Taking the Waveform Apart

Waveforms

The waveform of a sound is a graph of the way the pressure changes between the wavefronts. This is usually a very convoluted pattern and the actual sound of the wave is not apparent from looking at the waveform. As a matter of fact, the waveform does not usually repeat exactly from one cycle to another.

At this point I am going to have to digress into some mathematics.

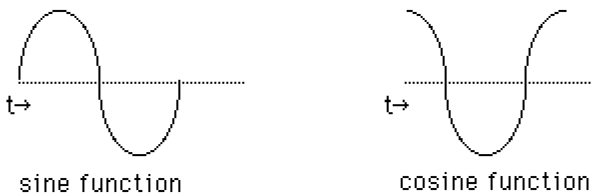

Fig 1. Sine and cosine functions

The waveform produced by simple harmonic motion is the SINE WAVE. We graph a sine wave by plotting the function:

$$f(t)=A \sin 2\pi ft$$

To do this we divide up our graph paper horizontally into equal chunks to represent a time scale, and for each time t we want to plot, we multiply t by 2[pi]f (f=frequency) and look up the sine of the result. That sine value is what gets used for the vertical part of the graph.

There is also a function called a cosine wave. The expression is

$$f(t)=A\cos 2\pi ft$$

and it looks just like the sine wave. The difference is that the cosine of an angle is equal to the sine of an angle 90 degrees bigger. When we have two waveforms which have the same shape and frequency but are offset in time, we say they are out of phase by the amount of angle you have to add to the 2[pi]ft term of the first to move them together. In other words the wave defined by sin(2[pi]ft) is out of phase with the wave defined as sin(2[pi]ft+p) by the angle p.

The second simplest waveform is probably the combination of two sine waves. Any combination of waves is interpreted by the ear as a single waveform, and that waveform is merely the sum of all of the waves passing that spot. Here are a few rules about the addition of two sine waves:

- If both have the same frequency and phase, the result is a sine wave of amplitude equal to the sum of the two amplitudes.
- If both have the same frequency and amplitude but are 180 degrees out of phase, the result is zero. Any other combinations of amplitude produce a result of amplitude equal to the difference in the two original amplitudes.
- If both are the same frequency and amplitude but are out of phase a value other 180 degrees, you get a sine wave of amplitude less than the sum of the two and of intermediate phase.
- If the two sine waves are not the same frequency, the result is complex. In fact, the waveform will not be the same for each cycle unless the frequency of one sine wave is an exact multiple of the frequency of the other.

If you explore combinations of more than two sine waves you find that the waveforms become very complex indeed, and depend on the amplitude, frequency and phase of each component. Every stable waveform you discover will be made up of sine waves with frequencies that are some whole number multiple of the frequency of the composite wave.

Fourier Analysis

The reverse process has been shown mathematically to be true: Any waveform can be analyzed as a combination of sine waves of various amplitude, frequency and phase. The method of analysis was developed by Fourier in 1807 and is called Fourier Analysis.

The actual procedure for Fourier analysis is too complex to get into here, but the result (with stable waveforms) is an expression of the form:

$$A\sin\omega t + B\cos\omega t + C\sin 2\omega t + D\cos 2\omega t + E\sin 3\omega t \ldots$$

and so forth. The omega (looks like a w) represents the frequency in radians per second, also known as angular frequency. The inclusion of cosine waves as well as sine waves takes care of phase, and the letters represent the amplitude of each component. This result is easily translated into a bar graph with one bar per component. Since the ear is apparently not sensitive to phase, we often simplify the graph into a sine waves only form. Such a graph is called a spectral plot:

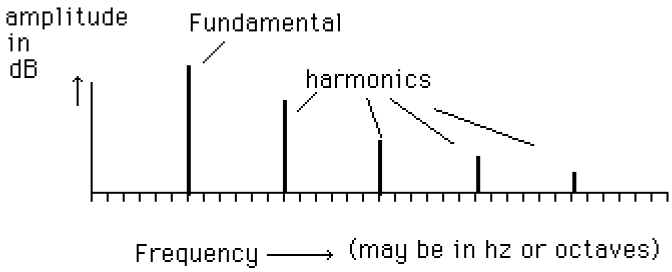

Fig. 2 A typical spectral plot

The lowest component of the waveform is known as the FUNDAMENTAL, and the others are HARMONICS, with a number corresponding to the multiple of the fundamental frequency. The second harmonic is twice the fundamental frequency, the third harmonic is three times the fundamental frequency, and so forth. It is important to recognize that the harmonic number is not the same as the equivalent musical interval name, although the early harmonics do approximate some of the intervals. The most important relationship is that the harmonics numbered by powers of two are various octaves.

Non-repeating waveforms may be disassembled by Fourier means also, but the result is a complex integral that is not useful as a visual aid. However, if we disregard phase, these waveforms may also be represented on a spectral plot as long as we remember that the components are not necessarily whole number multiples of the fundamental frequency and therefore do not qualify as harmonics. We should not say that a non-harmonic waveform is not pitched, but it is true that the worse the spectral plot fits the harmonic model the more difficult it is to perceive pitch in a sound.

There are sounds whose waveforms are so complex that the Fourier process gives a statistical answer. (These waveforms are the sounds commonly called noise.) You can express the likelihood of finding a particular frequency as a component over a large enough time but you cannot assign any component a constant amplitude. To describe such sounds on a spectral plot, we plot the probability curve. A very narrow band of noise will sound like a pitched tone, but as the curve widens, we lose the impression of pitch, aware only of a vague highness or lowness of the sound.

Noise that spreads across the entire range of hearing is called WHITE NOISE if it has equal probability of all frequencies being represented. Such noise sounds high pitched because of the logarithmic response of the ear to frequency. (Our ears consider the octave 100 hz to 200 hz to be equal to the octave 1000 hz to 2000 hz, even though the higher one has a much wider frequency spread, and therefore more power.) Noise with emphasis added to the low end to compensate for this is called PINK NOISE.

Sonograms

A sound event is only partially described by its spectral plot. For a complete description, we need to graph the way the sound changes over time. There are two ways in which such graphs are presented. In the Sonogram, the horizontal axis is time, the vertical axis is frequency, and the amplitude is represented by the darkness of the mark. There is a machine that produces this kind of chart by mechanical means.

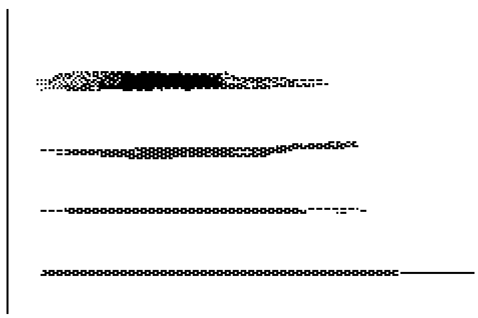

Fig 3. A Sonogram

Computer analysis usually produces a three dimensional graph:

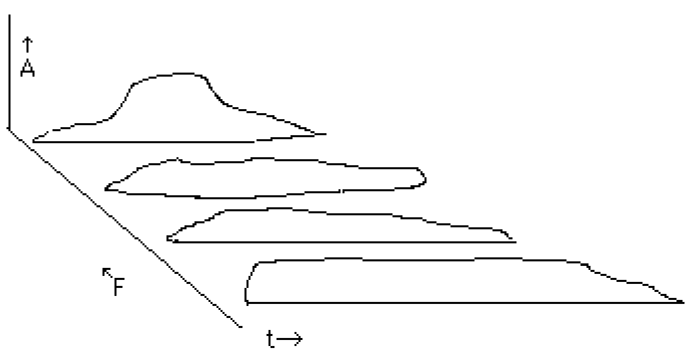

Fig 4. Spectragraph

The three dimensional graph gives a clearer sense of how the amplitudes of various components of a sound change. This really shows amplitude envelopes for each partial of the sound. In this case, frequency is represented by the apparent depth into the screen. Most analysis programs allow you to either show high frequency behind low, as this one does, or low behind high. This and the ability to swap parameters among the three axes allows you to pick a view with the least information hidden.

Source: http://www.co-bw.com/Audio_Sound_Spectra.htm