VE215 Fall 2017

Lab 5: Filter Lab

I. Goals

Learn about four types of filters – Low-Pass, High-Pass, Band-Pass, and Band-reject.
Learn about transfer functions.
Predict the theoretical result and make comparison with lab data.

II. Introduction

Filter

Filters are everywhere in our lives. The circuits built to operate on signals usually apply filters. For example, telephone lines pass the sounds at frequencies between about 100Hz and 3kHz and practically blocks all other frequencies.

Transfer function

Mathematically, the transfer function is used to analyze what the circuit did to the signal:

$$\text{Transfer function } = \frac{Output\ signal}{Input\ signal}$$

This function can also be expressed as

$$H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)}$$

The magnitude of the transfer function is called “voltage gain”, often measured as the ratio of the peak-to-peak (ppk) voltages:

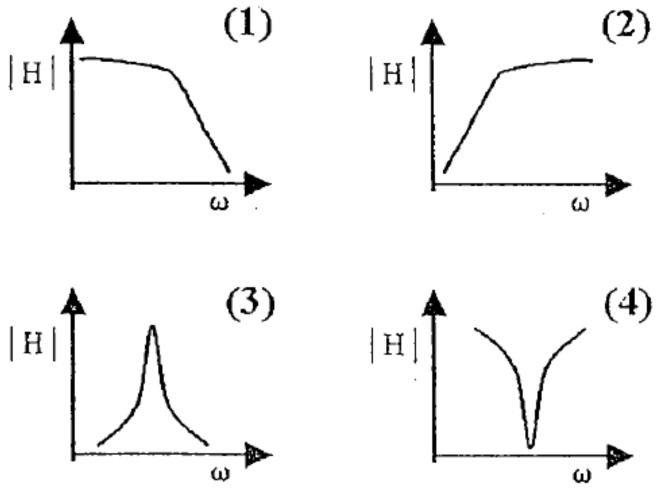
$$|H(\omega)| = \left|\frac{V_{out}(\omega)}{V_{in}(\omega)}\right| = \frac{V_{out,\ ppk}(\omega)}{V_{in,\ ppk}(\omega)}$$

It is convenient to express and plot the magnitude of the transfer function on the logarithmic scale using decibels:

$$|H(\omega)|_{dB} = 20 \cdot \log_{10}\left(\frac{V_{out,\ ppk}(\omega)}{V_{in,\ ppk}(\omega)}\right)$$

Since both ppk voltages are always positive, the transfer function magnitude is positive and thus can always be converted to decibels. The use of decibels allows us to review data over a broad range.

Types of filters



In the figure above are the four main families of filters:

(1): Low-Pass; (2): High-Pass; (3): Band-Pass; (4): Band-reject (also called band-stop or notch)

Summary of the characteristics of ideal filters.

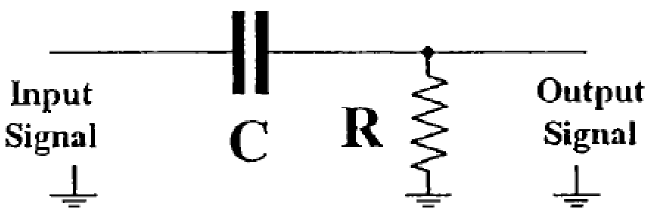
Type of Filter	$H(0)$	$H(\infty)$	$H(\omega_c)$ or $H(\omega_0)$
Lowpass	1	0	$1/\sqrt{2}$
Highpass	0	1	$1/\sqrt{2}$
Bandpass	0	0	1
Bandstop	1	1	0

ω_c is the cutoff frequency for lowpass and highpass filters; ω_0 is the center frequency for bandpass and bandstop filters.

Filter circuits, which you are going to build in this lab, contain resistors, capacitors, and inductors. They are all passive filters.

High-Pass filter

The high-pass filter we are going to build uses a capacitor and a resistor.

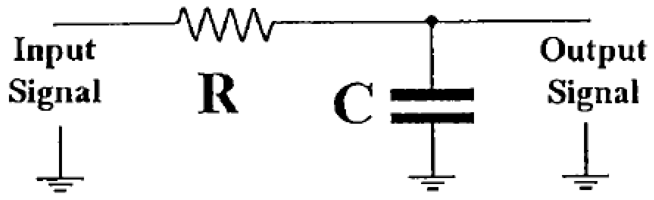


For the high-pass filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{R}{R+\frac{1}{j\omega C}} = \frac{j\omega RC}{1+j\omega RC}$.

Note that H(0) = 0, H(∞) = 1. Hence, it would only let high frequency pass.

Low-Pass filter

The low-pass filter we are going to build uses a capacitor and a resistor.

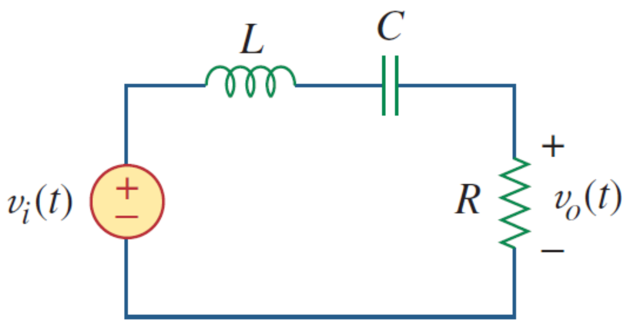


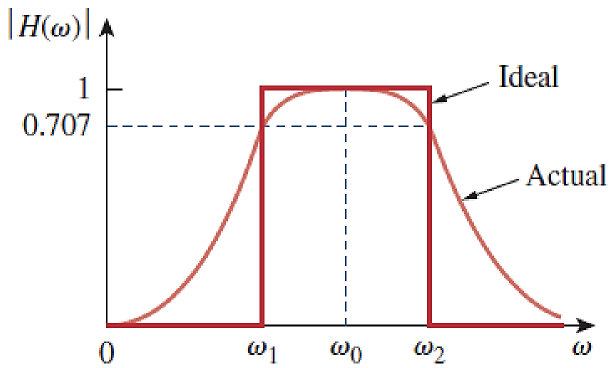
For the low-pass filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}} = \frac{1}{1+j\omega RC}$.

Note that H(0) = 1, H(∞) = 0. It would only let low frequency pass.

Band-Pass filter

The band-pass filter we are going to build uses a capacitor, an inductor and a resistor.



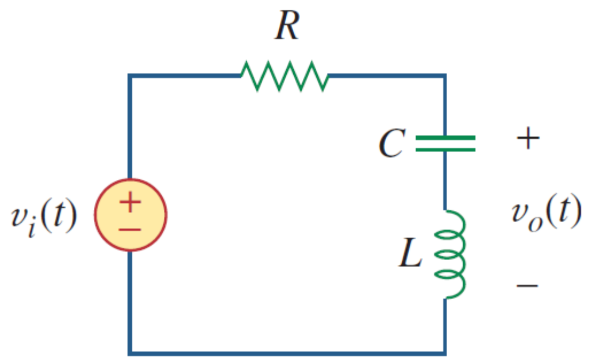


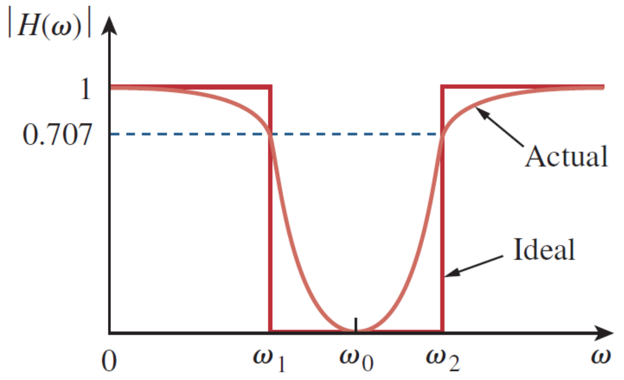
For the band-pass filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{R}{R+j(\omega L-\frac{1}{\omega C})}$.

Note that H(0) = 0, H(∞) = 0. The band-pass filter passes a band of frequencies centered on the center frequency ω_0, which is given by $\omega_0 = 1/\sqrt{LC}$.

Band-Stop filter

The band-stop filter we are going to build uses a capacitor, an inductor and a resistor.





For the band-stop filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{j(\omega L - \frac{1}{\omega C})}{R + j(\omega L - \frac{1}{\omega C})}$.

Note that H(0) = 0, H(∞) = 0. The band-stop filter rejects a band of frequencies centered on the center frequency ω_0, which is given by $\omega_0 = 1/\sqrt{LC}$.

III. Pre-lab assignment

1. What is decibel value? (You may give a typical example to help your explanation.) What is the advantage of dB scale?

2. How to calculate the band width of rejection of a band-reject filter? (You may refer to Chapter 14.7 of the textbook.)

3. Predict the theoretical result of this lab. You need to estimate the *Expected transfer function magnitude* $|H(\omega)|$ and *Expected transfer function magnitude in dB* $|H(\omega)|_{dB}$ of **all of the four types** of filter. Fill in the tables in the Data Sheet to show the **expected** results (which will not be collected during the lab). **Also,** make a table for each type of filter to show the respected results (which will not

collected during the lab as pre-lab assignment). We are using Resister of **R = 982Ω**; Capacitor of **C = 0.1μF**; Inductor of **L = 1mH**.

e.g. For high-pass filter

Frequency	1MHz	100kHz	50kHz	10kHz	5kHz	1kHz
$\lvert H(\omega)\rvert$						
$\lvert H(\omega)\rvert_{dB}$						

Tip: *You may use MATLAB or Mathematica program to help you calculate this result.*

References:

[1]. *Circuits Make Sense,* Alexander Ganago, Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor.
[2]. Clarles K. Alexander, Matthew N.O. Sadiku. *Fundamentals of Electirc Circuits.* New York: McGraw-Hill, 2013. Print.