UM–SJTU Joint Institute

Physics Laboratory
(VE215)

Laboratory Report

Exercise 5
Filter Lab

Name: Yihao Liu ID: 515370910207

Date: 17 Nov 2016

[rev. 1.0]

1 Goal

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

2 Introduction

2.1 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.

2.2 Transfer function

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

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

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:

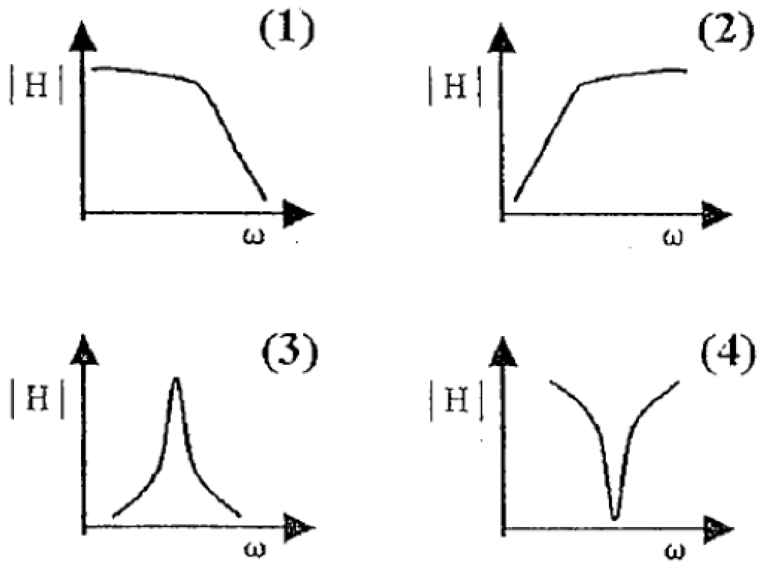
$$|H(\omega)| = \left|\frac{V_{out}(\omega)}{V_{in}(\omega)}\right| = \frac{V_{out,ppk}(\omega)}{V_{in,ppk}(\omega)}$$

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

$$|H(\omega)|_{db} = 20 \cdot \log_1 0 \left(\frac{V_{out,ppk}(\omega)}{V_{in,ppk}(\omega)}\right)$$

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.

2.3 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.

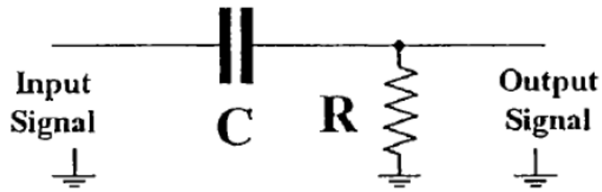
Type of Filter	$H(0)$	$H(\infty)$	$H(\omega_c)$ or $H(\omega_0)$
Lowpass	1	0	$1/\sqrt{2}$
Highpass	0	1	$1/\sqrt{2}$
Bandpass	0	0	1
Bandstop	1	1	0

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.

2.4 High-Pass filter

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

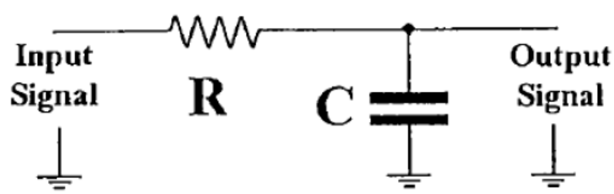


For the high-pass filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{R}{R+\frac{1}{j\omega C}} = \frac{j\omega RC}{1+j\omega RC}$.

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

2.5 Low-Pass filter

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

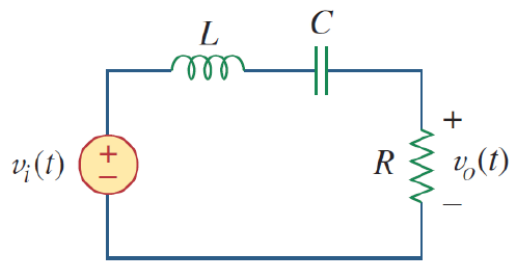


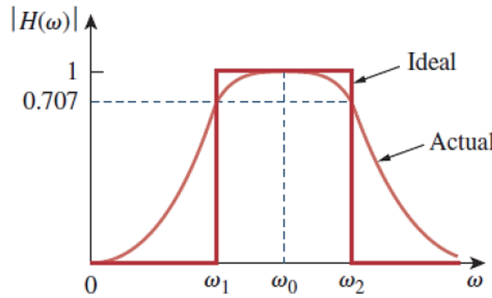
For the low-pass filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}} = \frac{1}{1+j\omega RC}$.

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

2.6 Band-Pass filter

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



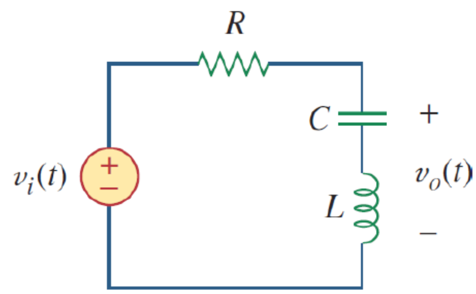


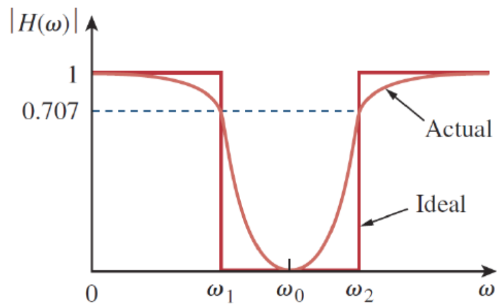
For the band-pass filter, $H(\omega) = \dfrac{V_{out}(\omega)}{V_{in}(\omega)} = \dfrac{R}{R + j(\omega L - \frac{1}{\omega C})}$.

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 $\omega_0 = 1/\sqrt{LC}$.

2.7 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 $\omega_0 = 1/\sqrt{LC}$.

3 Results and Discussion

3.1 Low-pass Filter

Frequency	Input signal amplitude, Vppk	Output signal amplitude, Vppk	Transfer function magnitude	Expected transfer function magnitude	Transfer function magnitude, in dB	Expected transfer function magnitude, in dB
1000000Hz	4.80	0.024	0.005	0.002	-46.167	-55.806
100000Hz	4.72	0.109	0.023	0.016	-32.730	-35.807
50000Hz	4.68	0.208	0.044	0.032	-27.044	-29.790
10000Hz	4.72	0.904	0.192	0.160	-14.355	-15.918
5000Hz	4.72	1.680	0.356	0.308	-8.973	-10.219
1000Hz	4.88	4.160	0.852	0.851	-1.387	-1.401
500Hz	4.92	4.600	0.935	0.956	-0.584	-0.395

3.2 High-pass Filter

Frequency	Input signal amplitude, Vppk	Output signal amplitude, Vppk	Transfer function magnitude	Expected transfer function magnitude	Transfer function magnitude, in dB	Expected transfer function magnitude, in dB
1000000Hz	4.76	4.720	0.992	1.000	-0.073	-0.000
100000Hz	4.72	4.680	0.992	1.000	-0.074	-0.001
50000Hz	4.68	4.600	0.983	0.999	-0.150	-0.005
10000Hz	4.72	4.480	0.949	0.987	-0.453	-0.113
5000Hz	4.72	4.240	0.898	0.951	-0.932	-0.434
1000Hz	4.84	2.260	0.467	0.525	-6.615	-5.595
500Hz	4.88	1.300	0.266	0.295	-11.490	-10.610
100Hz	4.96	0.286	0.058	0.062	-24.782	-24.211

3.3 Band-pass Filter

Frequency	Input signal amplitude, Vppk	Output signal amplitude, Vppk	Transfer function magnitude	Expected transfer function magnitude	Transfer function magnitude, in dB	Expected transfer function magnitude, in dB
1000000Hz	5.04	0.296	0.059	0.154	-24.623	-16.224
500000Hz	5.00	1.290	0.258	0.299	-11.768	-10.498
100000Hz	4.80	4.080	0.850	0.849	-1.412	-1.427
50000Hz	4.72	4.440	0.941	0.961	-0.531	-0.345
10000Hz	4.72	4.480	0.949	0.995	-0.453	-0.042
1000Hz	4.84	2.280	0.471	0.527	-6.538	-5.570
500Hz	4.88	1.320	0.270	0.295	-11.357	-10.602

3.4 Band-reject Filter

Frequency	Input signal amplitude, Vppk	Output signal amplitude, Vppk	Transfer function magnitude	Expected transfer function magnitude	Transfer function magnitude, in dB	Expected transfer function magnitude, in dB
1000000Hz	4.88	3.760	0.770	0.988	-2.265	-0.105
500000Hz	4.96	4.840	0.976	0.954	-0.213	-0.406
300000Hz	4.92	4.720	0.959	0.886	-0.360	-1.048
200000Hz	4.84	4.120	0.851	0.786	-1.399	-2.091
100000Hz	4.72	2.260	0.479	0.529	-6.397	-5.528
50000Hz	4.68	1.320	0.282	0.276	-10.993	-11.172
10000Hz	4.65	0.584	0.126	0.098	-18.021	-20.209
5000Hz	4.68	1.480	0.316	0.280	-10.000	-11.044
1000Hz	4.76	4.160	0.874	0.850	-1.170	-1.410
500Hz	4.80	4.040	0.842	0.955	-1.497	-0.396

4 Conclusion

We learned about four types of filters Low-Pass, High-Pass, Band-Pass, and Band-reject.
We learn about transfer functions.
We predicted the theoretical result and make comparison with lab data.

5 Reference

Lab 5 Manual.

6 Pre-lab and Data sheet