Tool Kit VI
Electrical Oscillation – Making Sound from Electrons

Objective

Investigate how the creation of oscillations in electrical energy can be used to create audible sound via a transducer and how amplitude is related to voltage. Explore the basic principles of square and sine waves as well as the compound waves that are more commonly found in nature. Understand the basic concepts of binary computation and the way in which binary "digital" systems, or bits, are used to create audible sound.

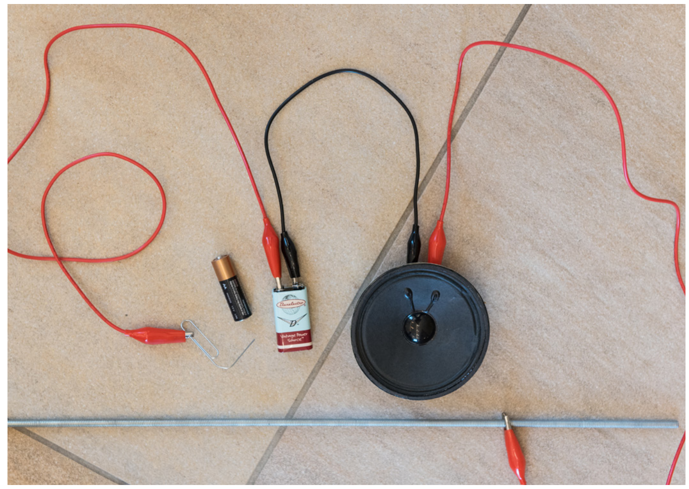
Materials

- Small speaker (such as can be salvaged from old computer monitors, car stereos, or old home entertainment systems)
- 9-volt battery
- 1.5-volt battery (AA, AAA, C, or D)
- 3 wires with alligator clips on each end
- 12-inch threaded rod
- Paper clip

Background Information for Educators

An **oscillator** is anything that creates a regular variance in electrical energy. A light switch is a very simple oscillator. Placed in a **circuit** (e.g., loop) between a light bulb and an energy source, the light switch can create an **oscillation** between a light being "off" or "on." In this case, the light bulb is a **transducer** that converts **electrical energy** to **radiant light energy**. If we wanted to convert these electrical oscillations to **sound energy**, we would need another type of **transducer**: a **speaker**.

The **speaker** responds to the **oscillation** (e.g., variance) in electrical charge by moving up or down. This up-and-down motion creates **sound waves** that our ears can process as sound. The faster the oscillation in the electrical charge, the faster the speaker will move up and down, resulting in a sound wave of higher **frequency**. If the electrical oscillation is slow, the resulting speaker movement will also be slow, resulting in a sound wave of low **frequency**.



Simple circuits including batteries and speakers demonstrate how sound is created from electrical oscillation.

Activity

How does an oscillator work?

Investigate

Present students with the components of a simple circuit composed of the speaker, two wires with alligator clips, and a battery.

A. ***What happens to the speaker when you complete the circuit by using the alligator clips to connect the speaker to the battery?*** The speaker moves either in or out in response to the electrical charge.

> NOTE: Leaving a speaker continuously connected to a continuous electrical charge can result in speaker burnout. Complete the circuit just long enough to see how the speaker moves.

B. ***How does the direction the speaker moves change depending on the direction (+ to -) that the battery is connected to your circuit?*** The direction the speaker moves is in response to the direction (e.g., polarity) of the electrical energy. For example, if the speaker moves outward when it is connected to the battery, you reverse the direction of the battery in your circuit to make it move inward. The polarity of your electrical charge does not matter for the purposes of this experiment.

Speakers vibrate in response to a varying electrical charge.

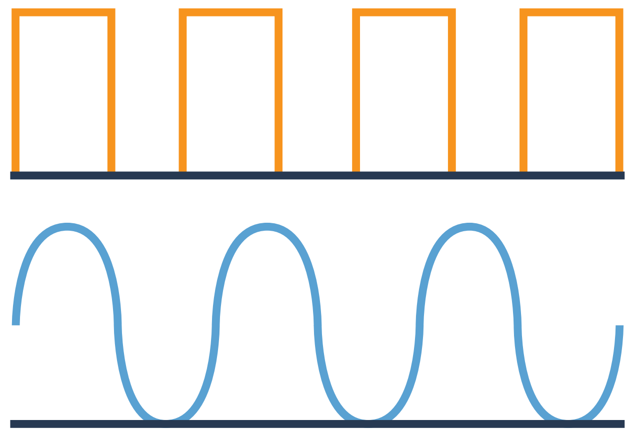
C. ***How does the speaker move differently when connected to the 9-volt battery as compared to the 1.5-volt battery?*** In very simple terms, the higher-voltage battery causes the speaker to deflect/move more than the lower-voltage battery. Speakers being powered by higher voltages can produce sound waves of greater amplitude (loudness) than speakers powered by lower voltages. In simple terms, the volume buttons on your electronic music player increase or limit the available voltage to the speaker, which then directly affects the amplitude of the sound waves it can produce.

Create

Present students with the threaded metal rod and paper clip. Attach the threaded rod to the speaker using one of the cables. Using a second cable, attach the other side of the speaker to the battery. Using the third cable, attach the other side of the battery to the paper clip.

D. ***What happens when you run the paper clip along the length of the threaded metal rod?*** The threading on the rod momentarily "breaks" the circuit created between the battery and the speaker, creating a fast oscillation between the electrical circuit being complete or broken. This is just like flipping a light switch on or off very quickly.

E. ***What happens when you run the paper clip along the metal rod quickly? Slowly?*** The speed at which you run the paper clip along the threaded metal rod will affect the frequency of the wave being created by the speaker. Running the paper clip faster, turns the energy on and off more frequently, which in turn causes the speaker to create a sound wave of higher frequency. Running the paper clip slower turns the energy on and off with less frequency, in turn causing the speaker to create a sound wave of lower frequency. The sound wave being created here is what we call a square wave. A square wave is a wave that is abruptly either "on" or "off" and can be seen illustrated in orange below.

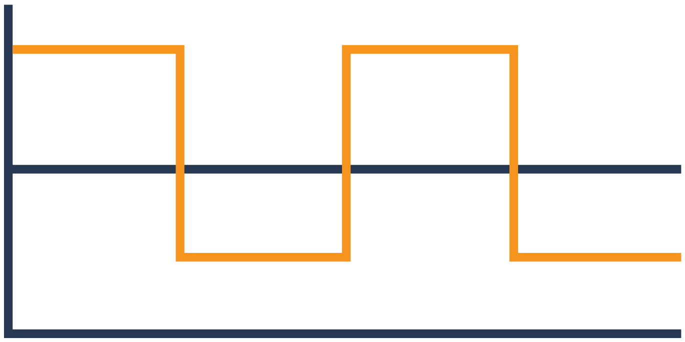


The abrupt angles of the square wave refer to the instantaneous nature of an electrical circuit being connected or disconnected, the power being turned on or off. The greater the amplitude of the wave, the more energy or voltage the wave will carry, and the more it will cause a speaker to move up and down.

Computers can oscillate between the power being on or off extremely quickly. This ability to oscillate only

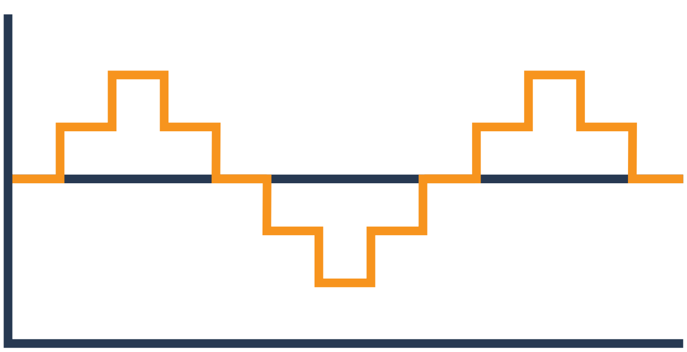
Electronic devices, from phones and computers to theremins and synthesizers, all create sound by sending an oscillating electrical current to a speaker.

between on or off is what we call a binary system, and binary systems are the foundation of modern computers. Computers literally switch between the power being on or off in order to perform all of their functions. The type of oscillation done by computers is known as digital oscillation.



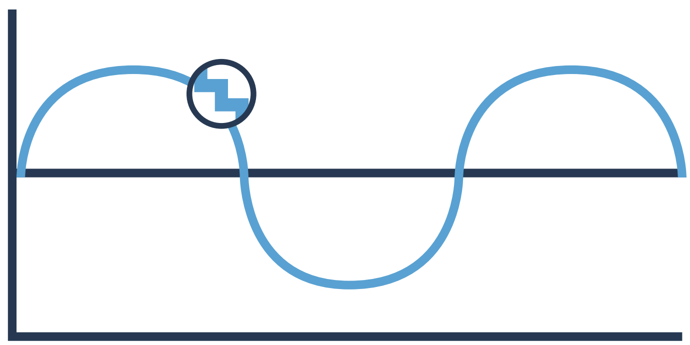
1-bit

Unlike the square waves created by the oscillation of an electrical circuit between on and off, the types of sound waves created by most acoustic or analog instruments are typically not so abrupt in nature. A sine wave oscillates between high and low energy more gradually, as seen in the distinctly curved wave illustrated in blue. In order for a computer to reproduce the sound wave that we might hear as typical of an acoustic instrument, it must not only oscillate between on and off, but also oscillate the amount of electrical energy being delivered to a speaker. Computers do this by breaking down the sound wave into individual variables we call bits. A simple square wave, such as the one we produce with a battery and a speaker, has only one variable, being either "on" or "off." We call this a bit rate of 1. As we increase the bit rate to include variation in the amount of energy being delivered to a speaker, the bit rate will increase. The closer the binary



2-bit

system comes to mimicking the natural curve of the sine wave, the less computer-like it will sound. We can observe this by looking at graphs of sound waves of differing bit rates. We can also hear the differences. A 1-bit sound, such as that made by our simple battery and speaker, is distinctly electronic-sounding; a 4-bit sound, such as that commonly used in many old video games, is distinctly computer-like. A 16-bit sound (or higher!) is common to compact discs and MP3 players and is comparatively more similar to the sound of an acoustic instrument. You can see how the graphic representation of the wave appears more "smoothed out" than the lower bit rate examples, and yet, if we were to look closely, we would still see the stepwise character of a sound wave being divided into multiple discrete variables. An acoustic instrument oscillates with perfect smoothness naturally. To achieve such oscillations from electronic sources requires complex circuitry. The conversion of electronic bits into audible sound is called digital-to-analog conversion.



16-bit

Assessment

Formative

Students will demonstrate their conceptual understanding of electrical oscillators and binary systems by creating a simple circuit and demonstrating how a speaker interacts with a source of electrical energy (battery) to create both low and high frequency sounds. Students will also demonstrate how the amount of electrical energy (voltage) affects this interaction.

Summative

Students will explain how the oscillation of electrical energy creates sound. Students will also explain the basic functions of a binary system, including how the bit rate of such a system affects the resulting sound it can produce.

Activity on your visit to MIM: Try to play the theremin.

The theremin relies completely on electricity to produce sound. It utilizes a loudspeaker connected to an oscillating system and amplifier that are all plugged into an electrical outlet. The oscillators provide a source of repetitive, alternating currents of electrical energy. The theremin creates a small electrical field surrounding each of its antennas just like a small radio broadcaster. The player disrupts these fields due to the electrically capacitive nature of the human body. In essence, you become a part of the electrical circuit of the theremin. The closer your hand is to the straight antenna determines which frequency, or pitch, is heard, while the closer your hand is to the looped antenna controls loudness, or amplitude.

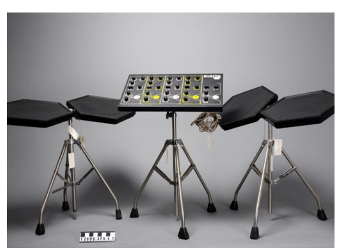
Collection Connection: Clara Rockmore and the Theremin

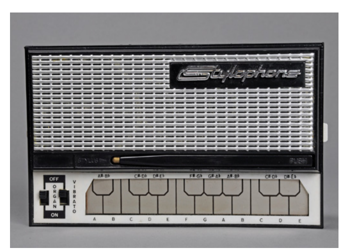
The theremin was invented by Russian scientist Léon Theremin and patented in 1927 in New York. It was there that he met Clara Rockmore, who soon established a successful career as a concert soloist on the theremin. MIM is proud to display the very instrument Léon Theremin built for her.

Collection Connection: Synthesizers

The theremin is not a common instrument today, but it influenced generations of electronic musical instruments. The theremin was one of the first electronic synthesizers (e.g., instruments that make sound using only electronics) that was ever built. MIM has numerous other synthesizers on display, including the Moog, Hammond organ, Elsita drum machine, and Oberheim. Some synthesizers, such as the Hammond organ or the Moog, use what appears to be a normal piano keyboard to control the sounds. Others, such as the theremin, Elsita, or Stylophone, use something different. MIM's collection of synthesizers can be found spread around the United States / Canada Gallery as well as the Artist Gallery. Regardless of how the synthesizer is controlled, it makes its sound using the oscillation of electrons.

The theremin is a historic example of an electronic synthesizer.





MIM displays musical synthesizers of all types.

Additional Resources

Up Close with a Curator: Theremin

Theremin Virtuosa Clara Venice Speaking at TEDxVaughan 2016

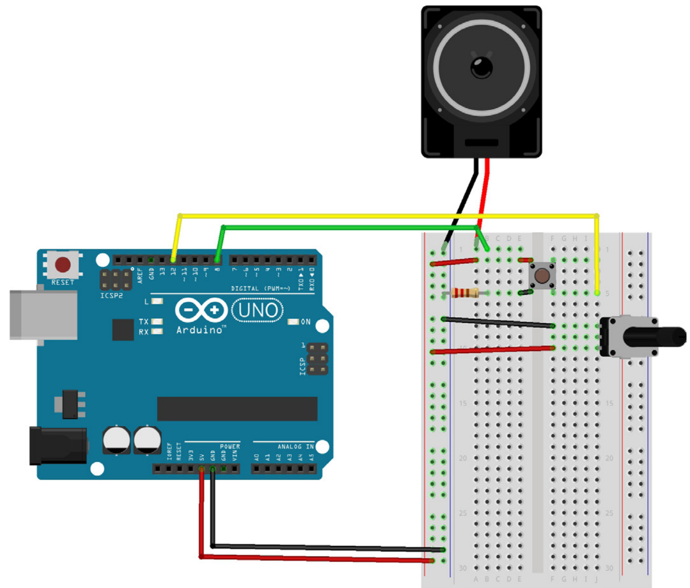
Online Activities Exploring the Intersections of Math, Science, and Music

Arizona State University's Consortium for Innovation and Transformation in Music Education (CITME) Curates Numerous STEM/STEAM Music Education Resources

Extensions

There are numerous resources available online to help educators introduce principles of electronic sound synthesis to students, including principles of electrical engineering and computer programming.

- Fritzing is a free program that facilitates circuit design and computer programming in a fun virtual environment.
- The Arduino microcontroller can facilitate hands-on experimentation with circuit building, computer programming, and design. The "tone" function is a great introduction to digital synthesizer circuits.
- The littleBits Synth Kit is a user-friendly device for creating analog musical synthesizer circuits.



Simple musical synthesizers can be constructed from simple circuits. Software programs such as Fritzing enable users to create such circuits virtually using a computer.