



Waveshapes

Sawtooth, square and triangle waveshapes are fundamental to contemporary music production, but what exactly are they? **Mark Cousins** makes waves.

You need only to glance at a typical subtractive synth to realise that waveshapes form the building blocks of sound creation, whether it's a sawtooth, square, triangle or pulse waveform or even a simple sine wave. But what are the factors that make a sawtooth wave, for example, so radically different from a sine wave? Not surprisingly, a closer investigation of the theory behind waveshapes offers some remarkable insights into both the process of synthesis and, more importantly, into the nature of sound itself.

In harmony

A waveshape can be visualised in two ways: as a plot of the compression and rarefaction of air molecules as sound travels through air (also known as a time-

domain plot) or as a frequency-domain plot, in which sound is broken down into its spectral properties. In a DAW, for example, you'll use a time-domain plot (or waveform view) to edit audio, while an FFT frequency-domain plot might accompany an EQ plug-in.

Spectral analysis breaks down a sound into a series of harmonic overtones or partials, with the unique combination and

rather less complex sound of a flute will contain relatively few harmonics. Immediately, therefore, we can see that both the number and density of the harmonics directly correlates to the relative richness and timbre of the sound and shape of the waveform.

Looked at more closely, the harmonics of a typical waveform can be seen as series of pure tones, each based on a

to offer in the way of musical interest than other waveforms – indeed, even in the acoustic world, many of the 'purest' sounds will usually contain a few additional harmonic components to keep the ear entertained. In synthesis, the sine wave comes in handy for additive synthesis applications, where multiple sine waves are stacked to replicate the various partials in the harmonic series.

The sawtooth wave is a popular starting point for creating a range of sounds.

arrangement of these harmonics forming the timbre – or waveshape – of the note in question. The bright timbre of a trumpet, for example, will contain multiple harmonics stretching into the upper extremes of the sound spectrum, while the

multiplication of the fundamental pitch of the note – the harmonic series, in other words. The sound of a string plucked at 50Hz, for example, will contain harmonics at 100Hz (the second harmonic), 150Hz (the third), 200Hz (the fourth) and so on. The root note – also known as the fundamental or first harmonic – will be the loudest of this series of harmonics, with the remaining harmonics sounding at reduced amplitude.

It's also interesting to note that the harmonics are often broadly divided into two groups based on their mathematical relationship: odd harmonics, based on odd multiplications of the fundamental (the third, fifth and seventh partials, for example) and even harmonics, based on even multiplications.

Sine on

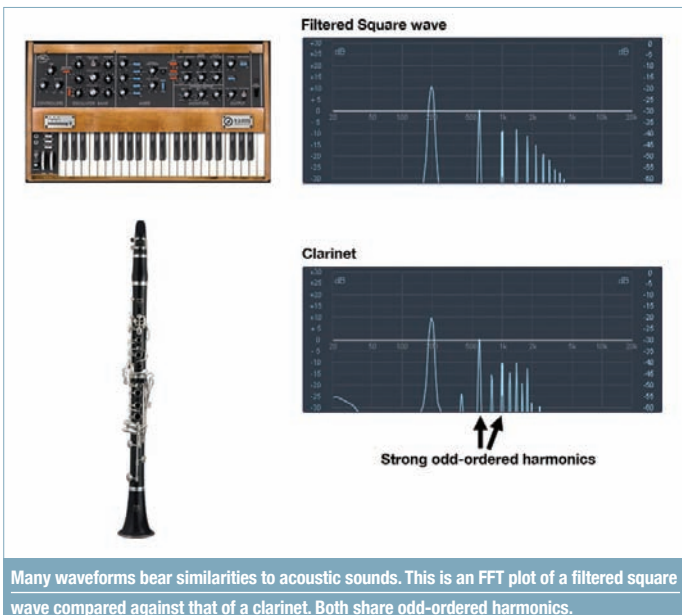
The simplest waveform is one that's devoid of any harmonics at all – the sine wave. Given this harmonic simplicity, it could be said that a pure sine wave has less

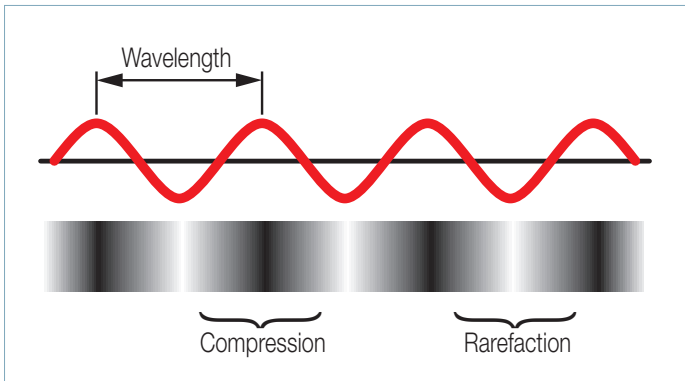
On the opposite side of the spectral coin, though, we have the familiar buzz of the sawtooth wave. Harmonically, the sawtooth consists of a dense collection of both odd- and even-numbered harmonics, with an amplitude that is inversely proportional to the fundamental harmonic (the harmonics get quieter as you move up the harmonic series).

In traditional music, many sounds that we associate with richness – strings or brass, for example – often have a waveshape that's similar to a sawtooth wave, although rarely with as many of the higher-order harmonics. In subtractive synthesis, the sawtooth wave is a popular starting point for creating a range of sounds, which can then be low-pass filtered to produce a less bright but increasingly warmer timbre.

Square root

As you'd expect, there's a much wider spectrum of sounds in the musical palette than simply 'pure'





A time-domain plot charts the compression and refraction of air molecules as sound travels through air, giving a visual description of a waveshape.

or 'rich' timbres. The square wave, for example, makes use only of odd harmonics, although again, at an amplitude that's inversely proportional to its position in the harmonic series. As a result, the square wave sounds hollower than an equivalent sawtooth.

In the acoustic world, the most comparable sound to the square wave is the clarinet, which, not surprisingly, has a bias towards odd-ordered harmonics. It's also interesting to note that the process

The pulse wave, however, is an altogether more complicated beast. On a subtractive synthesizer, the process of adapting the duty cycle of a square wave creates a pulse wave. For example, a 50% duty cycle – keeping the 'on' and 'off' components equal – creates a square wave. By reducing the duty cycle so that the 'on' state is active longer than the 'off' state – the square wave turns into a pulse wave. As a result, the sound starts

What's interesting is how our appreciation of music is so inextricably linked to maths.

of waveform distortion (clipping) often 'squares off' the top of a waveform, producing both a waveshape progressively closer to that of a square wave and, correspondingly, a greater number of odd-ordered harmonics. As an experiment, try running a square wave through a heavily resonant filter. You should be able to sweep through it and easily pick out the distinctly spaced harmonics.

On the pulse

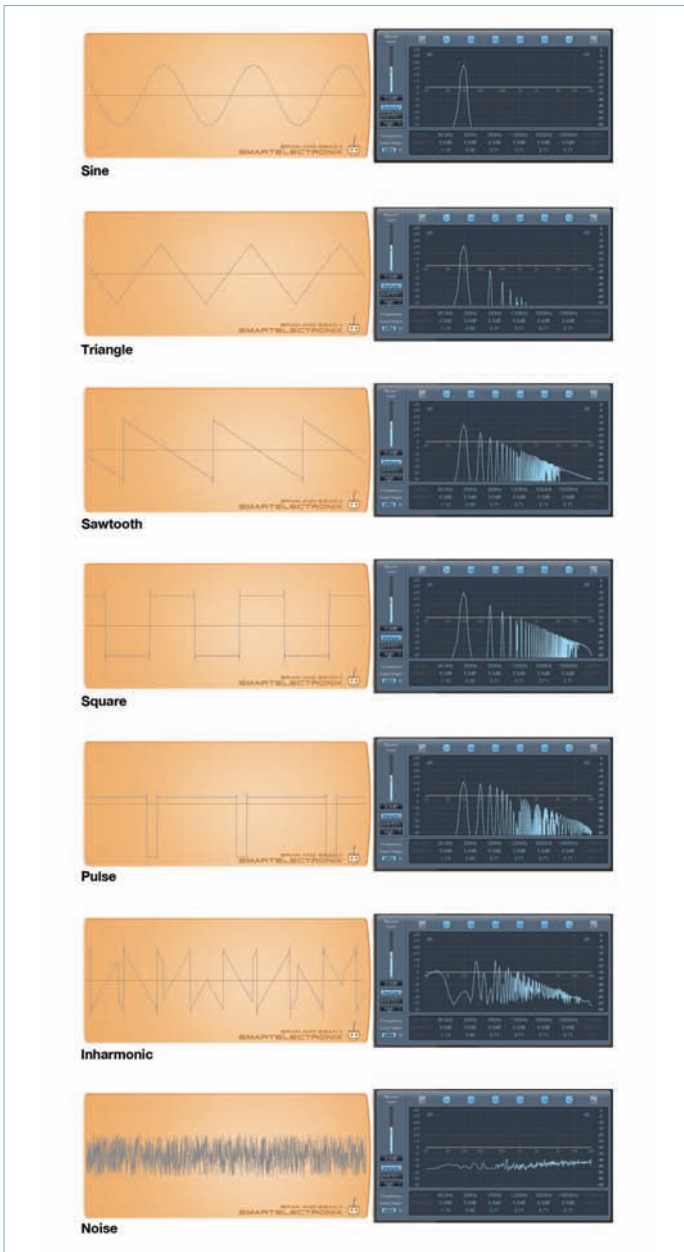
Two further variations on the square wave include the triangle and pulse waveshapes. The triangle again has the distinctive series of odd-ordered harmonics, although in this case, at a far lower amplitude than that of the square wave. As a result, the triangle wave loses some of the open and hollow qualities of the square wave, and has an output that's much closer to the relative purity of the sine wave.

to become thin and nasal (much like an oboe) rather than open and hollow. As the duty cycle is reduced further, this nasal quality becomes even more pronounced.

Taking the auditory qualities of the pulse wave, it's interesting to relate them to what happens in the harmonic series. By reducing the duty cycle, we effectively see gradual amounts of even-ordered harmonics being added back into the equation. Rather than exhibiting a gentle roll-off as you move up the harmonic series, however, the amplitude seems to vary from one harmonic to the next.

Maths and music

What's interesting about all these waveshapes is how our appreciation of music is so inextricably linked to maths. Put simply, sonority or musicality is formed by neat mathematical relationships: odd harmonics, even harmonics, the relative amplitudes



Spectral analysis reveals the unique sonic fingerprint of different waveforms. Notice the differences in odd and even harmonics that define the sounds they produce.

of those harmonics and so on. Indeed, our ear almost seems to seek out and crave these relationships as part of what we appreciate as music. **MTM**

Low-pass filter

A low-pass filter attenuates high frequencies and lets low frequencies 'pass' through. Square, sawtooth or pulse waves have lots of high-order harmonics, so a low-pass filter is often essential to soften the output.

Tech Terms

- Clipping**
Clipping is a form of distortion whereby the waveshape's upper section is aggressively sliced off. A softer, saturation-like distortion tends to gently skew the waveform.
- FFT**
FFT (Fast Fourier Transform) is a mathematical process used to deconstruct a signal into its constituent frequencies. You're most likely to encounter FFT analysis as part of an audio-editing application.

FURTHER INFO

- For more information on combining harmonics, see:** www.musictechmag.co.uk/mtm/features/additive-synthesis
- For a detailed look at the harmonic series, visit:** www.musictechmag.co.uk/mtm/features/harmonics
- Information on waveshapes can be found at:** www.csounds.com/ezone/spectra