

Pitch, Frequency, Overtones, Timbre and All That Stuff

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The fundamental building block of all sounds is the sine wave. This can be thought of as a fixed length vector rotating at a constant rate, rather like the second hand of a clock. This is the simplest repetitive motion we can get. This motion is fully described by the magnitude of the vector (e.g., the length of the second hand) and its angular velocity or rotational speed (e.g., one revolution in sixty seconds). Humans can hear sounds with rates between 20 and 20,000 revolutions per second. This rate is called the *frequency* of the source. The unit of revolutions (or cycles) per second is also known as *Hertz* and abbreviated as *Hz*. You can create something very close to a simple sine wave by whistling. Typically, this will produce a tone in the 1000 to 2000 Hz range. Frequency and pitch are tightly correlated and the terms are often used synonymously although that is not entirely accurate. If you make the whistle rise in pitch, you are increasing its frequency.

More complex sounds, such as the human voice, a musical instrument, or the sound of a waterfall, are made up of several different sine waves. The collection of all of the different sine waves that make up a sound at any given instant is referred to as its *spectrum*. Each of the individual components is referred to as a *partial*. Typically, the lowest partial (i.e., the lowest frequency in the spectrum) is called the *fundamental* and all of the other elements are called the *overtones*. The overtones are numbered sequentially from the fundamental on up. For example, a sound might consist of sine waves at 100 Hz, 260 Hz and 400 Hz. The set of three frequencies comprise the spectrum. Each of the components is a partial. The fundamental is 100 Hz and the overtones are 260 Hz and 400 Hz. 260 Hz is called the first overtone while 400 Hz is called the second overtone.

In music theory, the set of overtones is part of what is referred to as the sound's *timbre*. Timbre is what makes two musical instruments sound different when they are playing the same note. It is important to remember that the set of overtones does not have to be static. Individual partials can become quieter or louder as the sound evolves through time. In fact, some partials might disappear completely while new ones are created.

Overtones can be classified as either *harmonic* or *inharmonic*. If the overtone is a simple integer multiple of the fundamental then it is harmonic, otherwise it is inharmonic. In the example above, 260 Hz is inharmonic while 400 Hz is harmonic. Often, environmental sounds such as thunder, the sound of splattering rain and the like are inharmonic. In contrast, musical instruments often produce a harmonic sequence of overtones. This is particularly true of instruments that rely on the resonance of tensioned strings (guitar, violin, piano, etc.) or air columns (trumpet, saxophone, flute, etc.). By their very nature, these sound sources produce overtones that are integer multiples of the fundamental. The fundamental is determined in part by the length of the mechanical system (e.g., length of the guitar string or distance from the mouthpiece to the effective end of an air column). The overtones are similarly constrained and they must wholly "fit" within that length, hence only integer multiples are produced. Consequently, when discussing musical instruments, the overtones are often referred to as *harmonics*, which is short for *harmonic overtone*. Many of the signal waveforms used in electronic circuitry, such as square waves and triangle waves, exhibit an integer overtone sequence and the term harmonic is commonly used there as well.

If a sound source has a harmonic overtone structure, it is classified as being *definitely pitched*. The fundamental supplies the pitch or note name and the overtones establish the timbre. For example, if we tension a guitar string a certain way, it might produce a fundamental at 220 Hz with overtones at 440 Hz, 660 Hz, 880 Hz, 1100 Hz and so on. Note that these overtones are all integer multiples of the fundamental, they “line up” with it and reinforce it. By convention, 220 Hz is known as the note A (A below middle C to be precise). We could also tension a piano string to produce a 220 Hz fundamental. It would also produce harmonic overtones at 440 Hz, 660 Hz, and so on, although the relative strength of each partial and they way evolve over time would be somewhat different than that produced with the guitar. For example, the guitar’s first overtone might be louder than the piano’s first overtone but the second overtone might be quieter. Because both instruments produce a 220 Hz fundamental we say both are producing an A below middle C. In contrast, because the corresponding overtones are not identical in strength, we recognize one as a guitar and the other as a piano.

Some instruments produce a strong fundamental but produce an inharmonic overtone sequence. A drum is a classic example. Unlike a string or air column, a drum head can move along two axes. Instead of integer overtones at $2X$, $3X$, $4X$ and so forth above the fundamental, a drum produces overtones at $1.59X$, $2.14X$, $2.3X$, $2.65X$ et al times the fundamental. These overtones do not reinforce the fundamental in the manner of integer overtones. Consequently, drums are said to be *indefinitely pitched*. When one drum is said to be of “lower pitch” than another, what this really means is that it has a lower fundamental. The drum isn’t truly pitched, the “pitch” is indeterminate. We could tension the drum head to produce a fundamental at 220 Hz but the drum isn’t really producing an A below middle C the way the guitar or piano did. The inharmonic overtones create a much more complex waveform and the human sensation of true pitch is lost. Interestingly, it is possible to reduce or mute certain overtones when designing and playing drums in order to achieve an overtone sequence that is closer to the harmonic ideal. Such is the case with timpani; drums which produce a true sense of pitch.

Some sound sources have neither a stable fundamental nor a harmonic overtone structure. Examples include explosions and the sound of wind through trees. The list of partials appears to be more or less randomly assigned through the frequency spectrum and continually evolves. These sources are said to be *unpitched*.

Regarding human speech, vowel sounds are generally pitched. Consonants, particularly plosives such as ‘p’ or ‘d’, are unpitched.