

Harmonics and the Superposition Principle

- Purpose:**
1. To gain a better understanding of the superposition principle by analyzing the sound waves produced by a simple musical instrument.
 2. To compare the musical waveform of two or more musical instruments.
 3. To gain further experience using the computer for data collection and analysis.

Equipment: windows based computer, Logger Pro software, microphone, LabPro interface, flute recorder, slide whistle.

Introduction:

As you have learned in class, the superposition principle can be used to explain how a complex waveform can be thought of as the sum of a number (sometimes a great number) of simpler sinusoidal waves of varying frequency and amplitude. In this laboratory you will use a microphone connected to the computer to gather and analyze information about the shape of a sound wave produced by a musical instrument. The data will be graphed and then Fourier analyzed to determine the various harmonics (frequency components) in the sound wave.

It should then be possible to take the amplitudes and frequencies of the sine waves in the various harmonics recorded by the computer and reconstruct mathematically the original wave. The reconstructed wave would be represented by a function that will have this basic form:

$$y(t) = A_1\sin(2\pi f_1t) + A_2\sin(2\pi f_2t) + A_3\sin(2\pi f_3t) + \dots$$

Procedure:

Part I:

1. Connect the LabPro interface to the computer and the microphone to channel 1 of the LabPro. Turn on the computer and load the **Logger Pro** software by double clicking on its icon located within the **Physics Apps** folder. A file named music will be used to set up the computer for collecting the data needed for this experiment. To open this file, first select **File/Open** (with the mouse) and then open the **sound** folder by double clicking on its icon. When this folder opens, double click on **music** to open the file.
2. When the music file opens you will see two windows on the monitor. The one on the left is a graphical representation of the voltage produced by the microphone. (This voltage varies in time in precisely the same manner as the sound waves that entered the microphone.) The other window is a frequency spectrum of the same sound wave after it has been analyzed by the computer. It is basically a plot of amplitude vs frequency for the various harmonics present in the sound wave. Get some experience with the data collection process by using your own voice. Press the **collect** bottom to begin collecting data. Sing or hum a note (try an "ah" sound) into the microphone to observe the resulting waveform. When you have a good waveform that you like, press the **collect** bottom to stop collecting data. Adjust the vertical and horizontal scaling up or down to show the wave most clearly. Take a moment to observe the waveform and the frequency spectrum in the window on the right. You should observe that the waveform is periodic. From the graph window, determine the frequency of the wave (click on the "x=" icon at the top of the window and record the time between cycles). Compare this frequency with the first "spike" on the frequency spectrum graph. To change the harmonic content, sing or hum a different note (maybe try making an "oooooh" sound this time). Again observe the waveform and frequency spectrum. Next try a "sh" sound and then try a click sound made with your tongue and teeth. Experiment! Write down any interesting effects that you notice.
3. Now play a note with the flute recorder and go through the above procedure. Once you have a good clear wave displayed on the monitor (your frequency spectrum graph should have a minimum of four or five harmonics present), record the amplitudes and frequencies, and obtain a printout by selecting **File/Print**.

4. Repeat step 3 for the slide whistle. Obtain a printout. Compare and contrast the characteristics of the different waveforms for each instrument.

Part II:

1. Write a mathematical function to represent one of your waveforms (one that you previously printed out) as a sum of approximately five sine waves as shown in the introduction above. Use the frequencies and amplitudes given in the frequency spectrum graph in the right window of the printout. Have your instructor take a look at the function you come up with.

2. Now we will use the computer to plot your function. Close out (or minimize) the **Logger Pro** software and run the **Graphical Analysis** program by clicking on its icon in the Physics Apps folder. Choose **File/Open** and double click on the **sound** folder. Double click on the file named **music.ga3**. You should see an empty graph in one window and a data table in the other. Notice the columns of data in the table. There should be a "time" column and several columns labeled "y1", "y2", "y3", etc. Double click on the "y1" heading. This will allow you to enter the expression for the first harmonic ($A_1 \sin 2\pi f_1 t$) in the **Equation** box. After the expression is typed in, click on **OK** and then repeat for each of the remaining terms in the function that you have written in step 1. Finally, define the column labeled "yR" in a similar way by entering "y1"+ "y2"+ "y3"+... in the **Equation** box for "yR" and clicking **OK**.

3. Label the axes on the graph with the appropriate names by double clicking on the heading of the y1, ... yR columns in the data table window and typing the new name in the **Name** box. Also put in the proper units in the **Units** box. Click on okay and observe the corresponding changes in the graph window. Display the waveform ("yR") by double clicking the label on the y axis and checking the "yR" waveform. Close the data table window by right clicking in that window and choosing **Delete**. Also delete the "notes" window by first deleting all notes and then right clicking in that window and choosing **Delete**. This will allow your graph window to fill the screen. If you'd like, you can superimpose the individual harmonics on the same graph by selecting them also in a similar way. (Use different colors to easily distinguish one graph from another.) Examine the graph and see how it compares to the actual wave form you collected from the flute recorder. Compare and contrast the two waveforms in your lab report. Once you're satisfied with the constructed waveform, obtain a printout (**File/Print**).

4. Repeat steps 1-3 for the slide whistle.