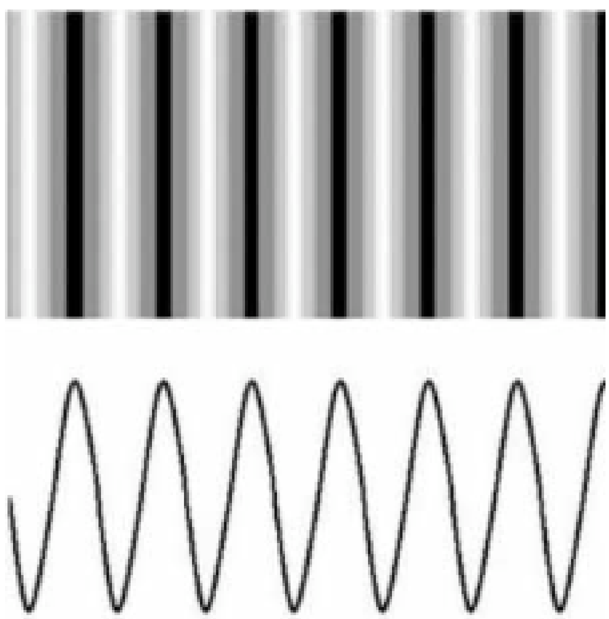
Sound & Waveforms

Sound is a waveform in matter

Sound is a waveform that travels through matter. Although it is commonly associated in air, sound will readily travel through many materials such as water and steel. Some insulating materials absorb much of the sound waves, preventing the waves from penetrating the material.

Sound is a compression wave

The back-and-forth vibration of an object creates the compression waves of sound. The motions of a loudspeaker cone, drumhead and guitar string are good examples of vibration that cause compression waves.



Definition of wave motion

Wave motion is defined as the movement of a distortion of a material or medium, where the individual parts or elements of the material only move back-and-forth, up-and-down, or in a cyclical pattern.

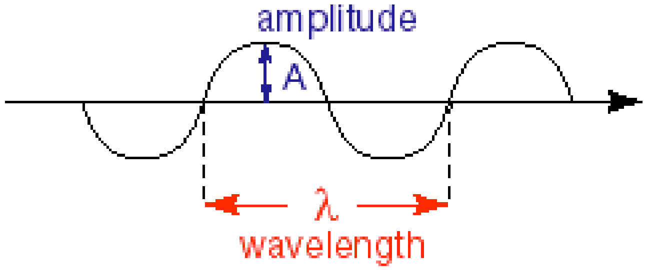
It appears as if something is actually moving along the material, but in reality it is just the distortion moving, where one part influences the next.

Characteristics of sound

A sound wave has characteristics just like any other type of wave, including amplitude, velocity, wavelength and frequency. In musical terms, velocity is constant (the speed of sound), and the wavelength and frequency are the same thing, we can just focus on **Amplitude** and **Frequency**. **Timbre** is a third characteristic that is simply a combination of frequencies at different amplitudes. We will explore these three characteristics of sound individually below.

Amplitude (loudness)

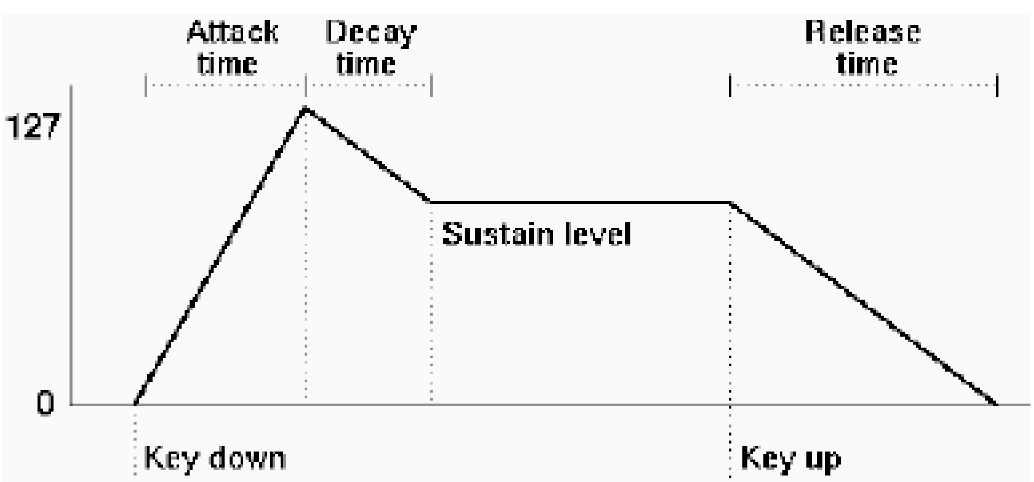
The amplitude of a sound wave is the same thing as its loudness. Since sound is a compression wave, its loudness or amplitude would correspond to how much the air is compressed. Drawn on a graph, the taller the waveform is, the higher the amplitude.



Amplitude Envelope

In electronic music, amplitude is most often thought of in terms of an amplitude envelope which shapes the volume of a note over time. An **ADSR envelope** is the most common type of amplitude envelope. It stands for **A**ttack, **D**ecay, **S**ustain, **R**elease. Synthesizers will usually have an ADSR envelope attached to each tone, that you can program.

- **Attack** - begins at the Note On. The volume starts from 0 to the maximum.
- **Decay** - the volume drops from the maximum value to a level called "Sustain level"
- **Sustain** - the volume remains constant until the key is depressed (Note Off).
- **Release** - the volume drops to zero



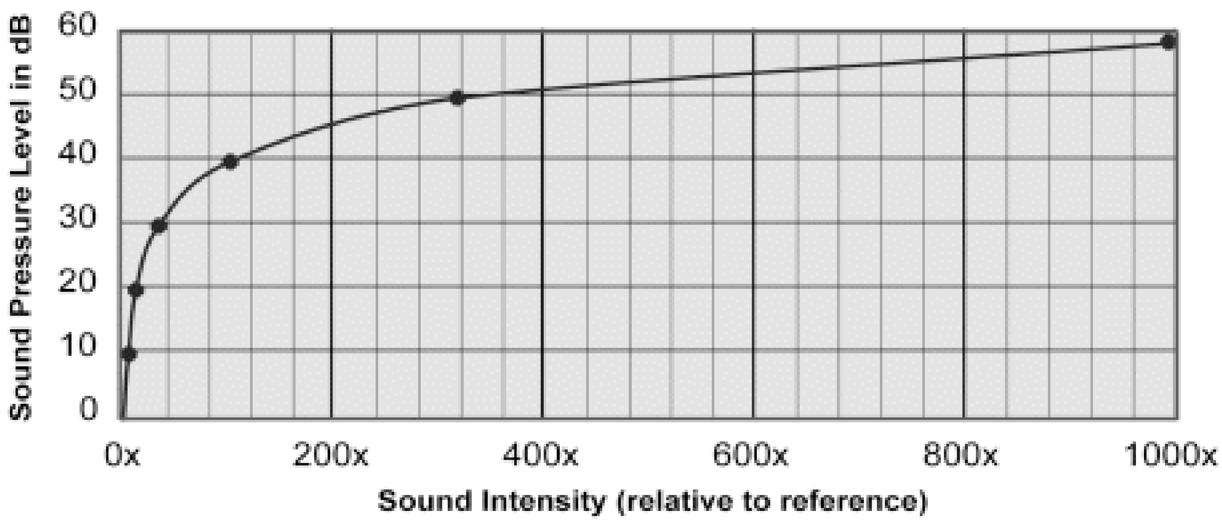
Decibel

A common measurement of loudness is the decibel (dB). It is really 1/10 of a bel, which was named after the inventor of the telephone, Alexander Graham Bell. It is a complex unit that varies as the ratio of the logarithms of loudness.

One decibel measures the very limit of human hearing, the threshold point where sound can be detected by the ear and recognized by the brain. The noise produced by a single leaf falling to the ground is a single decibel.

Our ability to hear spans an enormous range of pressure amplitudes - a vary large dynamic range. A logarithmic response helps to compress this range so that our response to variations in weak sounds is similar to the response to variations in loud sounds.

Relationship of sound pressure level (perceived loudness) to sound intensity



The human hearing system has a dynamic range of about 120 dB between the threshold of hearing and threshold of pain. A fighter jet at takeoff may produce 120 decibels. The difference in intensity between that and a falling leaf is an unbelievable trillion times, but is perceived as 120 times as loud by the human ear.

Type of Sound	**Intensity**	**Perceived loudness in dB**
Rustle of leaves	10	10
Whisper	100	20
Soft conversation	1,000	30
Average residence	10,000	40
Average office	100,000	50
Telephone conversation	10,000,000	70
Heavy traffic	1,000,000,000	90
Subway traffic	10,000,000,000	100
Airplane engine	1,000,000,000,000	120

Frequency (Pitch)

Hertz

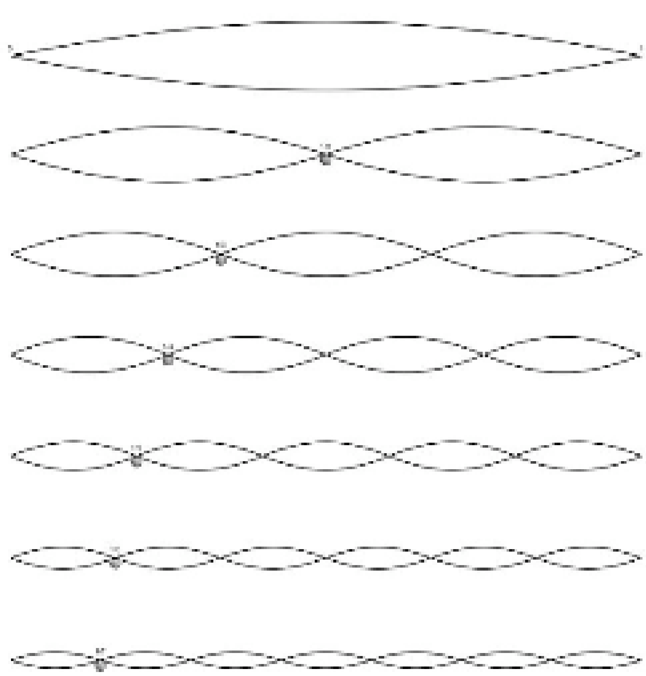
Each repetition of a wave is called a cycle. The **frequency** is the number of **cycles per second**. For example, when a tuning fork sounds the note A4, its tines vibrate 440 times per second. Its frequency is 440 cycles per second, which is usually written as 440 **Hertz** or 440 **Hz**.

Cents

Pitch differences depend on the ratio of frequencies. If the frequency is doubled (2/1), we hear the pitch rise by an octave. If it increases by a factor 3/2, the pitch rises by a fifth. The higher the frequency is, the higher the pitch. However, we do not hear pitch linearly, just as we do not perceive loudness linearly. For this reason, in electronic music the scale of **cents** is often used instead of Hertz because it is easier to think about. **100 cents equals a half step**, and **1200 cents equals an octave** (because there are 12 half steps in one octave).

Harmonic series

In nearly every musical instrument, the fundamental note is always accompanied by other, higher-frequency tones that are generally called overtones. In pitched instruments, these shorter, faster waves are reflected between the two ends of the string or air column. As the reflected waves interact, frequencies whose wavelengths do not divide evenly into the length of the string or air column are suppressed, and the vibrations that persist are called harmonics. Their wavelengths are 1, 1/2, 1/3, 1/4, 1/5, 1/6, etc. of the length of the string or air column.

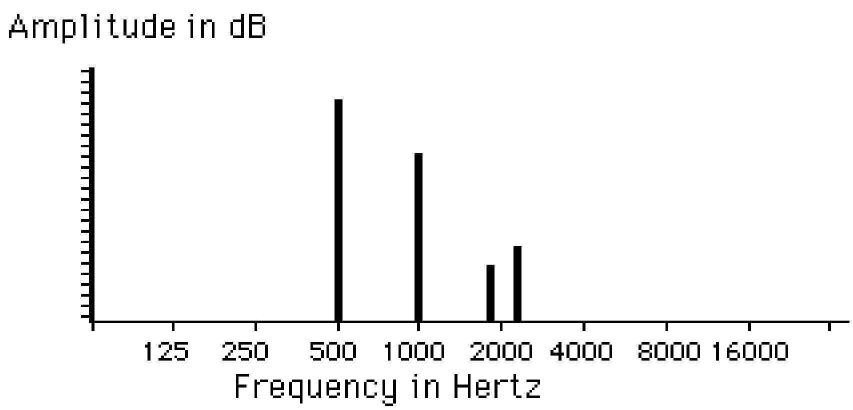
	Theoretically, these wavelengths produce vibrations at frequencies that are 2, 3, 4, 5, 6, etc. times the fundamental frequency. In terms of frequency (measured in cycles per second, or hertz (Hz)), the difference between consecutive harmonics is therefore constant. But because our ears respond to sound logarithmically, we perceive higher harmonics as "closer together" than lower ones. In the same sense, the octave series is an exponential progression (2xf, 4xf, 8xf, 16xf, ...), and we hear these distances as "the same" in all ranges.

Timbre (tone quality)

Timbre is the quality of a musical note or sound that distinguishes different types of sounds, such as voices or different musical instruments. The physical characteristics of sound that mediate the perception of timbre include the **spectrum** (the set of frequencies at specific amplitudes) and the **amplitude envelope**.

Spectrum

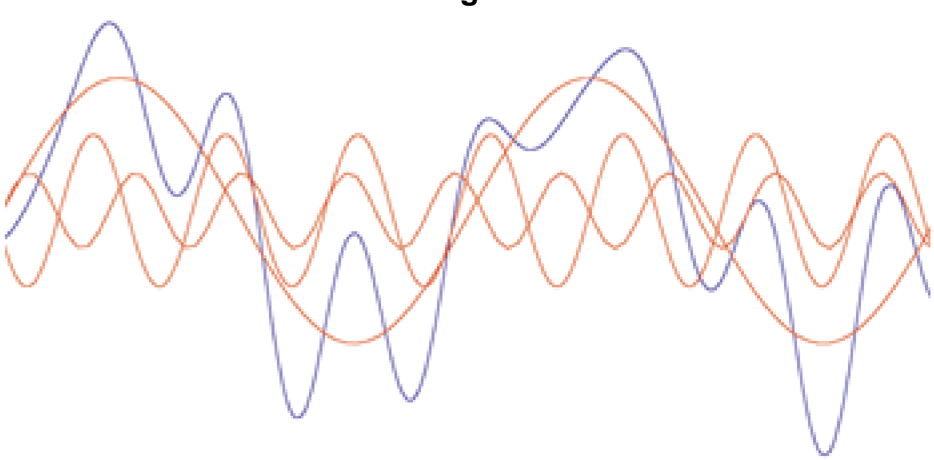
The **spectrum** of a sound refers to the specific **frequencies (sine waves)** that make up the sound and respective **amplitude** of each one. The graph of a spectrum is usually shown in this form:



In this case, the **fundamental frequency** is 500 Hz, with the first harmonic (1000 Hz) and two harmonics above that. The fundamental is usually the loudest, and is the pitch that you hear. The harmonics above the fundamental are what give the sound its **tone quality**, or **timbre**.

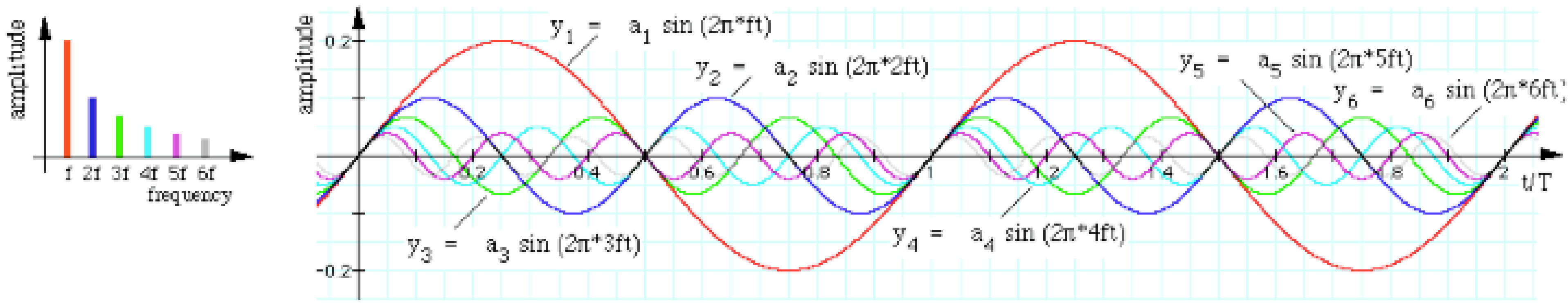
Adding sine waves

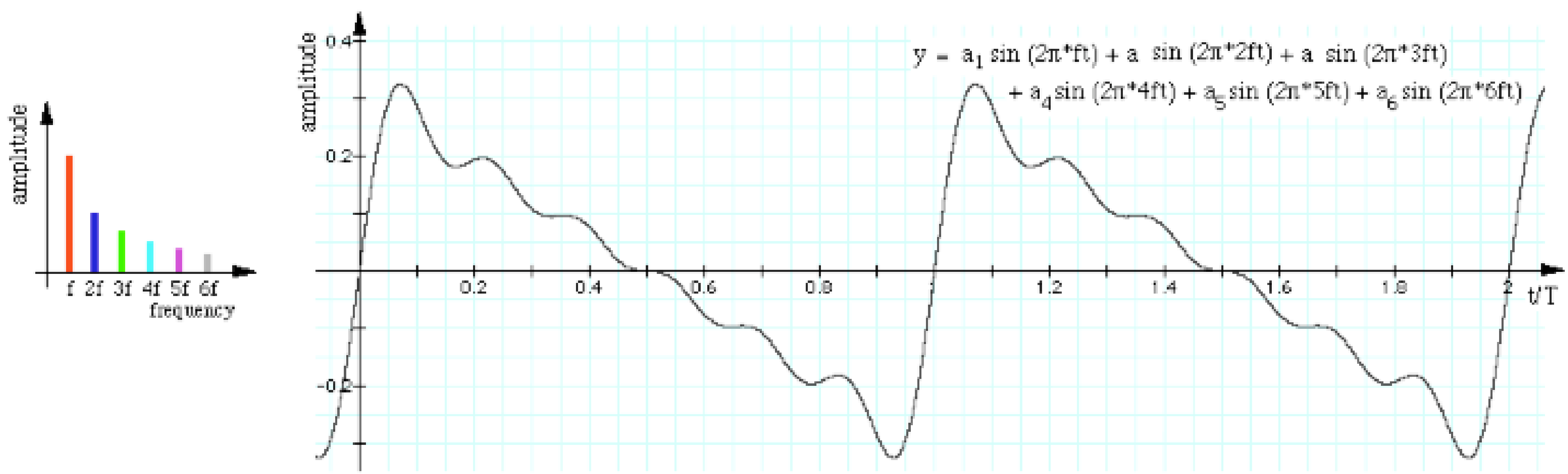
Another way to view this is to look at the individual harmonics and to view the more complex waveform that is created when they are added together. Below, three red sine waves are added to create the blue sine wave. In this case, the biggest red sine wave is the **fundamental**, which **is the pitch that you perceive**, and the two softer (shorter), higher (narrower) sine waves are two **harmonics** that **give the waveform it's character.**



Creating a sawtooth wave with additive synthesis:

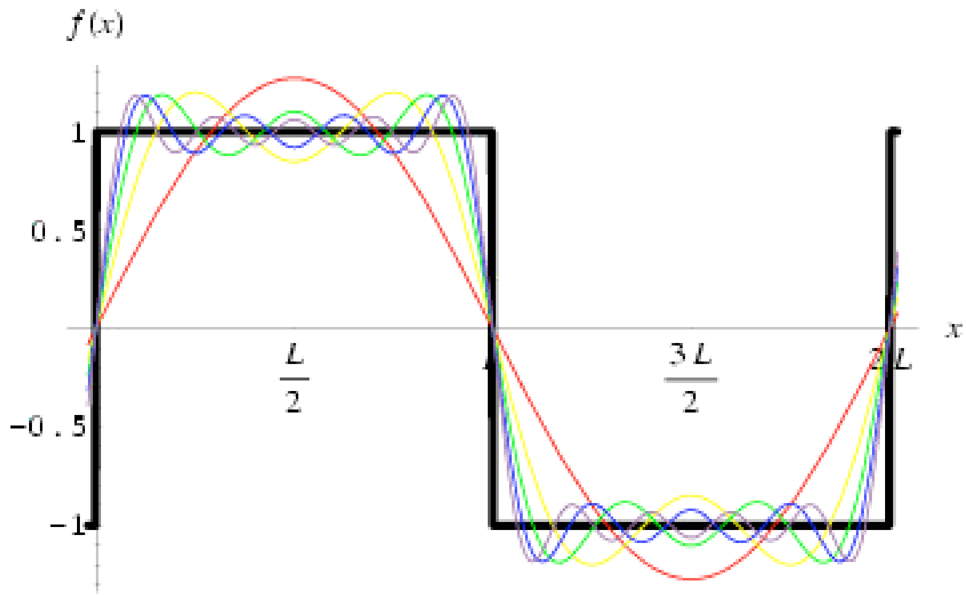
The graphs with colored vertical lines on the left represent the first six harmonics, decreasing in amplitude. This is just another way to represent the individual colored sine waves below, and it also represents the sawtooth wave shown in black. When the sine waves are added together they create a sawtooth wave. As more and more higher harmonics are added, a more accurate sawtooth wave is created. In summary, sawtooth waves are comprised of both even and odd harmonics, decreasing in amplitude for higher harmonics. The "spectrum" of the waveform can be depicted as straight lines showing the frequency and amplitude of each component sine wave.





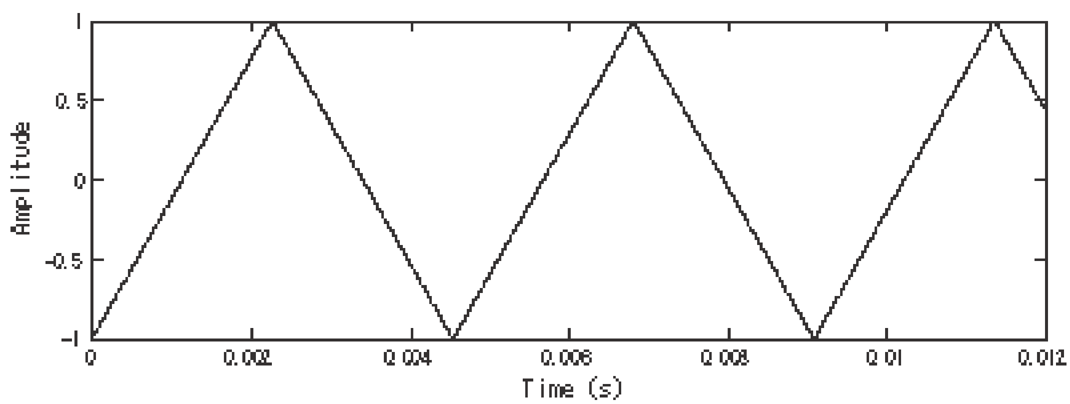
Square wave

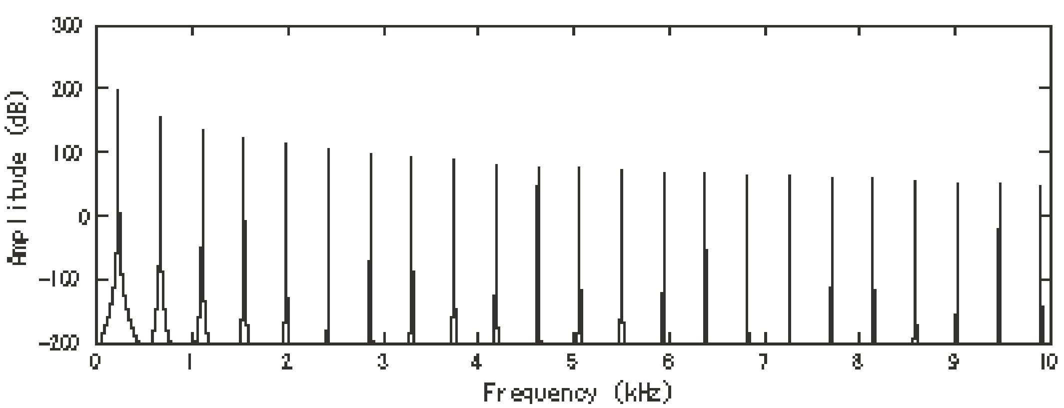
The colored sine waves added together create the black square wave. A square wave contains only **odd harmonics**. In musical terms, square waves are often described as sounding **hollow**, and are used as the basis for **wind instrument** sounds.



Triangle wave

Like the square wave, a triangle wave contains only **odd harmonics**. However, the higher harmonics roll off much faster than in a square wave. Because it has softer high frequencies, its sound is **smoother than a square wave** and is **nearer to that of a sine wave**.

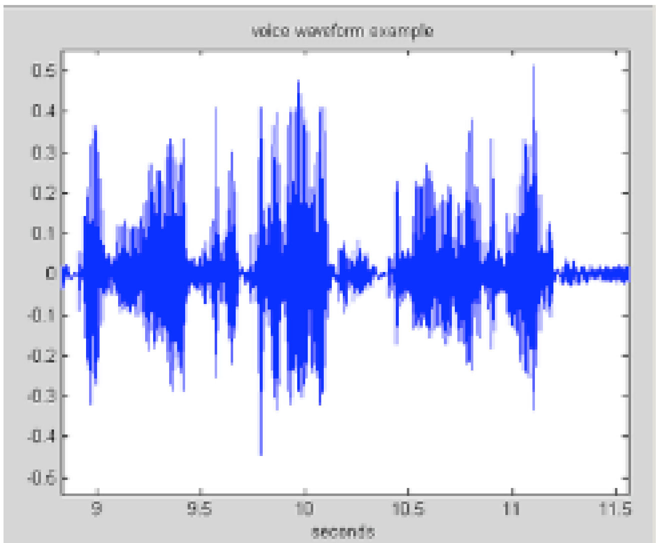


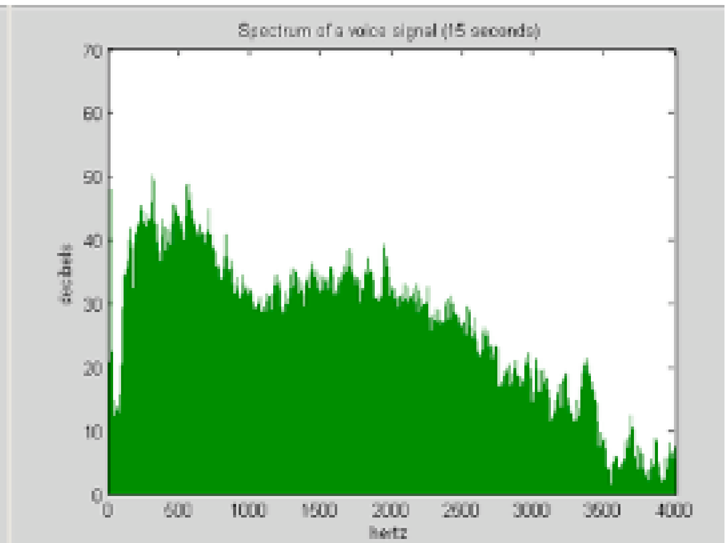


Non-Periodic Waveforms:

Voice Spectrum over time

A waveform of a voice (in blue) is an example of a non-periodic waveform. It doesn't have a set pitch, as the pitch is constantly changing. The harmonic spectrum shown in green is very filled in because it is all of the frequencies that occurred in a 15 second timeframe, with the respective amplitudes.





3D spectral plot over time

This 3 dimensional display shows a note being played, over time, combining the **spectral plot** (odd harmonics in this case) and an **amplitude envelope** for each **individual harmonic** over time.