

ESE 150 – Lab 05: PsychoAcoustics

LAB 05

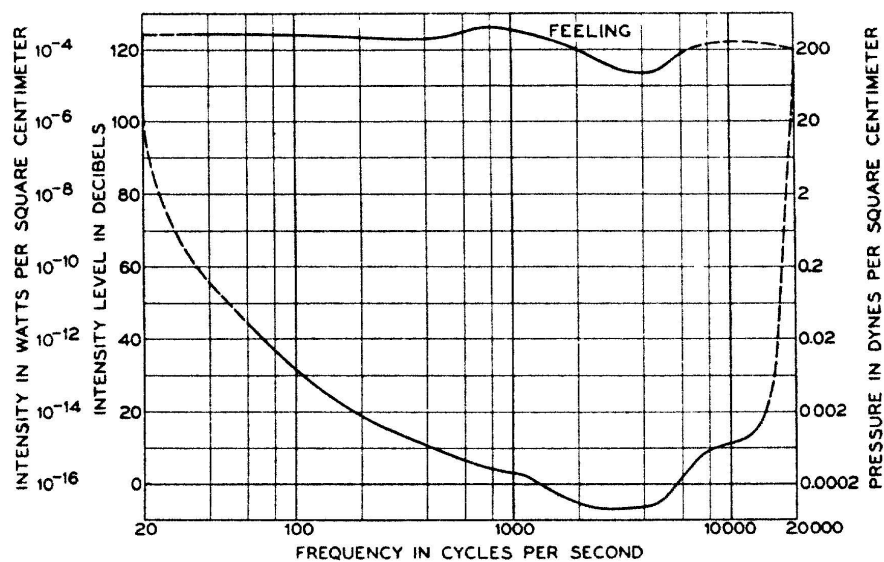
In this lab we will do the following:

1. Use a lab tool called: LabView for the first time
2. Examine and characterize hearing thresholds in terms of frequency and loudness
3. Investigate frequency masking and critical bands
4. Investigate Off-frequency masking and temporal masking

Background:

In lecture we discussed Psychoacoustics, which is a branch of psychophysics that focuses on the study of the psychological and physiological responses associated with sound. In other words, it is a study of the way our brains interpret sound. This branch of science is used heavily in the MP3 algorithm to implement a lossy compression algorithm that makes MP3 compression ratios reach nearly 12:1!

In lab today you'll experiment with some pre-made programs to investigate several interesting psychoacoustic effects. You'll work with your lab partner to see how your brain interprets sound. The first experiment you'll perform is seeing how your brain interprets the loudness of sounds at different frequencies. Recall from lecture the "Fletcher Curve":



This curve above represents the way most humans interpret the loudness of different frequencies vs how "loud" or how large the amplitude of the signals they hear really were. The two biggest things to notice are that we have to make the amplitude of low frequency and high frequency signals VERY high, in order for us to feel they are at the same volume as frequencies in the range of human conversation.

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In the first section of lab today, you'll measure and generate a Fletcher curve for you and your lab partner. In the later sections of lab, you'll investigate frequency masking. This is the situation when we have a loud signal blocking out our ability to hear other sounds in similar frequencies.

For both of these, you'll want to think about the critical bands in the Cochlea:

Number	Center frequencies Hz	Cut-off frequencies Hz	Bandwidth Hz
		20	
1	50	100	80
2	150	200	100
3	250	300	100
4	350	400	100
5	450	510	110
6	570	630	120
7	700	770	140
8	840	920	150
9	1000	1080	160
10	1170	1270	190
11	1370	1480	210
12	1600	1720	240
13	1850	2000	280
14	2150	2320	320
15	2500	2700	380
16	2900	3150	450
17	3400	3700	550
18	4000	4400	700
19	4800	5300	900
20	5800	6400	1100
21	7000	7700	1300
22	8500	9500	1800
23	10 500	12 000	2500
24	13 500	15 500	3500

What is LabView?

LabView is a program that allows one to control lab equipment using GUIs. Say you'd like to turn on a power source and then measure some signals with an oscilloscope. You can write a simple program in LabView to turn on a power supply and actually record data from the scope. It is very powerful and intended for the control and interaction with lab equipment. But LabView is actually a graphical programming language, and it can be used for more than just working with lab equipment. You can write very simple GUIs with LabView, too. One can use it to write programs very quickly, because you drag and drop components to build GUIs or what we call: VIs in LabView.

In Lab today, the GUI programs you'll use to characterize your hearing capabilities have been written in LabView. We won't learn how to program with LabView today, but you'll use programs written in LabView, so you should be aware of its powers!

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Prelab:

1. Read lab.
2. Where does the critical band centered at 1000Hz begin and end?
3. Given strong signals at 1200Hz and 1700Hz, which of the following frequencies are likely to be masked, and why?
 - a. 1070Hz
 - b. 1260Hz
 - c. 1400Hz
 - d. 1620Hz
 - e. 1760Hz
 - f. 4120Hz
4. Write MATLAB code to read the first 2048 samples of a song, convert them to frequencies, and identify the strongest frequency (largest magnitude) in each of the 24 critical bands.
 - a. Download song1.wav from the course syllabus.
 - b. In MATLAB's command window type:
[samples_time, samp_rate]=audioread('lab5_song.wav')
 - c. This has imported the PCM quality .WAV file into a matrix called: samples_time
 - d. It has also determined the sampling rate with which the .WAV file was created.
 - e. Extract 2048 samples starting 60 seconds into the song. (Hint: How do you tell MATLAB to extract a range of values from a vector?)
 - f. Use the provided a plot_dft function (similar to the one you wrote in Lab 4) to convert the samples to frequencies.

```
function [samples_freq, freq_mag] = plot_dft(samples_time,
      samp_rate, figure_num)

samples_freq = fft(samples_time);
samples = length(samples_time); % # of samples
samples_freq_new = abs(samples_freq / samples);
samples_freq_new =
samples_freq_new(1:round(length(samples_freq)/2.0),:) * 2;
freqs = (0:(samples - 1));
freqs = freqs * (samp_rate/(samples - 1));
freq_half = freqs(1:round(length(freqs) / 2, 0));
figure(figure_num);
freq_mag = samples_freq_new;
stem(freq_half, samples_freq_new);
title('Frequency Domain');
xlabel('Frequency (Hertz)');
ylabel('Amplitude (Volts)');
end
```

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- g. Write a MATLAB function:
function [critical_band_max] = max_freq_per_band(samples_freq)
The return value should be a vector of 24 frequencies (in Hz), one for each critical band.
- i. Function should only take about 10 lines of Matlab code
 - ii. Hint: Define two vectors of 24x1, one for start_band and one for stop_band, and assign the cut-off band frequencies to the vector entries. Use a for loop to iterate over each of the bands (i.e. 24 times) and finds the maximum frequency in the band.
 - iii. Hint: find() Matlab function will likely be helpful:
<https://www.mathworks.com/help/matlab/ref/find.html>
 - iv. Include your MATLAB function in your report.
 - v. Save your code. You will need to perform an operation much like this in Lab 6.
- h. Use your function to report the strongest frequencies and include the frequencies in your report.
5. Bring headphones to lab.

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Lab Procedure:

Lab – Section 0: Setting up and starting “LabView”

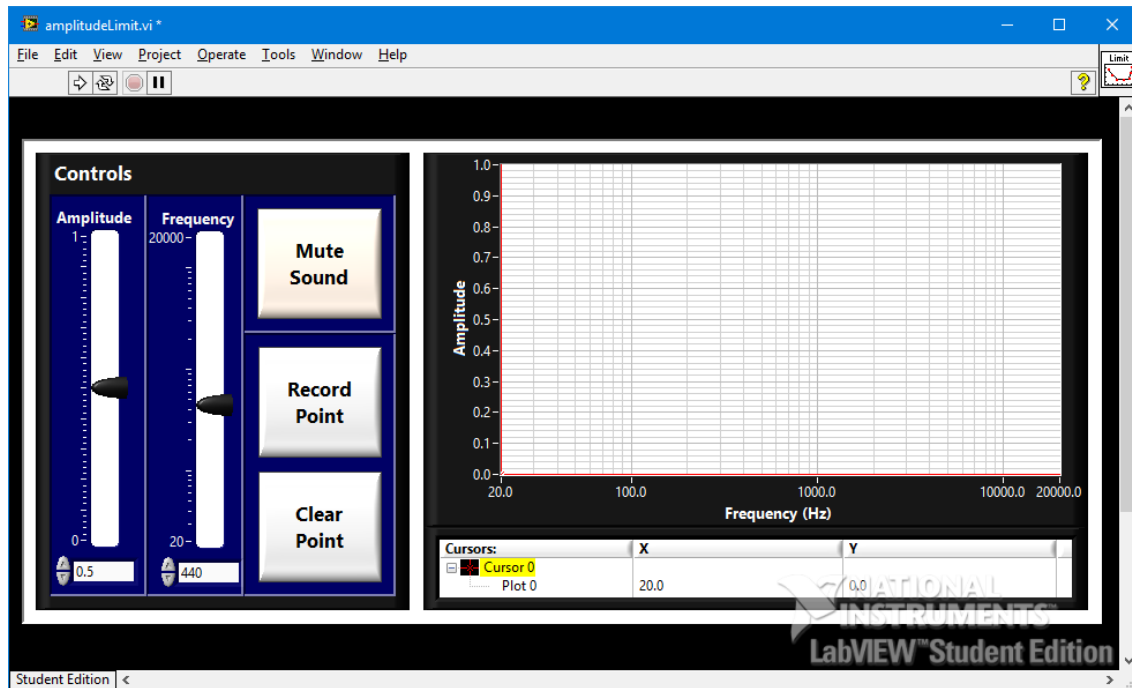
- In this section you’ll setup your LabView environment for today’s lab
 - You must complete this section so that future sections will work properly
1. Download the helper file for today’s lab from canvas: ESE150_Lab05-PsychoAcoustics-Files.zip (under Files in the Lab 5 directory).
 - a. You must use a lab computer for today’s lab as it has a program called: LABVIEW which would most likely do not have on your laptop**
 2. UNZIP the contents of this file to your “S:\” drive, make a folder called: **ese150\lab05**
 - a. You will need to unzip these files for today’s lab to work;
DO NOT simply open the zip file and try to use the files directly from the zip.
 - b. Also, make certain you know where you are unzipping the files to, you’ll need this information later in lab.
 3. Examine the unzipped file contents:
 - a. Look under **s:\ese150\lab05**
 - b. Notice there are 5 files:
 - i. amplitudeLimit.vi
 - ii. generateBandNoise.vi
 - iii. generateTone.vi
 - iv. masking.vi
 - v. playWaveform.vi
 - c. These files are called: Labview “VIs”, essentially each of these is a small program written in the LabView programming language.
 - d. Each file will be used in a separate section of today’s lab below.

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Lab – Section 1: Measuring Hearing Thresholds

- In this section you'll use a premade LabView program to generate your own Fletcher Curve
- It is assumed that you have unzipped the ZIP file discussed in Section 0.

1. From the S:\ drive ese150\lab05 folder, double-click on the “**amplitudeLimit.vi**” file
 - a. LabView should open
 - b. The following “VI” should now appear:



2. Run the LabView “VI” by performing the following steps:
 - a. From the top menu choose: Operate->Run
 - b. Plug your headphones into the lab computer and listen.
 - c. You should hear a single TONE.
3. Play with the VI a bit:
 - a. Adjust the “frequency” slider bar up and down, you’ll hear the frequency of the tone go up and down
 - b. Adjust the “amplitude” slider bar up and down, you’ll hear the loudness of the tone go up and down.
 - c. Just for fun, click the “Record Point”
 - i. you’ll see it records the amplitude and frequency on the graph to the right.
 - d. Adjust the frequency to any other value and click “Record Point” again.
 - i. The VI records the amplitude and frequency again, but it connects the two points.
 - e. Click on the “clear point” button twice to remove these two data points.

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4. Generate a Fletcher curve for lab partner #1
 - a. The goal of this section is to generate a Fletcher Curve for both lab partners.
 - b. Each person has their own Fletcher curve, they'll be similar, but not exactly the same.
 - c. Perform a “blind” experiment on your lab partner:
 - i. Have 1 lab partner put on the headphones, while the other partner controls the LabView VI.
 - ii. Have the lab partner with the headphones **close his/her eyes**.
 - iii. Have the lab partner running LabView set the frequency down to 20 Hz with an amplitude as high as possible.
 - iv. If the blinded lab partner can hear the tone, the LabView operator should click “record point” on the VI.
 - v. If not, increase the frequency until the blinded lab partner can hear it (that's around 100 Hz for most people).
 - vi. When the blinded lab partner can hear the first tone, click “record point”.
 - vii. Increase the frequency into the middle of the next critical band and lower the amplitude until this slightly higher frequency sounds equally “LOUD” to your lab partner as the last tone did. (Recommended amplitude precision of increment or decrement is 0.55.)
 - viii. Repeat this process, recording one point per critical band until you have covered all critical bands.
 - ix. If your partner can still hear sounds in the top critical band, continue to increase the frequency until it is so high your lab partner can no longer hear the tones.
 1. Use an efficient binary search to find the peak frequency your partner can hear.
 2. Record the amplitude-frequency threshold for a few points between this maximum point and the last critical band.
 - x. Remember, lower frequency tones must be made very loud for us to hear (and high frequency tones). Your job is to determine what the actual amplitude that each frequency needs to be played at, for your lab partner to think it's actually at the same volume.
 - xi. You'll end up with a graph that is very similar to the one in the “Background” section of this lab (from lecture).
 - d. Once you have a complete Fletcher curve for your lab partner do the following:
 - i. Right click anywhere on the graph.
 - ii. Scroll down to “export”.
 - iii. Choose: Export Simplified Image.
 - iv. Then click on “Save to file” and type:

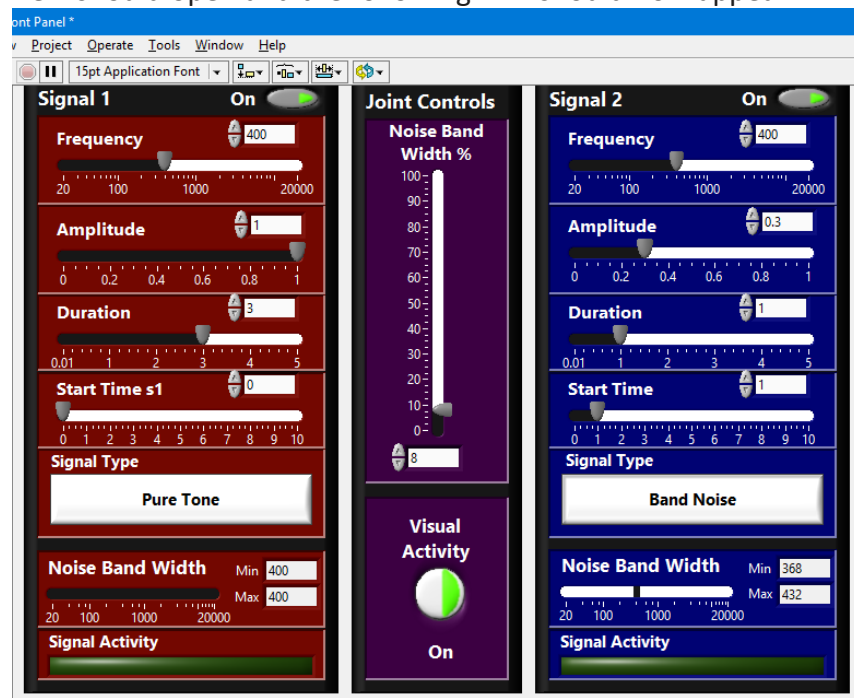
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1. S:\ese150\lab05\partner1.bmp
 - v. Then import this BMP file into WORD so you can turn in your lab data in 1 single file.
5. Repeat Step 4 for the other lab partner.
- a. A Fletcher curve for each lab partner must be submitted for your group to receive full credit.
 - b. In your lab data file, indicate which fletcher curve is for which partner! **Additionally, show a TA these fletcher curves before moving on.**

Lab – Section 2: Frequency Masking and Critical Bands

- In this section you'll use a premade LabView program to investigate **masking**
 - Both types of masking can be investigated: frequency & temporal
- It is assumed that you have unzipped the ZIP file discussed in Section 0

1. From the S:\ drive ese150\lab05 folder, double-click on the “**masking.vi**” file
 - LabView should open and the following “VI” should now appear:



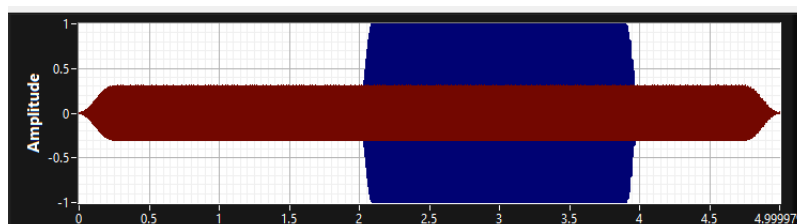
- Look carefully for the “right arrow” on the top-left of the VI:



- i. This right arrow is a shortcut to the “RUN” button to start the VI.

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- This VI allows you to setup two signals (in terms of frequency, amplitude, duration, start time). You can make one tone a PURE tone, and the other tone a BAND NOISE
 - i. A PURE TONE is just a signal at 1 frequency
 - ii. A BAND NOISE is many frequencies played at the same time, centered around a particular center frequency.
2. Understanding the VI:
- In this section, you'll learn to use the VI and see the effects of on-frequency masking
 - i. Click on the right arrow button to start the VI.
 - ii. On the right hand side of the VI, change the signal type to PURE TONE.
 - iii. The VI will stop playing very quickly.
 - iv. For Signal 1 set the following parameters:
 1. Frequency = 1000 Hz (you can type it in if you'd like)
 2. Amplitude = 0.3
 3. Duration = 5
 4. Start Time = 0
 5. Signal Type: Pure Tone
 6. Don't adjust the Noise Band Width
 - v. For Signal 2 set the following parameters:
 1. Frequency = 1000 Hz (you can type it in if you'd like)
 2. Amplitude = 1
 3. Duration = 2
 4. Start Time = 2
 5. Signal Type: Pure Tone
 6. Noise Bandwidth: Min = 1000, Max = 1000
 - a. *(This means there is no noise bandwidth!)*
 - vi. Once again, click on the right arrow to start the tones:
 1. Listen carefully; signal 1 will play immediately for 5 seconds. Signal 2 will start at time 2 seconds and play for 2 seconds.
 2. Look at the "Visual Activity" Window on the bottom of the VI.
 - a. It shows a visual representation of these two waves, carefully ensure your graph looks like this (and make sure you understand how it lines up to your settings above).



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3. Notice signal 2 “masks” signal 1 as it is at the same exact frequency and it is much louder! Your ear cannot differentiate between the two signals at that time.
3. Simultaneous Masking – On Frequency Masking
- Simultaneous masking occurs when a sound is made inaudible by a noise or unwanted sound of the same duration as the original sound.
 - i. There are four basic parts to simultaneous masking:
 1. Critical Bandwidth, similar frequencies, lower frequencies, and the effects of intensity.
 - Recall from lecture the 24 Critical bands of the Cochlea (in background section).
 - We think of the 24 bands as a bank of auditory filters that our ear has.
 - If a “masker” signal is loud enough it can mask other frequencies that are in the same auditory filter bank and make it so you cannot hear them.
 - i. This is called “on-frequency masking”
 1. This is used heavily in the MP3 algorithm
 - In this section you’ll create a masker signal at a fixed frequency and characterize its effect on your audio filter! Then you’ll plot the results.
 - a. In the VI, we’ll make signal 1 the MASKER, an signal 2 the signal that will get masked.
 - b. Using the VI, set signal 1 (the masker tone) as follows:
 - i. Frequency = 1000 Hz
 - ii. Amplitude = 0.3
 - iii. Duration = 4
 - iv. Start Time = 0
 - v. Signal Type = Pure Tone
 - c. Set signal 2 (the tones being masked) as follows:
 - i. Frequency = 1000 Hz
 - ii. Amplitude = 0.3
 - iii. Duration = 5
 - iv. Start Time = 1
 - v. Signal Type = **Band Noise**
 - vi. **Noise Bandwidth** Min = 990, Max = 1010
 - d. Set the Joint Controls Noise Bandwidth % to 1
 - e. Press the right-arrow to start the experiment
 - i. You will hear the “noise” – the signals ranging from 990 to 1010 Hz.
 - ii. And you may not hear the masker as it is at the same amplitude as the noise.
 - iii. **Make sure the masker signal range stays where you set it**; if it changes to larger values, you probably haven’t set the Joint Controls Noise Bandwidth appropriately.

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- f. Increase the amplitude of the masker (signal 1) until the “noise” is masked (until you can’t hear the noise when signal 1 is playing).
 - i. Record for each amplitude if masking is occurring.
- g. Next, increase bandwidth of the noise by 10 Hz (1%) on each side of the band
 - i. You need to change the Joint Controls and the Noise Bandwidth for Signal 2.
 - ii. Reduce the amplitude of the noise signal until you no longer hear it.
 - iii. Record the amplitude of the noise signal that is masked.
- h. Work in 10 Hz (1%) increments on each side of the band until you reach the bandwidth of this auditory filter (look to the 24-bin chart given above to find bandwidth).
 - i. Record the highest amplitude of the noise that is masked for each noise bandwidth.
- i. Create a graph of amplitude (y-axis) vs. noise bandwidth from your data.
 - i. Your data is largely subjective, but that’s the way auditory experiments go!
 - ii. **Before moving on, show your graph to a TA.**
 - iii. Save the graph and submit it with the lab.

4. Simultaneous Masking – Frequency Resolution

- Another interesting auditory experiment is to determine one’s ability to discern between two similar frequencies.
 - If two sounds of two different frequencies are played at the same time, two separate sounds can often be heard rather than a combination tone.
 - i. The ability to hear frequencies separately is known as *frequency resolution* or frequency selectivity.
 - But, when signals of two different frequencies are played at the same time and are perceived as a combination tone, they are said to reside in the same critical band.
- a. Work with the 1000Hz frequency band for which you identified the band limits in Prelab 2.
 - b. Use the labView VI to generate two signal as follows:
 - i. Signal 1: pure tone of 1000 Hz, amplitude = 0.3, duration 3, start time 0
 - ii. Signal 2: pure tone of 1001 Hz, amplitude = 0.3, duration 3, start time 0
 - c. Play the two signals and listen (but don’t look at the visual activity window –or turn it off).
 - i. Can you differentiate between the two signals? Record Yes or No
 - ii. What do you actually hear? Describe this.

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- iii. Also, zoom in on the visual activity window, what do you see? Take a screen shot and record this.
 - d. Increase the frequency of signal 2 by a small amount (a few Hz).
 - i. do you still hear the tones the same way?
 - ii. Are you able to differentiate between them?
 - iii. Now increase frequency until tones are differentiable and record distance required to achieve that. Is it in the same critical band?
 - iv. Move to a tone outside of this critical band for signal #2
 1. Play both tones, does it sound different?
 2. Is what your hearing a combination tone? Or two separate tones?
 - e. Describe the result of your experiments to your TA; this is your exit ticket.
5. Temporal Masking (optional – time permitting)
 - Recall from lecture temporal masking (time-based masking)
 - If a really loud sound occurs, then your ear may not hear sounds that immediately follow that loud sound (this is called post-masking)
 - Also a really loud sound occurs, then your ear may not hear sounds that immediately preceded that loud sound (this is called pre-masking)
 - Notice the VI has the capability to “delay” the start-time of a tone...with this in mind design an experiment to quantify this effect:
 - i. Write out an experimental methodology that would let you observe each masking type in your lab submission (the steps you followed to complete your experiment).
 - ii. Next, carry out the lab experiment you have designed on your partner and see if you and your partner can understand each masking type.
 - iii. Graph your data when appropriate (Amplitude vs delay(time)). Otherwise, explain your data and how it verifies your methodology and draw a conclusion!

Postlab:

1. A typical siren is not a pure tone but will shift through a large range of frequencies. With what you now know about masking, explain why a pure tone might make a poor siren and how a siren that spans a large frequency range would address the problem.
2. Consider someone with hearing damage such that they cannot hear any tones above 8kHz. How could you create a hearing aid that would allow them to “hear” sounds above that occur between 8kHz and 22kHz. (a similar question, how you could create a “hearing aid” that would allow you to “hear” sounds between 20kHz and 50kHz.)
3. What masking phenomena might you need to consider in your “hearing-aid” solution?

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HOW TO TURN IN THE LAB

- Upload a PDF document to canvas containing:
 - Prelab answers (2, 3, 4h)
 - MATLAB from prelab (4g)
 - All images (fletcher curves, masked amplitude vs. noise bandwidth, etc)
 - Answers to questions in Section 2.4
 - All excel data (representing the data you recorded)
 - Formulation of data into graphs, and explanations as to what they are
 - Postlab answers