UM-SJTU Joint Institute

Intro to circuits
(VE215)

Laboratory Report

Lab 4

AC Lab

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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:

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

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:

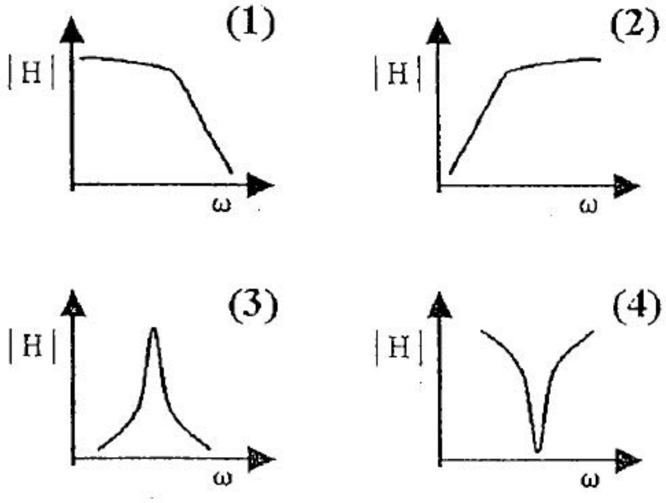
$$|H(\omega)| = \left|\frac{V_{out}(\omega)}{V_{in}(\omega)}\right| = \frac{V_{out,ppk}(\omega)}{V_{in,ppk}(\omega)}$$

It is convenient to express and plot the magnitude of the transfer function on the logarithmic scale 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.

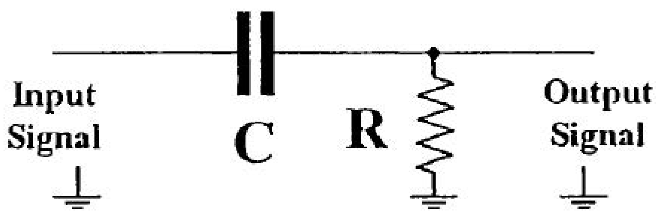
Type of Filter	$H(0)$	$H(\infty)$	$H(\omega_c)$ or $H(\omega_0)$
Lowpass	1	0	$1/\sqrt{2}$
Highpass	0	1	$1/\sqrt{2}$
Bandpass	0	0	1
Bandstop	1	1	0

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 we 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.

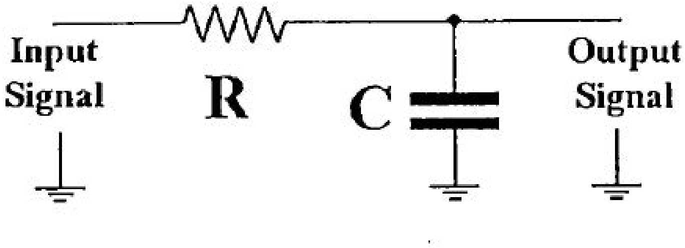


For the high-pass filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{R}{R+\frac{1}{j\omega C}} = \frac{j\omega RC}{1+j\omega RC}$.

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

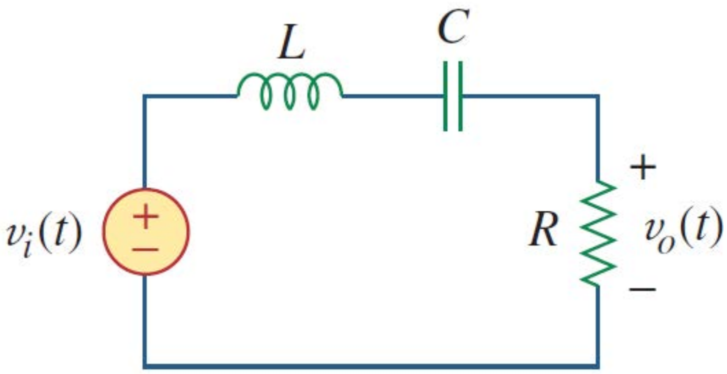
2.5 Low-Pass filter

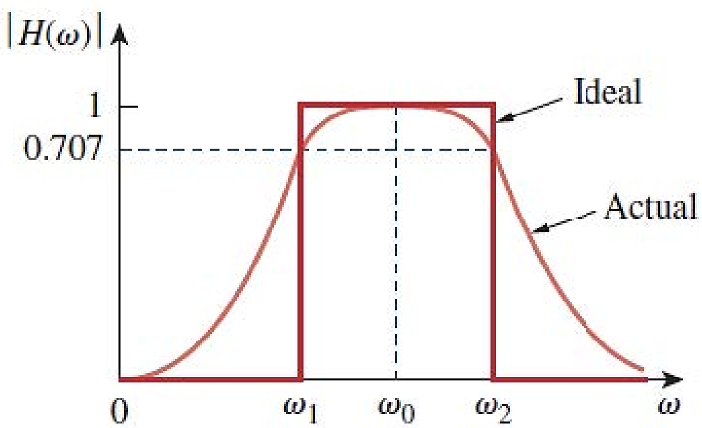
The low-pass filter we are going to build uses a capacitor and a resistor.



2.6 Band-Pass filter

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



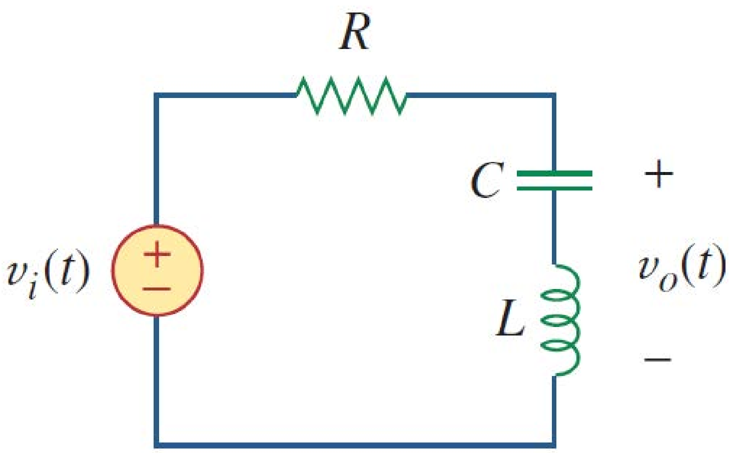


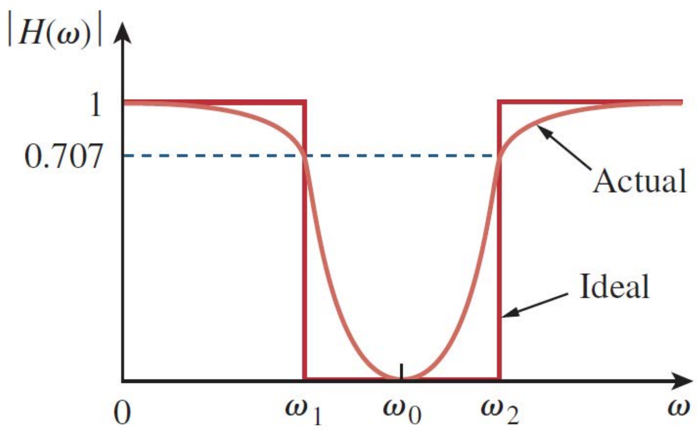
For the band-pass filter, $H(\omega) = \frac{V_{out}(\omega)}{V_{in}(\omega)} = \frac{R}{R+j(\omega L - \frac{1}{\omega C})}$.

Note that $H(0) = 0$, $H(\infty) = 0$. The band-pass filter passes a band of frequencies centered on the center frequency $\omega 0$, 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 $H(0) = 0$, $H(\infty) = 0$. 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 Measurement

1. According to the pre-lab assignments, we 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 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, we should calculate with the experimental data for the "Transfer function magnitude" and "Transfer function magnitude, in dB" columns.

4 Results and Calculations

4.1 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
1MHz	5.000	0.096	0.0192	0.0016	-34.33	-55.81
100kHz	5.000	0.125	0.0250	0.0162	-32.04	-35.81
50kHz	5.000	0.233	0.0466	0.0324	-26.63	-29.79
10kHz	5.000	1.09	0.2180	0.1600	-13.23	-15.92
5kHz	5.000	1.93	0.3860	0.3083	-8.268	-10.22
1kHz	5.000	4.6	0.9200	0.8510	-0.7242	-1.401
500Hz	5.000	5.0	1.0000	0.9556	0.0000	-0.3948

Table 1. Measurement data for low-pass filter.

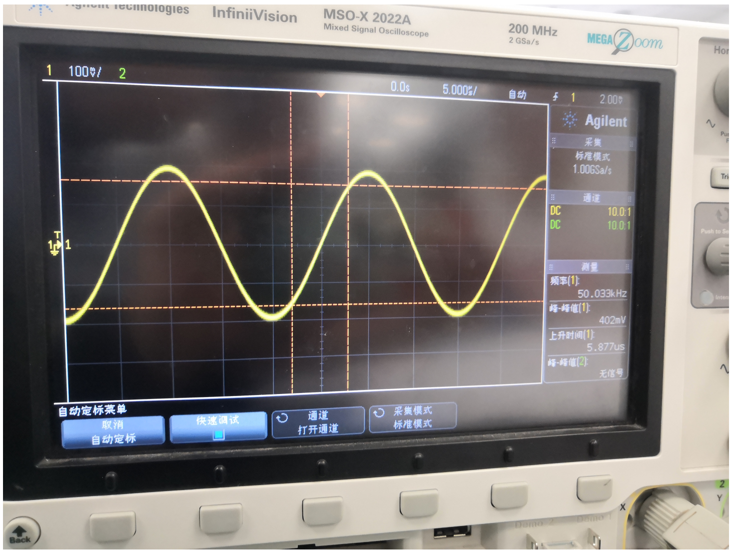


Figure 1. Measurement of low-pass filter.

4.2 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
1MHz	5.000	5.0	1.0000	1.0000	0.0000	-1.141×10^{-5}
100kHz	5.000	5.0	1.0000	0.9999	0.0000	-0.001141
50kHz	5.000	4.9	0.9800	0.9995	-0.1755	-0.004561
10kHz	5.000	4.8	0.9600	0.9871	-0.3546	-0.1126
5kHz	5.000	4.6	0.9200	0.9513	-0.7242	-0.4339
1kHz	5.000	2.21	0.4420	0.5251	-7.092	-5.595
500Hz	5.000	1.23	0.2460	0.2948	-12.18	-10.61
100Hz	5.000	0.281	0.0562	0.0616	-25.01	-24.21

Table 2. Measurement data for high-pass filter.

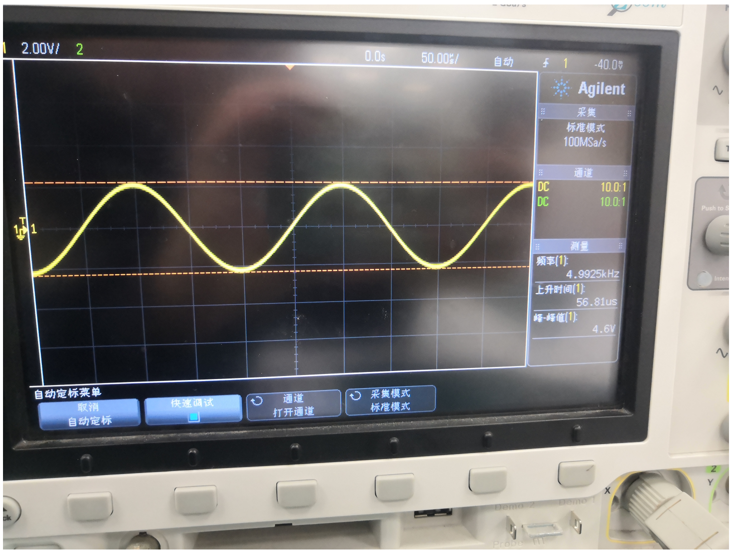


Figure 2. Measurement of high-pass filter.

4.3 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
1MHz	5.000	0.54	0.1080	0.1545	-19.33	-16.22
500kHz	5.000	1.47	0.2940	0.2986	-10.63	-10.50
100kHz	5.000	4.3	0.8600	0.8485	-1.310	-1.427
50kHz	5.000	4.7	0.9400	0.9611	-0.5374	-0.3449
10kHz	5.000	4.9	0.9800	0.9952	-0.1755	-0.04159
1kHz	5.000	2.21	0.4420	0.5266	-7.092	-5.570
500Hz	5.000	1.23	0.2460	0.2951	-12.18	-10.60

Table 3. Measurement data for band-pass filter.

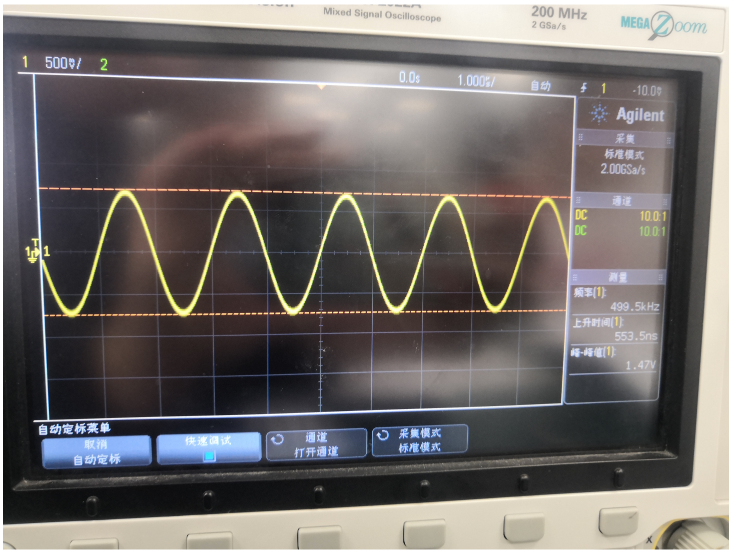


Figure 3. Measurement of band-pass filter.

4.4 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
1MHz	5.000	5.2	1.0400	0.9880	0.3407	-0.1049
500kHz	5.000	5.1	1.0200	0.9544	0.1720	-0.4056
300kHz	5.000	4.7	0.9400	0.8863	-0.5374	-1.048
200kHz	5.000	4.1	0.8200	0.7860	-1.724	-2.091
100kHz	5.000	2.61	0.5220	0.5292	-5.647	-5.528
50kHz	5.000	1.31	0.2620	0.2763	-11.63	-11.17
10kHz	5.000	0.73	0.1460	0.0976	-16.71	-20.21
5kHz	5.000	1.79	0.3580	0.2804	-8.922	-11.04
1kHz	5.000	4.7	0.9400	0.8501	-0.5374	-1.410
500Hz	5.000	5.1	1.0200	0.9555	0.1720	-0.3956

Table 4. Measurement data for band-reject filter.

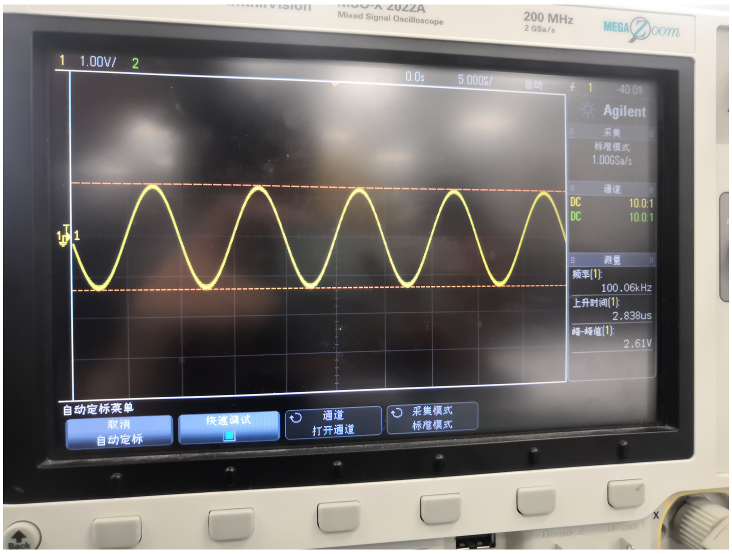


Figure 4. Measurement of band-reject filter.

5 Conclusion and Discussion

In this experiment, in general, we obtained reasonable data for output signal amplitude in V_{ppk} and see that the trend of the transfer function magnitude follows the trend of the ratio of the output signal amplitude to the input signal amplitude.

However, when we measurement the output signal amplitude of band-reject filter, 3 of the digits have higher value than 5.0, i.e. the input signal amplitude. This error may come from the error of input signal amplitude, which possibly higher than $5.000V_{ppk}$. Besides, the cursor is automatically generated by the oscilloscope without additional adjustment, which might be not accurate.

In conclusion, we learned about transfer functions and four types of filters – Low-Pass, High-Pass, Band-Pass, and Band-reject. Besides, We predicted the theoretical result of transfer function magnitude and made comparison with measurement data in lab.

Reference

Lab 5 Manual.

Data sheet

Filter Lab

Data Sheet

Name: [illegible] Lin Yihua   Student ID: 518021910998
Date: 2019.11.13   TA's Signature: [illegible]

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 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.

I) Low-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	5.000	~~[illegible]~~ 9.6		1.621×10^{-3}		-39.84
100 kHz	5.000	~~[illegible]~~ 125		~~[illegible]~~ 0.1013		-19.89
50 kHz	5.000	~~[illegible]~~ 233		~~[illegible]~~ 0.1996		-14.00
10 kHz	5.000	~~[illegible]~~ 1.09×10^3		~~[illegible]~~ 0.7135		-2.932
5 kHz	5.000	~~[illegible]~~ 1.93×10^3		~~[illegible]~~ 0.8971		-0.9380
1 kHz	5.000	~~[illegible]~~ 4.6×10^3		~~[illegible]~~ 0.998		-0.01468
500 Hz	5.000	~~[illegible]~~ 5.0×10^3		0.9988		-0.01046

II) 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
1 MHz	5.000	5.0 ~~[illegible]~~		0.9999		-4.503×10^{-4}
100 kHz	5.000	5.0 ~~[illegible]~~		0.9998		-1.801×10^{-3}
50 kHz	5.000	4.9 ~~[illegible]~~		0.9799		-0.1765
10 kHz	5.000	4.8 ~~[illegible]~~		0.7007		-3.0[illegible]
5 kHz	5.000	4.6 ~~[illegible]~~		0.4407		-7.116
1 kHz	5.000	421 ~~[illegible]~~		0.09773		-20.20
500 Hz	5.000	1.23 ~~[illegible]~~		0.04904		-26.19
100 Hz	5.000	0.281		9.810×10^{-3}		-40.16

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	5.000	340		0.7042		-3.046
500 kHz	5.000	4.47×10^3		0.8984		-0.9305
100 kHz	5.000	4.95×10^3		1.000		0.0001
50 kHz	5.000	4.7×10^3		0.9885		-0.1002
10 kHz	5.000	4.9×10^3		0.7042		-3.046
1 kHz	5.000	421×10^3		0.0977		-20.20
500 Hz	5.000	1.23×10^3		0.0490		-26.19

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	5.000	5.2×10^3		0.984		−[illegible]108
500 kHz	5.000	5.1×10^3		0.[illegible]914		−[illegible]0.0089
300 kHz	5.000	4.7×10^3		0.[illegible]886		−[illegible]1.0854
200 kHz	5.000	4.1×10^3		0.[illegible]786		−[illegible]2.0721
100 kHz	5.001	2.61×10^3		0.[illegible]529		−[illegible]5.3946
50 kHz	5.001	1.31×10^3		0.[illegible]276		−[illegible]10.9027
10 kHz	5.001	730		0.[illegible]098		−[illegible]20.43
5 kHz	5.000	1.79×10^3		0.[illegible]280		−0.[illegible]6748
1 kHz	5.000	4.7×10^3		0.[illegible]980		−0.[illegible]1676
500 Hz	5.000	5.1×10^3		0.[illegible]995		−0.[illegible]0430

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:						