.0** is a second-order bandpass active filter.

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

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

Find the expressions for A, ω_o and Q in terms of C, R_1, and R_2.

Pre-Lab workspace (show your analysis here)

$$H(S) = \frac{V_o}{V_i} = \frac{AS}{[S^2 + \frac{\omega_o}{Q}S + \omega_o^2]}$$

$$\omega_o^2 = \frac{1}{R_1 R_2 C^2}$$

$$\frac{\omega_o}{Q} = \frac{2}{R_2 C}$$

$$\omega_o = \left(\frac{1}{C}\right)\left(\frac{1}{\sqrt{R_1 R_2}}\right)$$

$$\frac{1}{Q}\left(\frac{1}{C\sqrt{R_1 R_2}}\right) = \frac{2}{R_2 C}$$

$\therefore$ ω_o is

$\hookrightarrow$ $\omega_o = \left(\frac{1}{C}\right)\left(\frac{1}{\sqrt{R_1 R_2}}\right)$

$$Q = \left(\frac{1}{2}\right)\left(\sqrt{\frac{R_2}{R_1}}\right)$$

$$A = \frac{-1}{RC}$$

$\therefore$ Q is known as

$\hookrightarrow$ $Q = \left(\frac{1}{2}\right)\left(\sqrt{\frac{R_2}{R_1}}\right)$

ii) Let C = 0.01μF. Find the values of $|H(S=j\omega_o)|$ in dB, ω_o, and Q when:

* $R_1 = 470\Omega$ and $R_2 = 27k\Omega$
* $R_1 = 1k\Omega$ and $R_2 = 12k\Omega$

Pre-Lab workspace (show your analysis here)

Part i) $R_1 = 470k\Omega$ & $R_2 = 27k\Omega$

$$Q = \left(\frac{1}{2}\right)\left(\sqrt{\frac{R_2}{R_1}}\right)$$

$$= \left(\frac{1}{2}\right)\left(\sqrt{\frac{27000}{470000}}\right)$$

$$= 3.7897$$

$$\omega_o = \frac{1}{C}\left(\frac{1}{\sqrt{R_1R_2}}\right)$$

$$= \frac{1}{1\times10^{-8}}\left(\frac{1}{\sqrt{(470)(27000)}}\right)$$

$$= 28071.7$$

$$= 28.1 \text{ rad/sec}$$

$$A = \frac{1}{R_1C} = \frac{-1}{(470)(1\times10^{-8})}$$

$$= 212765.96$$

$$= -2.12\times10^5$$

$$\frac{2}{R_2C} = \frac{2}{(27000)(1\times10^{-8})} = 7407.41$$

$$= 7.4\times10^3$$

$$\frac{1}{R_1R_2C^2} = \frac{1}{(470)(27000)(1\times10^{-8})}$$

$$= 788022064.6$$

$$= 7.88\times10^8$$

$$H(S) = \frac{AS}{\left[S^2 + \frac{\omega_o}{Q}S + \omega_o^2\right]}$$

$S = j\omega_o$

$$= \frac{-2.12S}{S^2 + 7.4\times10^3S + 7.88\times10^8}$$

$$= \frac{-2.12(j\omega_o)}{(j\omega_o)^2 - 7.4\times10^3(j\omega_o) + (7.88\times10^8)^2}$$

$$H(\omega_o) = \frac{2.12\times10^5\omega_o}{\sqrt{(7.88\times10^8 - \omega_o^2)^2 + (7.4\times10^3\omega_o)^2}}$$

$$H(\omega_o) = 28.391$$

$$\therefore |H(\omega_o)| = 20\log_{10}(28.391)$$

$$= 29.06$$

Part ii) $$Q = \frac{1}{2}\sqrt{\frac{R_2}{R_1}}$$

$$= \frac{1}{2}\sqrt{\frac{12000}{1000}}$$

$$= 1.7321$$

$$\omega_o = \frac{1}{C}\left(\frac{1}{\sqrt{R_1R_2}}\right)$$

$$= \frac{1}{1\times10^{-8}}\left(\frac{1}{\sqrt{(1000)(12000)}}\right)$$

$$\omega_o = 28867.51$$

$$\omega_o = 28.9k \text{ rad/sec}$$

$$\frac{1}{R_1C} = \frac{1}{(1000)(1\times10^{-8})}$$

$$= 100000$$

$$\frac{2}{R_2C} = 16666.7$$

$$\frac{1}{R_1R_2C} = 8.3\times10^8$$

$$H = \frac{AS}{S^2 + \frac{\omega_o}{Q}S + \omega_o^2}$$

$S = j\omega_o$

$$H = \frac{100000S}{S^2 + 16666.7S + 8.3\times10^8}$$

$$= \frac{100000(28867.5)}{\sqrt{[8.3\times10^8 - (28867.5)^2]^2 + [(16666.7)(28867.5)]^2}}$$

$$|H(\omega_o)| = 5.99998$$

$$|H(\omega_o)| = 6$$

$$|H(\omega_o)| = 20\log_{10}(6)$$

$$|H(\omega_o)| = 15.56$$

$$\therefore |H(\omega_o)| \text{ is } 15.56$$

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

Pre-Lab workspace (show your analysis here)