Module 4. Synthesizing Sound

The concepts of *frequency* and *period* were introduced in Module 1. These concepts were extended in Module 2, *Periodic Motion*. The way in which a sine wave can be used to synthesize tones was described in this module.

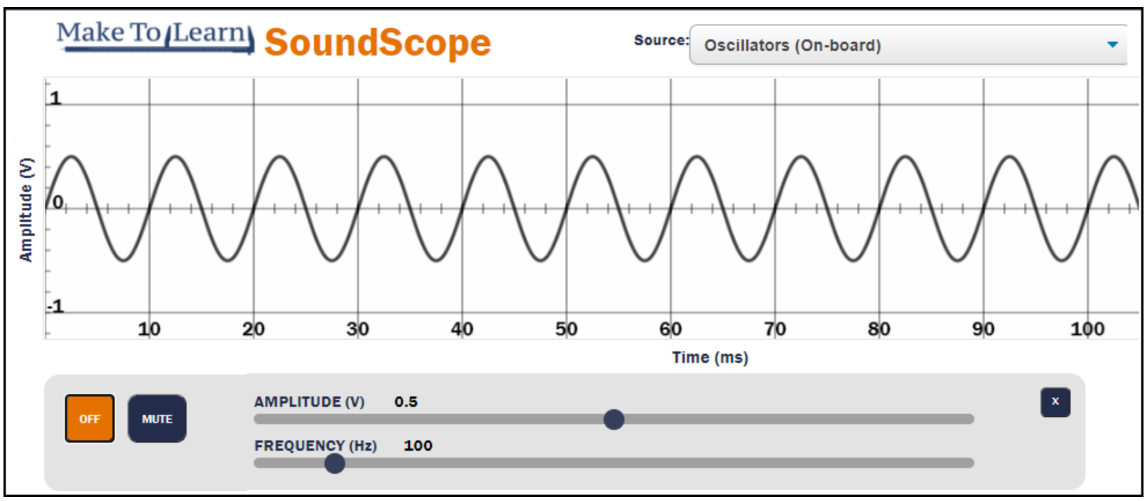
The third module in the series describes how sound can be synthesized with a computer using *SoundScope*, a tool developed in the *Make to Learn Laboratory* at the University of Virginia.

Topic 4.1 Generating a Pure Tone

SoundScope is a sound analysis and synthesis tool used for visualization of acoustic waveforms and synthesis of tones to generate sound. It can be accessed at:

https://maketolearn.org/tools/soundscope/

A series of digital oscillators can be used to generate pure tones. The resulting tone can be heard through the computer's speakers. The waveform that results can be used in the display in the top half of the screen.

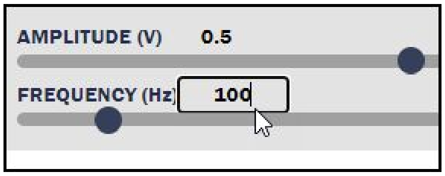


Two attributes of each tone can be adjusted: frequency and amplitude. *Frequency* refers to the number of back-and-forth movements that occur in each second. Amplitude refers to the height of the waveform.

Exploration 4.1 Generating a Pure Tone. Turn on a SoundScope oscillator. Use the oscillator controls to explore the effects of changing the amplitude and frequency of the tone generated.

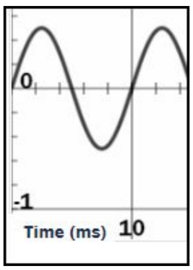
Topic 4.2 Frequency

The frequency of an oscillator can be adjusted either by moving a slide control or by directly entering a number.



The time increments on the horizontal axis are measured in milliseconds. A millisecond is one-thousandth of a second. There are 1,000 milliseconds in one second. Consequently, a 10 millisecond period is one hundredth of a second, since 1,000 divided by 10 is equal to 100.

When the frequency of an oscillator is set to 100 Hz, each cycle – representing one complete back and forth movement – will be completed in 10 milliseconds. When a 100 Hz tone is played on the computer's speaker, the speaker cone moves back and forth 100 times in one second.

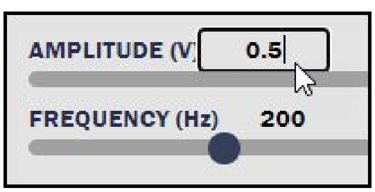


If one cycle can be completed in one hundredth of a second, then 100 cycles can be completed in a full second. Consequently, the period of time required to complete a single cycle and frequency measured in cycles per second are reciprocals. A 100 Hz tone has a period of 1 / 100 second.

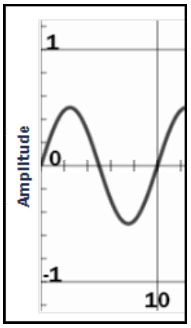
Exploration 3.2 Frequency. How does the number of cycles in the SoundScope display change as the frequency of the oscillator is increased? What is the period of one cycle of a 200 Hz tone?

Topic 4.3 Amplitude

The amplitude of an oscillator also can be adjusted either by moving a slide control or by directly entering a number. Amplitude refers to the height of the waveform.



The maximum positive amplitude that can be achieved without distortion is "1.0". When the synthesized tone is at its maximum amplitude, the voltage output sent to the computer's speaker is also at its maximum. The maximum voltage level varies from computer to computer. The maximum voltage output for one computer might be 3 volts, while the maximum voltage level for another computer might be 5 volts. If the computer speaker has a volume control, this setting will also affect the voltage level.



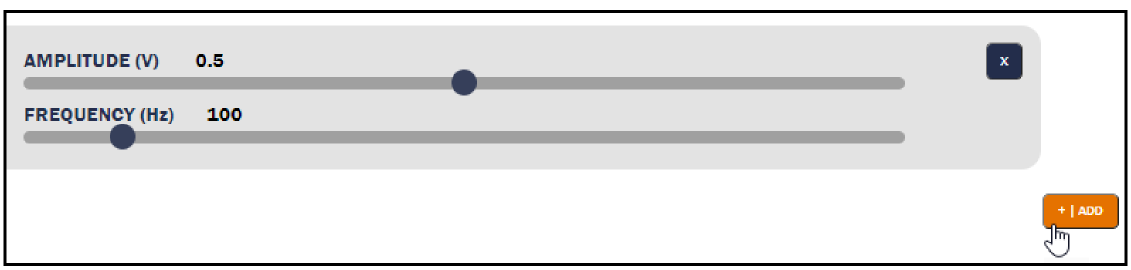
The voltage level affects the distance that the speaker cone travels as it moves back and forth. When the voltage level is at its maximum, the farthest excursion of the speaker cone will also be at its maximum. The distance that the speaker cone travels affects the perceived loudness of the sound produced. Consequently, maximum amplitude of the waveform results in the loudest sound for a given computer system and speaker.

To sum up, the frequency of the waveform affects the number of times per second that the speaker cone moves back and forth. The amplitude of the signal affects the distance that the speaker cone travels as it moves back and forth.

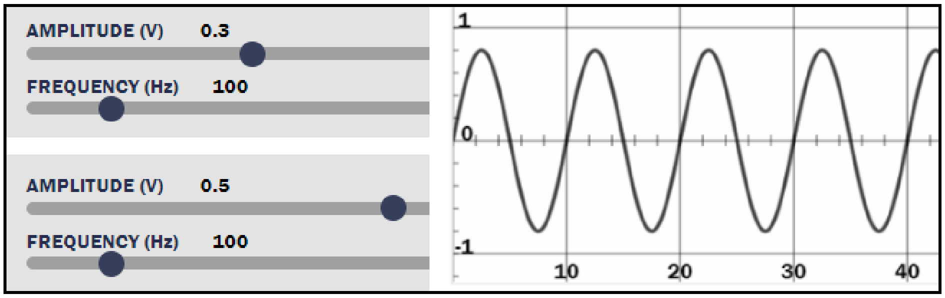
Exploration 4.3 Amplitude. Explore adjustment of the amplitude of a 100 Hz waveform. When the amplitude is set to 0.01, how loud is the perceived volume of the sound? When the amplitude is at a maximum of 1.0, how loud is the perceived volume of the sound?

Topic 4.4 Adding Two Tones

An orange *Add* button in the lower right-hand corner of SoundScope provides an option to add additional oscillators. All of the tones generated by additional oscillators created in this manner are combined to create a single tone as the output.



When two tones of the same frequency are combined, the resulting amplitude is the sum of the amplitudes of the two individual tones. For example, if a tone with frequency of 100 Hz and an amplitude of 0.3 is combined with a tone with a frequency of 100 Hz and an amplitude of 0.5, the result will be a combined tone with an amplitude of 0.8.

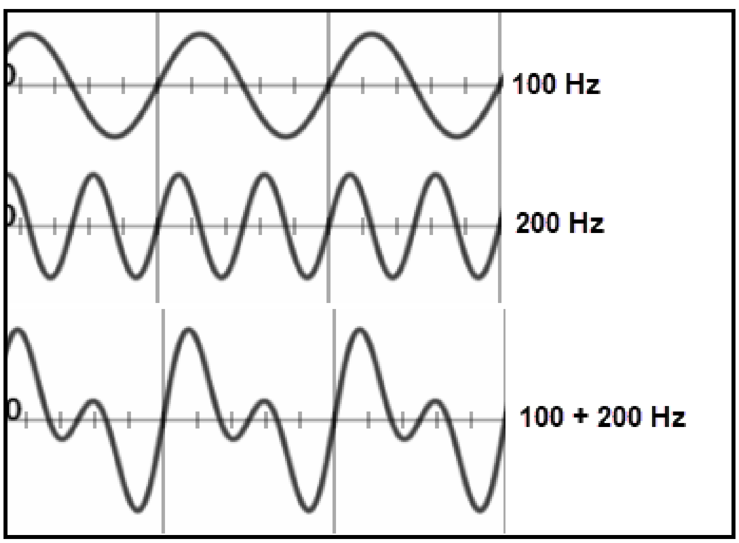


This result occurs because each point on the time line of one tone is added to the corresponding point on the timeline of the second tone. Since the points will align with one another if the frequencies of the two tones are the same, the result is an amplitude that is the sum of the amplitudes of the two tones.

Exploration 4.4 Adding Two Tones. Experiment with adding the amplitudes of different oscillators that are tuned to the same frequency. How does the process of combining two or more oscillators affect the perceived sound that results?

Topic 4.5 Complex Waveforms

When two tones of different frequencies are combined, a complex waveform is the result. In the illustration below, a 30-millisecond segment of a 100 Hz waveform and a 200 Hz waveform are shown in the top two graphs. As expected, the 200 Hz waveform has twice as many cycles as the 100 Hz tone in the 30-millisecond time period. The graph of the 100 Hz waveform depicts three cycles in 30 milliseconds, while the graph of the 200 Hz waveform depicts six cycles in 30 milliseconds.



The combined waveform, depicted in the third graph, has a higher amplitude than either of the two individual waveforms when the positive peaks of the two waveforms coincide. However, a negative peak in the 100 Hz waveform coincides with a positive peak of the 200 Hz waveform at about 6 milliseconds on the timeline. The result is a small secondary peak.

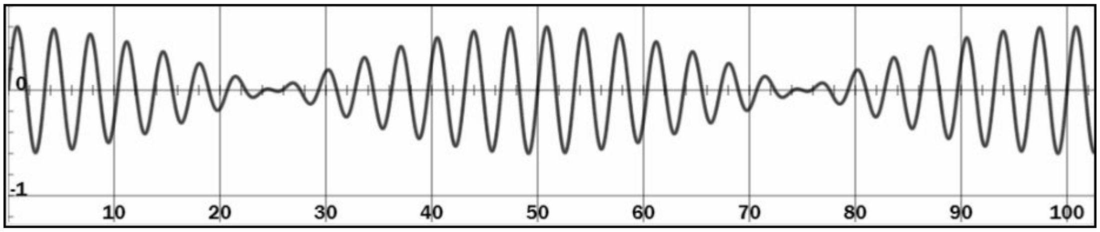
Most naturally occurring periodic sounds are not pure tones. Instead, naturally occurring periodic sounds have overtones that are multiples of the lowest frequency. This results in a complex waveform with secondary and tertiary peaks within a cycle.

The primary or *fundamental frequency* of the combined waveform is 100 Hz. The perceived pitch of a periodic sound is determined by its fundamental frequency. However, the overtones, sometimes known as *harmonics*, give the sound its perceived richness and depth. This quality of a sound is known as its *timbre*.

Exploration 4.5 Complex Waveforms. Explore the effect of combining two or more tones with different frequencies. How is the quality of the sound affected when the overtones are multiples of the fundamental frequency? How is the quality of the sound affected when the overtones are not multiples of the fundamental frequency?

Topic 4.6 Beats

The frequencies of the tones combined in the previous section were widely separated. When the tones with two frequencies that are close together are combined, the envelope of the peaks of combined tones can increase and decrease over time. For example, the illustration below depicts the result of combining a 280 Hz tone with a 300 Hz tone.



The gradually changing amplitude of the waveform of the combined tones is perceived as a pulsing sound. These pulses are known as *beats*, because they result from the amplitudes of the two tones beating against one another.

Exploration 4.6 Complex Waveforms. Explore the effect of combining different tones with similar frequencies. When the tones are only separated by two or three cycles per second, how does this affect the perceived sound? When the tones are separated by 15 or 20 cycles per second, how does this affect the perceived sound?