Sound Waves and Beats

Introduction

Sound waves consist of a series of air pressure variations. These pressure variations cause your eardrum to vibrate, which is interpreted by your brain as sound. In a similar fashion, a microphone diaphragm records these pressure variations and converts them to an electrical signal which can then be displayed on an oscilloscope.

When any two waves are passing through the same region of space, they can add up or cancel out (interference). Sound waves are no exception to this! When two sound waves of slightly different frequency are played simultaneously, “beats” (rhythmic pulses) are heard. These pulses are due to the fact that the waves are continuously passing from in-phase to out-of-phase and back, sequentially causing constructive and destructive interference.

For Part I of this laboratory you’ll generate audio tones using the resonance of a crystal drinking glass. You’ll record the sound generated using an audio program called Audacity and export your sound waves into a spreadsheet or similar tool for analysis. For Part II of the lab you’ll use Audacity to generate two tones of similar, though slightly different, frequency. You’ll record the tones when played simultaneously and export the results for analysis of their combined superposition waveform.

Pre-Lab Questions

Suppose you are adding two sound waves with equal amplitudes A and slightly different frequencies f_1 and f_2. Let us write the equations for the time dependence of these waves (at a fixed position x) as

$$\Delta P_1(t) = Acos(2\pi f_1 t)$$

$$\Delta P_2(t) = Acos(2\pi f_2 t)$$

(a) Using the trigonometric identities

$$cos(a) + cos(b) = 2cos\left(\frac{a-b}{2}\right)cos\left(\frac{a+b}{2}\right)$$

$$sin(a) + sin(b) = 2cos\left(\frac{a-b}{2}\right)sin\left(\frac{a+b}{2}\right)$$

write the sum of your two sound waves $\Delta P_{tot} = \Delta P_1(t) + \Delta P_2(t)$ as a product of two trigonometric functions.

(b) The two trigonometric functions which you found in the previous part have two different oscillation frequencies which depend on f_1 and f_2. Call these f_{fast} and f_{slow}. Write equations for f_{fast} and f_{slow} in terms of f_1 and f_2.

(c) Suppose $f_1 = 19Hz$ and $f_2 = 21Hz$. What are the first two times where the slowly oscillating trig function has a value of zero? These will be two times where the sound intensity is at a minimum.

(d) Suppose $f_1 = 19Hz$, and $f_2 = 21Hz$. Sketch the resulting wave if these two sounds interfere with each other. The x-axis of your sketch should be at least 1.0 second long. [Hint: the product of two trig functions can be thought of as a "cosine within a cosine" (or a "sine" within a cosine", etc...). For example, the trig function with the longer period can be thought of as amplitude of the faster oscillating function. Thus, you have a fast oscillation whose amplitude varies slowly in a sinusoidal manner.]

Audacity

For this experiment you'll use a program called Audacity to record and/or generate sound.

Audacity is freely available for download at https://www.audacityteam.org/. It can be installed on Windows, Mac, and Linux computers.

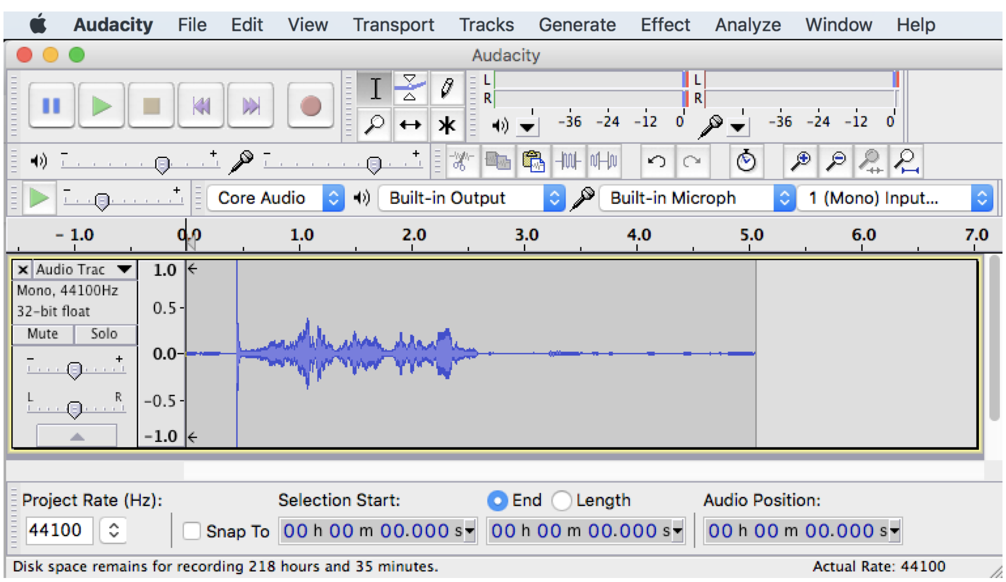

Figure 1. Audacity software interface

Figure 1 shows the Audacity user interface. Control features include:

- Play/Record control buttons (upper left)
- Speaker and microphone volume adjustment
- Speaker and microphone selection drop down menus
- Mono/stereo selection drop down menu
  - We'll use the "mono" option for our experiment, which generates/records a single audio channel. (Stereo would be useful for composing immersive "surround" sound effects, as in music recording or media soundtracks.)

Also note that the Audacity interface displays a recorded audio track, along with certain descriptive information:

- "Mono" idicates that we've recorded a single audio channel.
- "44100Hz" indicates that we've recorded our audio track at 44100 samples per second, also known as CD-quality recording rate. Note that when recording waves, the highest frequency component that can be captured and represented requires a minimum of 2 sample points, and therefore the upper frequency limit of CD-quality recorded sound is 22050 Hz, or by design, roughly the limit detectable by the human ear.
- "32-bit float" indicates the resolution of the recording (i.e. there are 232 possible amplitude values, and the smallest amplitude increment that can be distinguished is 1/232).
- Amplitude ranges between -1.0 and 1.0. (This is in arbitrary units. Volume can be independently adjusted to increase or decrease the audible speaker output without affecting the form of the actual soundwave.)

Before proceeding to your experiment, practice recording and replaying audio data. Tracks can be deleted using the "X" in the top left corner, or via the Tracks $\rightarrow$ Remove Track menu option.

Experiment

Part I - Recording and analyzing a tone

For Part I of this experiment you'll record and analyze a "clean" tone with a strong prominent frequency.

Generate Your Data

If available, you can use a crystal drinking glass or similar vessel to generate a clear resonant tone. If no such crystal glass is available, Youtube provides a variety of clips of "wine glass resonance" that can substitute.

To make a crystal glass resonate, dampen your finger and gently circle the rim of the glass with enough pressure that you feel some resistance as your finger moves. This takes practice. Your finger can't be too dry or too wet, and the speed with which you circle the glass rim is important. Done correctly, the friction between finger and glass causes the glass's crystal molecules to resonate at a frequency characteristic of the size and shape of the glass. Once a noise is produced, you can remove your finger and the tone will slowly fade in volume.

When you become efficient at generating tones this way, start recording a track within Audacity and capture your sound. Recording is best done in a quiet location, and with the glass close to your computer's microphone input.

When you've captured several clean sounding tones you can stop recording. You'll need only 0.1-0.5 seconds of sound, though it's advisable to record 20 or 30 seconds to ensure you have plenty of data to choose from.

Highlight a small region of sound that, ideally, captures a segment tone naturally dying away after you've removed your finger from the rim of the glass. With your sound highlighted, go to Tools → Sample Data Export.

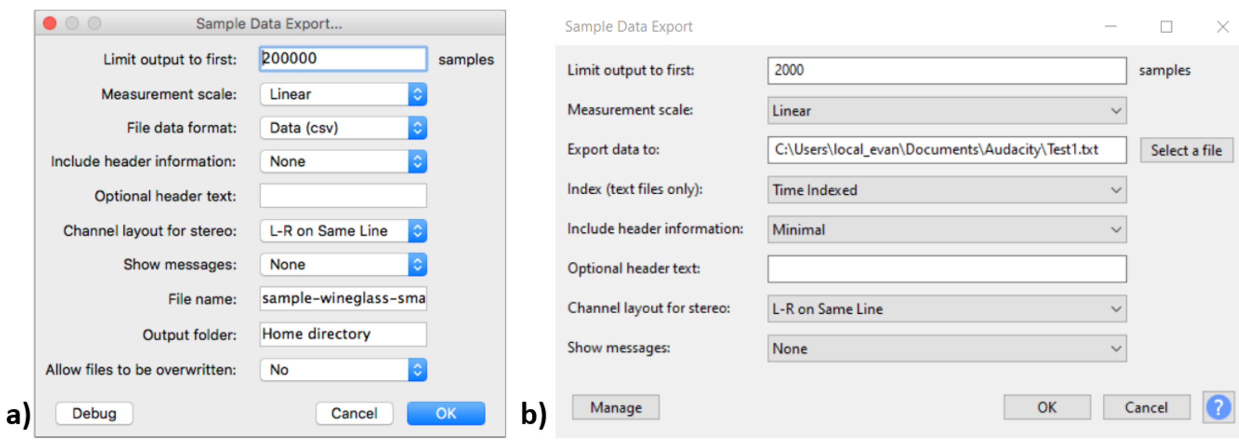

Figure 1. Audacity's 'Sample Data Export' menu tool. a) Mac interface b) Windows interface

Sample Data Export allows you to write your sound clip to a "plain text" (.txt) file, where the sound's waveform is represented by a space separated list tabulating time (or sample number) and amplitude values. When set to record at a sample rate of 44100Hz, how many samples are required to capture 0.25s?

In Sample Data Export, set:

- Limit output to first: Set to appropriate number of samples
- Measurement scale: Linear
- File type: Data (.txt)
- Include header: None

- Optional header Text: blank
- Channel layout for stereo: L-R on Same Line (has no effect since we're recording in mono)
- Show messages: None

Mac

- File name: Include some information indicative of sample parameters (e.g. wineglass, or f1-220-f2-260)
- Output folder: Can leave as"Home Folder" and file will appear in your home user directory
- Allow files to be over written: No (will automatically index file name so prior data isn't erased)

Windows

- Export data to: Select a file name and a location to save the file. Set the file type to '.txt'.

The resulting .txt file can be opened in a spreadsheet or data analysis program (Matlab, Python, etc.) of your choice.

Pre-Recorded Data

If a crystal glass or similar resonator is unavailable, record from a pre-recorded source to acquire an audio file (using Sample Data Export as above) for analysis. Locate an appropriate Youtube clip, and while playing the clip, record the sound with Audacity and save a short sample (0.1-0.5 seconds) as above.

Analysis I

Open your exported data file in a spreadsheet or similar data analysis program.

1.) Plot your amplitude data vs time. (You may need to add a column to convert sample number to time.)

2.) Adjust the x-axis of your plot to show only 10-15 sound oscillations.

3.) Determine the average amplitude (in arbitrary units) of your sound sample. To do this, calculate the average minimum-to-maximum value for each wavelength plotted.

4.) Determine the average period of your tone by measuring the time required for several oscillations. From period, calculate the frequency of your sound sample.

5.) Finally, fit your data with a wave of form $y(t) = Asin(Bt + C) + D$, where A, B, C, and D are fitting parameters representing amplitude, angular frequency, phase, and equilibrium offset, respectively. Of A, B, C, and D, are they in agreement with the frequency and amplitude values you measured directly from your plot in (3) and (4)?

Part 2 - Beats from a tone generator

In this part of the lab you'll mix two tones of similar frequency and analyze a recording of the result.

In Audacity, clear or mute any previously recorded tracks (or save your audio from Part I then reopen Audacity in order to start fresh).

Create a new track by going to Generate → Tone. Select a frequency in the range between 220 and 600 Hz. Select an amplitude less than 0.5. (If tone amplitude is greater than 0.5, what might happen when two tones are added together?)

Create a second new track by going to Generate → Tone again. Set the frequency 10-50 Hz higher than your previous tone but use the same amplitude as for your first previous track.

Having generated two similar tones, press **Transport** → **Recording** → **Record New Track**. Audacity will play the two tone tracks to your computer speakers and will record the result from your computer microphone.

In order to export your recorded audio for analysis, highlight a region of the recorded track representative of the effects you intend to analyze (i.e. several beats, which may require a few seconds). As before, go to Tools → Sample Data Export. You'll need to increase the number of samples to capture several seconds of data (i.e. every second Audacity records 44100 samples, so set the number of samples to export accordingly). You should also change the file name so that it will be identifiable for analysis.

Analysis II

Open your exported data file in a spreadsheet or similar data analysis program.

1.) Plot your amplitude data vs time. (You may need to add a column to convert sample number to time.)

2.) Adjust the x-axis of your plot to show only 5-10 "beats."

3.) Describe the sound wave's appearance.

4.) Ignoring the high frequency oscillation component of your data, fit only the overall "beat envelope" with a wave of form $y(t) = A' sin(B't + C') + D'$, where A', B', C', and D' are fitting parameters describing the envelope's wave shape.

5.) Compare now the beat frequency (found from the graph of the combined waveform) to the parameters you found by fitting the envelope (A', B', C', D'). You should find that the beat frequency is not the same as the frequency of this envelope fitting function. Explain why this is the case.

Part III - Analysis of an unknown beat pattern

You will be provided a set of .csv audio beat files, each in a numbered directory. Select the directory with number corresponding to the last digit of your student number.

Plot the file data, and using curve fitting, determine the frequencies of the two tones that compose the audio file. Report your answer, including an explanation of how you determined the frequencies.

Report

Reports should be written and submitted individually.Your TA may only mark select sections. Reports should include the following sections:

- **Introduction**
  - What is the experiment's objective?
- **Theory**
  - You may be able to show a derivation of the physics you're investigating, or you may want to reference a source that provides a description/equation representing the physics you're investigating.
  - You may want to provide graphs that illustrate or predict how you expect the system under study to behave.
- **Procedure**
  - Explain the systematic steps required to take any measurements.
- **Results and Calculations**
  - Tabulate your measurements in an organized manner.
  - Based on your procedure, you should know what your tables
  - Provide examples of any calculations.
- **Discussion and Conclusions**
  - Discuss the main observations and outcomes of your experiment.
  - Summarize any significant conclusions.
- **References**
- **(Appendices)**