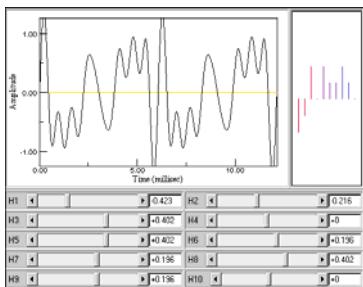


Worksheet for Exploration 18.2: Creating Sounds by Adding Harmonics



Begin by setting the slider for H5 (Harmonic 5) to the value of 1. You should hear a pure tone.

- a. What is the frequency of the fifth harmonic?

$$f_5 = \underline{\hspace{2cm}}$$

Now slowly decrease the value of H5 to zero. As you do this, note that the frequency remains the same, but the amplitude slowly decreases. Continue to decrease the value of H5 so that it is negative. Notice that the negative sign simply inverts the shape of the sound wave. Therefore, each slider controls the amplitude and phase (0 or π only) of the harmonic of the sound wave.

- b. What happens to the sound you hear as the slider value goes from +1 to zero?

- c. What happens to the sound as the slider goes from 0 to -1?

- d. Can you hear a difference in the sound at +1 and -1?

At this point you should have determined that loudness is related to amplitude. Now let's figure out what determines the pitch (musical note). Set H5 to zero. (You can do this using the slider or by typing zero into the text box beside the slider) Use the slider to turn on some other harmonics. The sound you will hear is the sum off all harmonics that are on, so if you want to hear an individual harmonic you will need to set all other values to zero.

- e. Based on your experimenting, what determines the pitch of a tone? Specifically, is this quantity larger or smaller for high vs. low notes?

Now comes the really cool part. *How does an electronic keyboard mimic the sounds of individual instruments?* To understand this, we first need to understand why (mathematically) a trumpet sounds different from a clarinet. When you only had one harmonic turned on you heard a pure tone. When you play a note on a trumpet, you do not create a pure tone. You set the trumpet vibrating, and this sets up resonant standing waves (pure tones). More than one resonant standing wave can exist at any one time. All of the resonant standing waves (harmonics) will add together, and what you hear is the sum of all these individual pure tones. The relative magnitudes of the individual harmonics are different for the clarinet and the trumpet, which is why the two instruments sound different even when they play the same note.

Try the following values for the harmonics.

| H | Clarinet | Trumpet |
|----|----------|---------|
| 1 | 0.91 | 0.53 |
| 2 | 0.51 | 1 |
| 3 | 0.71 | 0.94 |
| 4 | 0.86 | 0.95 |
| 5 | 1 | 0.66 |
| 6 | 0.71 | 0.58 |
| 7 | 0.54 | |
| 8 | 0.2 | |
| 9 | 0.18 | |
| 10 | | |

Do the resulting tones sound like the clarinet and trumpet? Well, sort of. You should be able to hear some similarities to the instruments they are supposed to represent and you should be able to tell that the sounds are different, but it does not exactly sound like the real thing.

- f. Can you think of some reasons why the sound you produced is not exactly like the real thing?

You should also note that in real instruments, the relative amplitudes of harmonics may differ slightly for different fundamental frequencies.