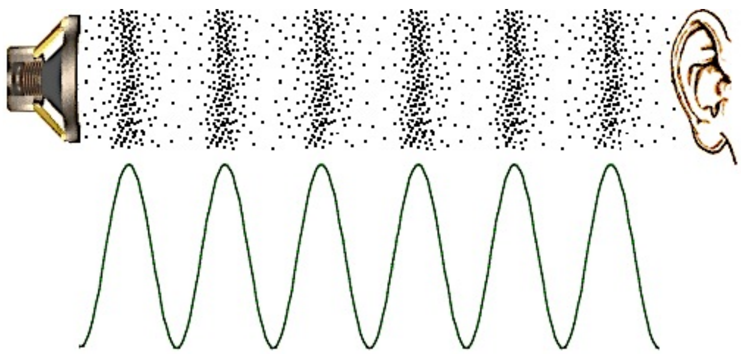
The Properties of Sound

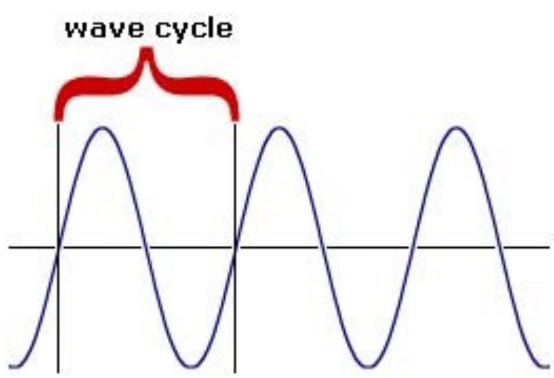
Sound Waves

When force is applied to a sound source it creates a change in atmospheric pressure. For example, if a guitarist plucks a guitar string, the vibration of the string causes changes in the atmospheric pressure in the form of vibrational disturbances. These vibrational disturbances are called ***sound waves*** and are transmitted as alternate compressions and rarefactions of the atmosphere's molecules.



Ex. 1

One single occurrence of the air molecules' compression and rarefaction is known as a ***cycle*** (or ***wave cycle***). A graphic representation of a cycle helps visualize how the oscillation of air molecules occurs both above and below the central axis of the sound wave. The example below shows how a waveform is graphically represented in a digital-audio wave-editing tool such as ***Audacity***:

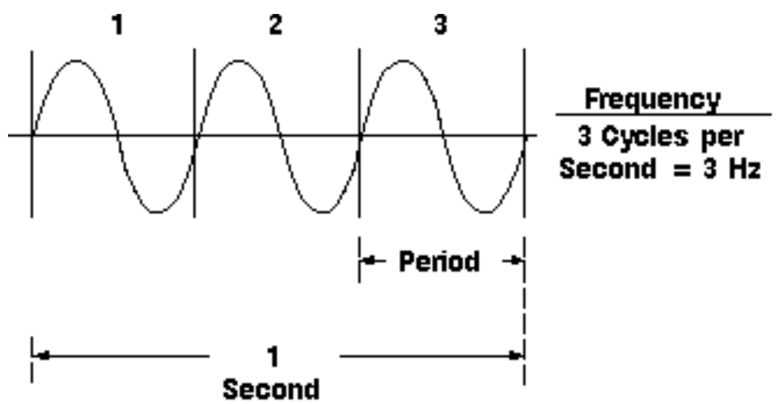


The Four Properties of Sound

The sounds we perceive in the world around us possess, in varying degrees, four unique properties. The variance of these four properties in one sound to the next is what makes, for example, a flute sound different from a violin.

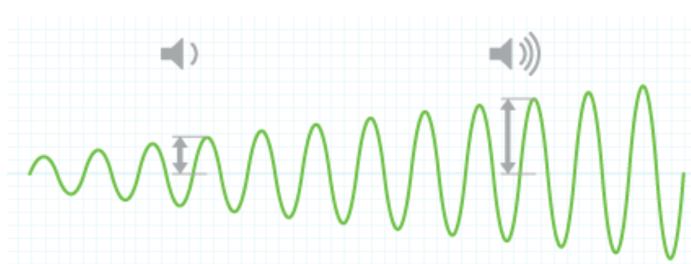
Pitch

There are a few important terms used when discussing the 'highness' or 'lowness' of a sound. ***Pitch*** is the term used to describe the 'highness' or 'lowness' of a sound. The pitch of each individual sound is measured by its number of wave cycles (or vibrations) per second. ***Frequency*** is the term used to describe the number of wave cycles that occur within one second. ***Hertz (Hz)***, a term named after the German physicist Heinrich Hertz, is the scientific unit of measurement for frequency vibration.



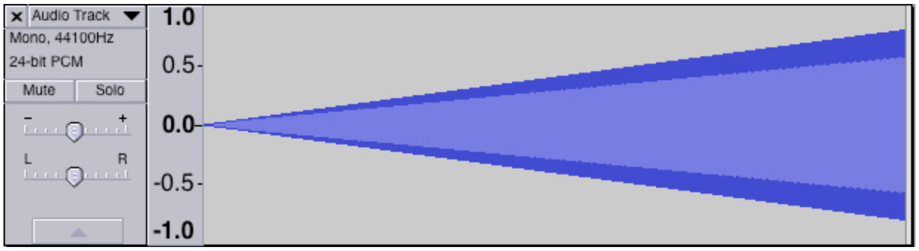
Intensity

Sound also has a perceived level of softness or loudness. ***Intensity*** is the term that describes the softness or loudness of a sound. When described in terms of a scientific measurement, a sound's intensity is referred to as ***amplitude***. The ***amplitude*** of a sound is measured in decibels (***dB***). A ***decibel*** is a logarithmic unit named after the inventor Alexander Graham Bell. The decibel measurement labels the *relative* amplitude of a sound's intensity.



Ex. 2

Wave Editor Representation of Amplitude in Decibels

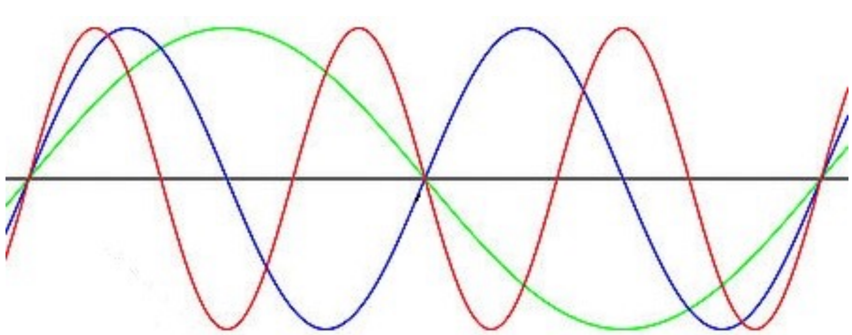


Timbre

The unique tone quality that distinguishes one sound from another is called ***timbre.*** Timbre is the 'brightness' or 'darkness' of a sound's tone quality. Timbre is a result of the number and intensity of a sound wave's secondary vibrations. To clearly understand timbre, we must take a closer look at a sound wave's secondary vibrations, or ***overtones***.

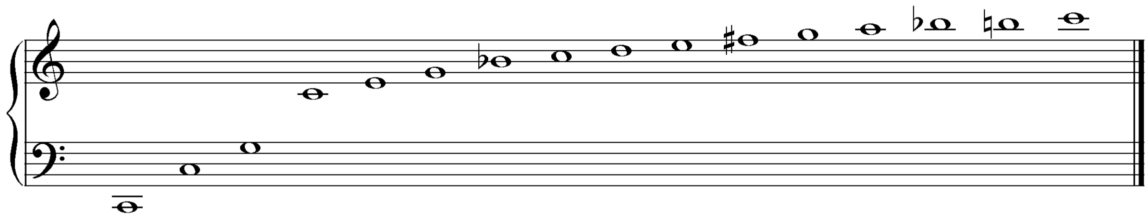
When energy is produced from a sound source, a sound wave is generated in the atmosphere. Because of the repercussions and 'spring-like' action of the sound wave's impact, secondary sound waves are generated. Imagine tossing a large stone into a still, standing pool of water. At first, you will notice that waves are generated outward from the point of impact. However, upon further observation, you will see many tiny ripples of water within the larger, original waveforms. This phenomenon is also true with sound waves. As we first listen to a sound, we will perceive the primary sound wave's frequency called the ***fundamental*** tone. However, there are also secondary vibrations that generate from the fundamental tone. These secondary vibrations are called ***harmonics*** or ***overtones***. ***Harmonics***, or ***overtones***, are a complex of pitches resulting from secondary vibrations along various points of the sound source's length.

A Fundamental (*green*) with Its Secondary Vibrations (*red* and *blue*)



The ***harmonic series*** is the number, distribution, and intensity of harmonics (***overtones or partials***) that occur above the fundamental tone. In the example below, the fundamental is the lowest note. Timbre is simply a result of the series of harmonics or overtones generated by the fundamental tone.

The Harmonic Series



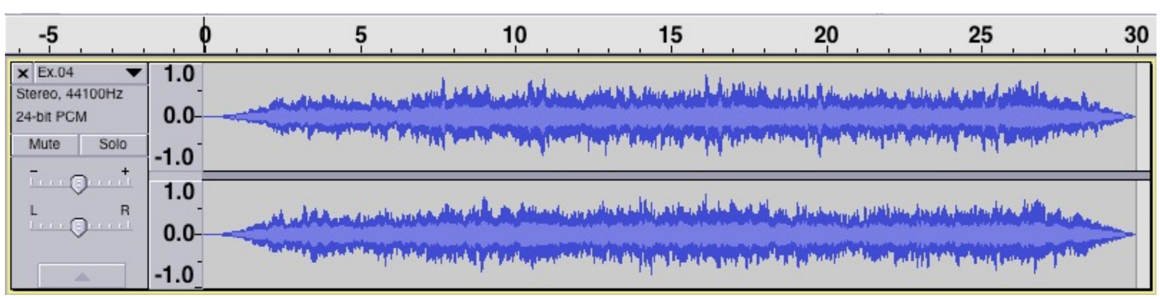
Ex. 3

In summary, a ***partial*** is any one of the harmonics generated by a primary or secondary vibration of the sound wave, the ***fundamental*** is the lowest partial in the harmonic series (i.e., the most prominent pitch as perceived by the listener), and an ***overtone*** or ***harmonic*** is any partial in the harmonic series except the fundamental.

Duration

A final sound property to be discussed is the ***duration*** of the sound. The duration of a sound is its length as measured in minutes, seconds, or any fraction thereof. All digital audio tools provide these various types measurements in their user interfaces.

A Sound Wave with Its Corresponding Timeline in Seconds

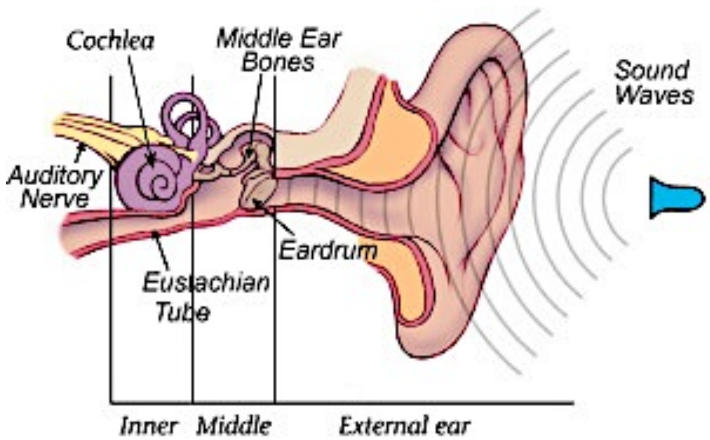


Ex. 4

The Process of Hearing Sound

To better understand some of the processes involved in digital audio, it is important to take a brief look at exactly how humans receive auditory information through the ears.

Anatomy of the Ear



When sound waves reach the ear, the ***eardrum*** (***tympanic membrane)*** begins to vibrate. This causes the three ***middle ear bones*** (the ***malleus, incus,*** and ***stapes)*** to pass the vibrations through a snail-shaped, fluid-filled structure in the inner ear called the ***cochlea*.** Then, the vibrations excite hair cells located on the basilar membrane of the cochlea. These vibrations generate a nerve impulse in the ***auditory nerve***. The nerve impulse is then sent to the brain and is perceived as pitch, intensity, timbre, and duration. It is important to remember that humans can only hear sound waves with frequencies between 20 and 20,000 Hz. Understanding this information allows musicians and sound designers to make important decisions during the audio production processes.

Analog to Digital Conversion

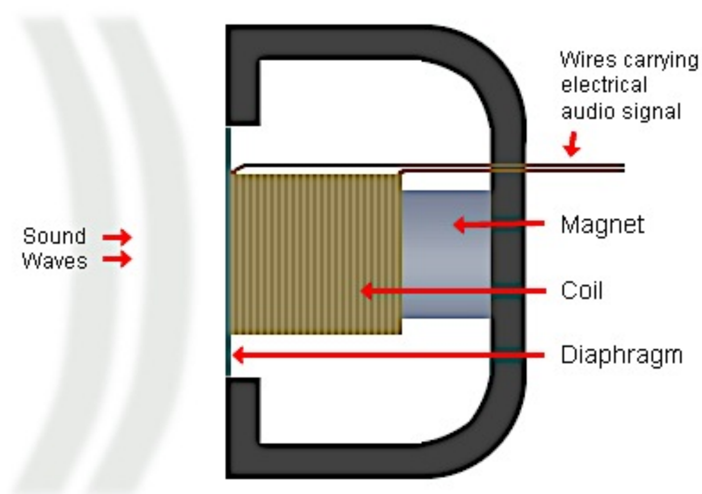
Musicians and sound designers employ a variety of methods to create soundtracks for animations, live action films, and games. One method may be running live recording sessions to capture the music and sound effects. Another method may be the manipulating and editing of pre-recorded sounds from a professional sound library. Regardless of the method used, a good, basic understanding of how live sound is captured and converted to digital audio is extremely important. So far, we have explored the fundamentals of the sound wave and its behavior in an acoustic environment. Now, it is time to delve into ***analog audio***, ***digital audio***, and the ***analog to digital conversion process*** (***A/D***) that allows musicians and sound designers to sculpt their custom sounds.

Analog and Digital Audio

When the sound waves travel through the atmosphere into a microphone and then, into a recording device, the sound waves are first captured as ***analog audio***. Analog audio is the representation of sound through electrical impulses that is *analogous* to a sound wave. The next step is to convert the analog audio to ***digital audio***. Digital audio is the reproduction and transmission of sound stored in a digital format consisting of binary code (ones and zeros). Therefore, ***analog to digital audio conversion*** is the process of capturing and converting sound energy from electrical impulses into a digital format. The following information outlines the lifecycle of the audio signal beginning with its generation from the initial sound source.

1) First, the sound source creates energy that travels as sound waves. The sound waves are then received through a microphone and converted into electrical energy:

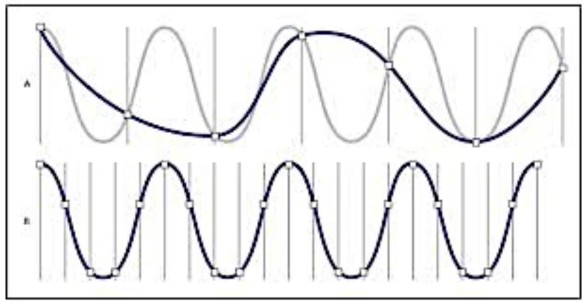
Cross-Section of Dynamic Microphone



2) Then, the electrical signal is processed with a ***low pass filter*** to eliminate any unwanted/unnatural high frequencies.

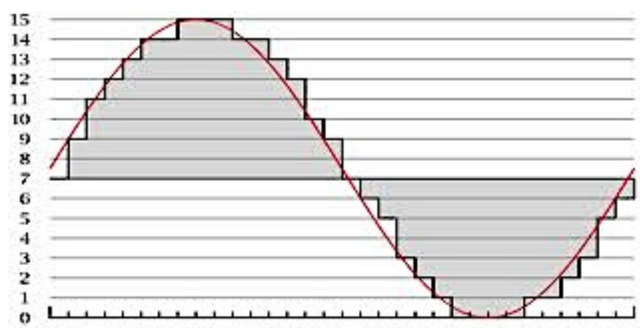
3) Next, the analog to digital converter (***A/D***) analyzes the analog signal and samples the sound wave. A ***sample*** is a 'sonic snapshot' of the audio signal being captured. The greater the number of samples captured (***sample rate),*** the more accurate the overall 'sonic snapshot' will be. The outcome of a larger sample rate will be a cleaner, more noiseless sound quality. The standard sample rate for CD quality is 44.1kHz or 44,100 times per second however, most professional musicians and sound designers work with a 48kHz sample rate (48,000 times per second).

Sample Rate
(low sample rate vs. high sample rate)



4) While the ***A/D*** converter is sampling the analog signal, it also analyzes the amplitude of the waveform (or its ***bit depth resolution***). The standard ***bit depth*** for CD quality is ***16-bit*** resolution (In professional audio production, 24-bit recording is the standard bit depth resolution). However, in final audio renderings, 16-bit is often the choice used in the final deliverable format. In summary, the greater the bit depth, the more accurate the conversion of the waveform's amplitude will be. Simply put, the larger the sample rate and bit depth resolution, the clearer and more noiseless the digital audio will be.

Bit Depth Resolution



5) Next, the digital information is then ***quantized*** (or 'rounded off') and stored as binary code.

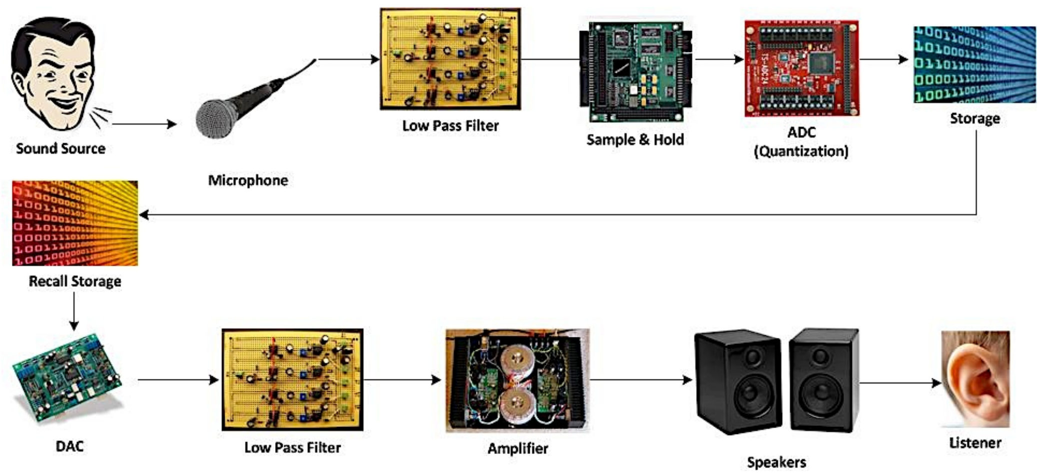
6) When the information is retrieved for playback, the ***A/D*** conversion process is reversed.

7) The binary code is processed, converted back to electrical impulses (***D/A***), receives additional processing through a low pass filter, and sent through the amplifier.

8) The audio signal receives a boost in amplitude by the ***amplifier*** that causes the electric impulses to vibrate the surface area of the ***speaker diaphragm***.

9) The vibrating speaker diaphragm creates alternate compressions and rarefactions of the molecules in the atmosphere. The oscillation of air molecules generates sound waves that are then sent to the listener's ears.

The Analog to Digital Audio Conversion Process

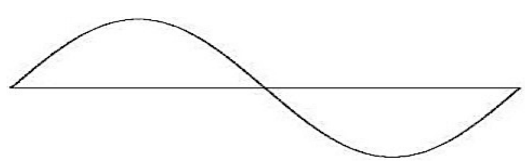


Types of Waveforms

Many of the sounds created in the early history of electronic music and video games used very basic waveforms. These waveforms were originally generated artificially through vacuum tube oscillators, transistors, and later by microprocessors. The following basic types of waveforms were among the first sounds heard in the early days of game audio and are still considered fundamental in crafting more sophisticated, modern-music compositions, and sound effects.

Sine (or Pure Tone) Wave

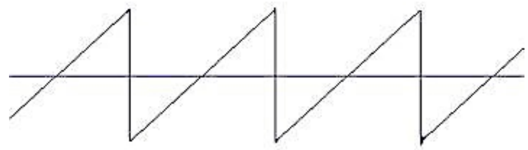
The ***sine wave (or pure tone***) is a waveform with only one frequency (the fundamental) and no overtones. In early game music, sine waves were frequently used for sound effects such as lasers and alarms. Sine waves were also commonly used as flute-like sounds in upper or lower melodic passages.



Ex. 5

Sawtooth (or Ramp) Wave

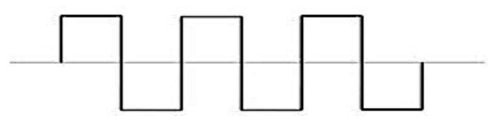
A ***sawtooth (or ramp) wave*** is a waveform that uses a combination of both odd and even overtones. Sawtooth waves are frequently used for melodic bass lines and have a mixture of raspy, warm, and round timbre qualities.



Ex. 6

Square (or Pulse) Wave

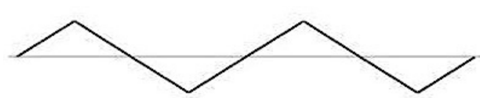
The ***square (or pulse) wave*** is a waveform with only odd overtones. Square waves are frequently used for a variety of melodic lines. Depending on the intensity of overtones, the square wave can sound fat, thin, raspy, or hollow.



Ex. 7

Triangle Wave

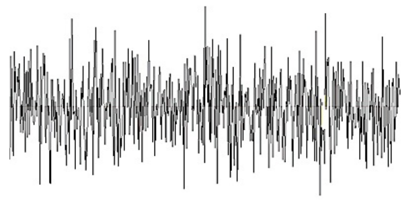
A ***triangle wave*** is a waveform with odd overtones that diminish faster than a square wave's overtones. Triangle waves are frequently used for a variety of melodic lines that require a smooth, round timbre quality.



Ex. 8

White Noise

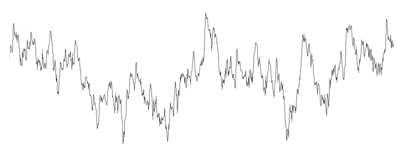
White Noise is a waveform that contains every frequency within the range of human hearing in equal amounts. White noise was often used as a percussive effect (e.g., the cymbal) in early game music. In traditional sound design, white noise has been used for sound effects such as radio static or windstorms.



Ex. 9

Pink Noise

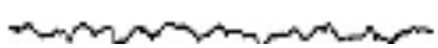
Pink Noise is a variation on white noise. Pink noise is filtered to reduce the amplitude of selected higher frequencies. In sound design, pink noise is sometimes used as a substitute for the sound of a waterfall. In early game music pink noise was also used as a percussive effect (e.g., the snare drum).



Ex. 10

Brown Noise

Brown Noise is a variation on white noise. Brown noise is filtered to reduce the amplitude of most of the higher frequencies. Brown noise is often used as an enhancement and reinforcement in explosive sound effects and percussive effects such as the kick drum.



Ex. 11