UM–SJTU Joint Institute

Introduction to Circuits

(Ve215)

Laboratory Report

Lab 5

Filter Lab

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1 Goals

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 100 Hz and 3 kHz 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:

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

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 decibels:

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

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.

2.3 Types of filters

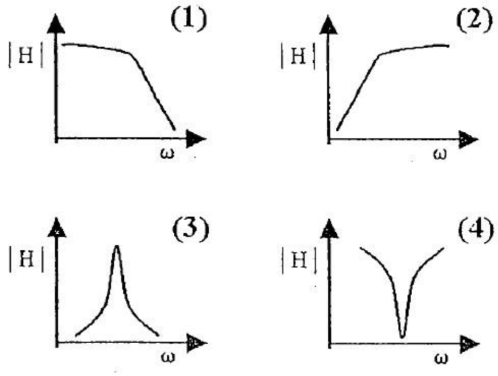

Figure 1: (1) Low-Pass; (2) High-Pass; (3) Band-Pass; (4) Band-reject (band-stop or north);

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.

Figure 2: Summary of the characteristics of ideal filters.

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

2.3.1 High-Pass filter

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

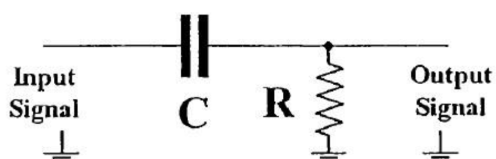

Figure 3: High-Pass filter.

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 $H(0) = 0, H(\infty) = 1$. Hence, it would only let high frequency pass.

2.3.2 Low-Pass filter

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

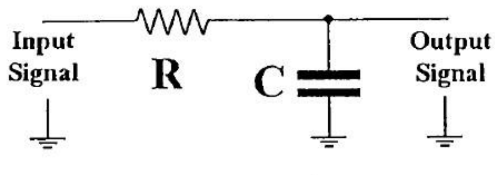

Figure 4: Low-Pass filter.

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 $H(0) = 1, H(\infty) = 0$. It would only let low frequency pass.

2.3.3 Band-Pass filter

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

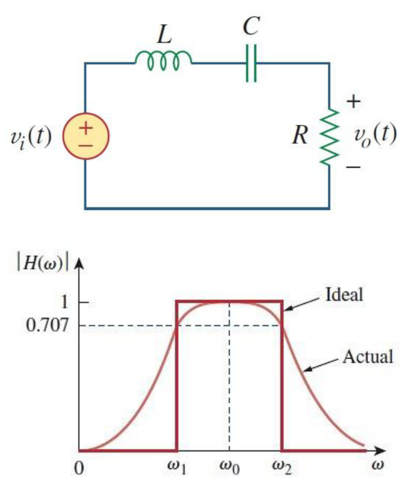

Figure 5: Band-Pass filter.

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

2.3.4 Band-Stop filter

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

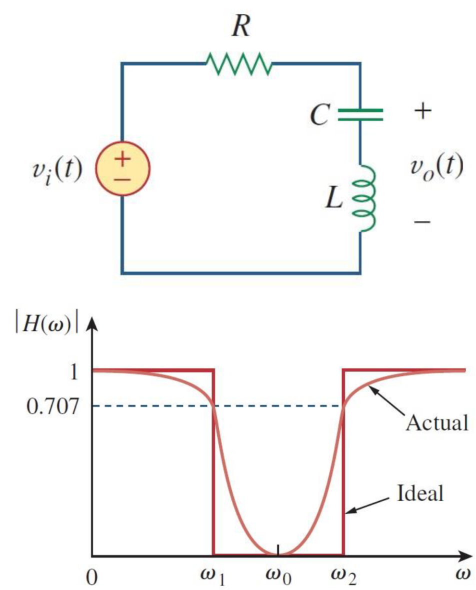

Figure 6: Band-Stop filter

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 $H(0) = 0, H(\infty) = 0$. 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 Procedures

1. Construct the circuit for each type of filter with resistor 1000 Ω, capacitor 0.1 μF, inductor 1 mH.

2. Set the input signal in the function generator to be sine wave with amplitude of 5 Vppk and change the frequency accordingly.
3. Use the oscilloscope to detect the amplitudes of the input and output signals. Records them respectively in the first two column in the tables.
4. Calcultate with the experimental data for the transfer function magnitude and transfer function magnitude in dB.

4 Results

In this section, for each type of filter, the value of transfer function magnitude and transfer function magnitude in dB are calculated from the corresponding experimental data using the definition formula of transfer function. All the results are presented below.

4.1 Low-pass Filter

The data for the low-pass filter are shown in Table 1.

Frequency	Input $[V_{ppk}]$	Output $[V_{ppk}]$	$\lvert H\rvert$	$\lvert H\rvert_{theory}$	ϵ_H	dB	dB_{theory}	ϵ_{dB}
1 MHz	5.16	0.0156	0.00302	0.0016	88.95%	-50.391	-55.8048	-9.88 %
100 kHz	5.12	0.110	0.021	0.0162	31.00%	-33.358	-35.8070	-6.57 %
50 kHz	5.08	0.232	0.0457	0.0324	39.24%	-26.808	-29.7898	-9.69 %
10 kHz	5.08	1.090	0.215	0.1600	32.53%	-13.369	-15.9184	-15.47%
5 kHz	5.08	1.820	0.358	0.3083	14.90%	-8.916	-10.2191	-11.92%
1 kHz	5.20	4.640	0.892	0.8510	4.50 %	-0.990	-1.4010	-27.86%
500 Hz	5.20	5.120	0.985	0.9556	2.93 %	-0.135	-0.3948	-65.06%

Table 1: Data for the low-pass filter.

4.2 High-pass Filter

The data for the high-pass filter are shown in Table 2.

Frequency	Input $[V_{ppk}]$	Output $[V_{ppk}]$	$\lvert H\rvert$	$\lvert H\rvert_{theory}$	ϵ_H	dB	dB_{theory}	ϵ_{dB}
1 MHz	5.16	4.64	0.899	1.0000	-10.08%	-0.923	0.000	/
100 kHz	5.12	4.60	0.898	0.9999	-10.15%	-0.930	-0.001	106993%
50 kHz	5.08	4.56	0.898	0.9995	-10.19%	-0.938	-0.004	21492%
10 kHz	5.08	4.40	0.866	0.9871	-12.23%	-1.248	-0.115	981.49%
5 kHz	5.12	4.16	0.813	0.9513	-14.48%	-1.804	-0.445	305.64%
1 kHz	5.24	1.98	0.378	0.5251	-27.39%	-8.453	-5.673	49.00%
500 Hz	5.28	1.19	0.225	0.2948	-22.68%	-12.942	-10.707	20.87%
100 Hz	5.28	0.258	0.049	0.0616	-19.63%	-26.220	-24.322	7.81%

Table 2: Data for the high-pass filter.

4.3 Band-pass Filter

The data for the band-pass filter are shown in Table 3.

Frequency	Input [V_{ppk}]	Output [V_{ppk}]	$\|H\|$	$\|H\|_{theory}$	ϵ_H	dB	dB_{theory}	ϵ_{dB}
1 MHz	5.40	0.400	0.074	0.1545	-51.46%	-22.607	-16.329	38.45%
500 kHz	5.40	1.48	0.274	0.2986	-7.19%	-11.243	-10.595	6.12%
100 kHz	5.16	4.08	0.791	0.8485	-6.49%	-2.040	-1.457	40.03%
50 kHz	5.08	4.40	0.866	0.9611	-9.80%	-1.248	-0.353	254%
10 kHz	5.08	4.44	0.874	0.9952	-12.17%	-1.170	-0.043	2641%
1 kHz	5.24	1.98	0.378	0.5266	-27.60%	-8.453	-5.648	49.66%
500 Hz	5.24	1.10	0.210	0.2951	-28.06%	-13.559	-10.698	26.74%

Table 3: Data for the band-pass filter.

4.4 Band-reject Filter

The data for the band-reject filter are shown in Table 4.

Frequency	Input [V_{ppk}]	Output [V_{ppk}]	$\|H\|$	$\|H\|_{theory}$	ϵ_H	dB	dB_{theory}	ϵ_{dB}
1 MHz	5.28	3.52	0.667	0.9880	-32.54%	-3.522	-0.1049	3345.20%
500 kHz	5.40	4.72	0.874	0.9544	-8.51 %	-1.169	-0.4056	194.99%
300 kHz	5.40	4.68	0.867	0.8863	-2.47 %	-1.243	-1.0481	21.16%
200 kHz	5.36	4.04	0.754	0.7860	-4.55 %	-2.456	-2.0911	19.74%
100 kHz	5.16	2.46	0.477	0.5292	-10.71%	-6.434	-5.5282	18.04%
50 kHz	5.08	1.20	0.236	0.2763	-15.48%	-12.534	-11.1721	13.20%
10 kHz	5.08	0.744	0.146	0.0976	48.24%	-16.686	-20.2092	-17.01%
5 kHz	5.08	1.68	0.331	0.2804	16.61%	-9.611	-10.38	-12.19%
1 kHz	5.24	4.20	0.802	0.8501	-6.03%	-1.922	-1.4105	39.15%
500 Hz	5.24	4.60	0.878	0.9555	-8.22%	-1.131	-0.3956	192.90%

Table 4: Data for the band-reject filter.

5 Conclusions and discussion

As can be seen from Table 1∼4, the experimental data basically conforms to the theoretical value. Therefore the trend of the change of value of transfer function with regard to frequency shown in Figure 1 for all the 4 types of filters is verified.

However, it should be noticed that some of our experimental data are not desirable. Some are of a relatively large error. This may because the measurement of the oscillator is not stable and the resolution and precision of it is not that sufficient. Also, since the measurement result displayed on the oscilloscope is not stable, all the readings are subjectively chosen by us. This may result in some uncertainty. Despite such discrepancy, our experimental results are acceptable in a certain range of uncertainty.

For improvement, apparatus with higher precision and resolution can be utilized.

To sum up, in this lab, we learn and construct four typical types of filters. Besides, the filtering property for each type is explored. Particularly, we examine the relationship between the transfer function and the frequency for each filter. The result of our experiment indicates conforms to the theoretical fact in an acceptable range.

6 References

[1] UM-SJTU Joint Institute VE215 "Filter Lab" lab manual.

7 Appendix

Please find the data sheet at the end of the report.

VE215 Lab 5

Filter Lab

Data Sheet

Name:	[illegible]	Student ID:	518021911220
Date:	NOV. 13. WED	TA's Signature:	

Note: You will get grade deductions if you violate the following rules:

1. **You are required to sign in the Logbook once you get your seat.**
2. **You are supposed to restore all the equipment and materials before you leave the lab.**
3. **You mustn't move any of the equipment and the material without TA's permission.**

Procedures:

1. According to the pre-lab assignments, you are supposed to fill in the **Expected Data columns** in the tables below before the lab.
2. During the lab:
   i) Construct the circuit for each type of filter. Resister: **R = 982Ω**; Capacitor: **C = 0.1μF**; Inductor: **L = 1mH**.
   ii) Set the Input Signal in the function generator to be **Sine Wave** with amplitude of **5** $\mathbf{V_{ppk}}$ and **change the frequency** accordingly.
   iii) Use the oscilloscope to detect the **amplitudes** of the **Input and Output** signals. Record them respectively in the first two column in the tables.
   iv) Additionally for the **Band-reject Filter**, when the frequency approach the critical frequency at which the **Transfer Function Magnitude** reaches its minimum, the **Output Signal Amplitude** changes rapidly. For a more accurate result, you can (but not strictly required to) add some more rows to record the data (**Table V**).
3. After the lab, you should calculate with the experimental data for the **"Transfer function magnitude"** and **"Transfer function magnitude, in dB"** columns.

Frequency	Input signal amplitude, Vppk	Output signal amplitude, (m)Vppk	Transfer function magnitude	**Expected** transfer function magnitude	Transfer function magnitude, in dB	**Expected** transfer function magnitude, in dB
1 MHz	5.16	15.6		0.0016		-55.8048
100 kHz	5.12	110		0.0162		-35.8070
50 kHz	5.08	232		0.0324		-29.7898
10 kHz	5.08	1090		~~0.1600~~ 0.1600		-15.9184
5 kHz	5.08	1820		0.3083		-10.2191
1 kHz	5.20	4640		0.8510		-1.4010
500 Hz	5.20	5120		0.9556		-0.3948

II) High-pass Filter

Frequency	Input signal amplitude, Vppk [V]	Output signal amplitude, Vppk [V]	Transfer function magnitude	**Expected** transfer function magnitude	Transfer function magnitude, in dB	**Expected** transfer function magnitude, in dB
1 MHz	5.16	4.64		1.0000		0
100 kHz	5.12	4.60		0.9999		~~-0.0053~~ -0.0011
50 kHz	5.08	4.56		0.9995		-0.0046
10 kHz	5.08	4.40		0.9871		-0.1126
5 kHz	5.12	4.16		0.9513		-0.4339
1 kHz	5.24	1.98		0.5251		-5.5952
500 Hz	5.28	1.19		0.2948		-10.6098
100 Hz	5.28	0.258		0.0616		-24.2107

III) Band-pass Filter

Frequency	Input signal amplitude, Vppk	Output signal amplitude, (m)Vppk	Transfer function magnitude	**Expected** transfer function magnitude	Transfer function magnitude, in dB	**Expected** transfer function magnitude, in dB
1 MHz	5.40	400		0.1545		-16.2240
500 kHz	5.40	1.48		0.2986		-10.4976
100 kHz	5.16	4.08		0.8485		-1.3100
50 kHz	5.08	4.40		0.9611		-0.3620
10 kHz	5.08	4.40		0.9752		-0.1791
1 kHz	5.24	1.98		0.5266		-5.5241
500 Hz	5.24	1.10		0.2951		-9.7111

IV) Band-reject Filter

Frequency	Input signal amplitude, Vppk	Output signal amplitude, (m)Vppk	Transfer function magnitude	**Expected** transfer function magnitude	Transfer function magnitude, in dB	**Expected** transfer function magnitude, in dB
1 MHz	5,28	3,52.		0,9880		-0,1049
500 kHz	5,40	4,72		0,9544		-0,4056
300 kHz	5,40	4,68		0,8863		-1,0481
200 kHz	5,36	4,04		0,7800		-2,0911
100 kHz	5,16	2,46		0,5292		-5,5282
50 kHz	5,08	1,20		0,2763		-11,1721
10 kHz	5,08	744 mV		0,0976		-20,2092
5 kHz	5.08	1,68 V		0,2804		-10,38
1 kHz	5,20	4,20V		0,8501		-1,4105
500 Hz	5,24	4,60V		0,9555		-0,3956

Theoretically find the corresponding frequency when the output signal amplitude reaches its minimal value and fill in the following table:

V) Band-reject Filter (Not Strictly Required)

Frequency	Input signal amplitude, Vppk	Output signal amplitude, (m)Vppk	Transfer function magnitude	**Expected** transfer function magnitude	Transfer function magnitude, in dB	**Expected** transfer function magnitude, in dB
Critical:						