# Sound Synthesis

A review of some techniques

## Synthesis

- **Synthesis** is the name given to a number of techniques for creating new sounds.
- Early synthesizers used electronic circuits to create sounds.
- Modern techniques now use digital systems (especially computers).

# Synthesis Techniques

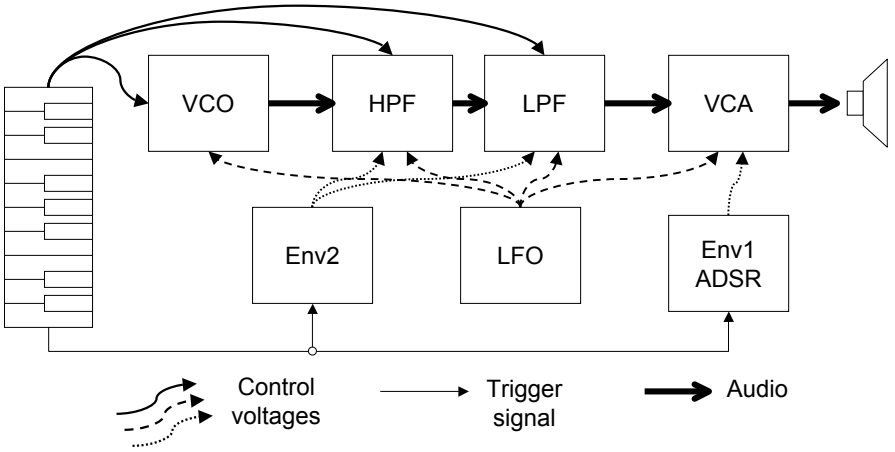
- Fourier-based techniques:
  - Subtractive synthesis
  - Additive synthesis/Wave Table synthesis
- Modulation techniques:
  - Frequency/Phase/Amplitude modulation
  - Bezier synthesis
- Waveshaping synthesis
- Granular synthesis
- Physical modelling

# Fourier-Based Techniques

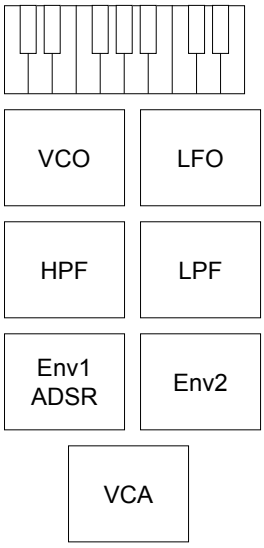
- These techniques use the principle that a complex waveform is made up of a sequence of harmonics and partials.
- Subtractive synthesis:
  - Starts with a harmonically rich waveform (such as square or sawtooth wave) and filters out unwanted spectral components.
- Additive synthesis:
  - Adds together multiple sine waves, each one a harmonic or partial, to produce a complex final result.
  - May also add noise for sibilant effects.

# Subtractive Synthesis

- A classic synthesis technique, originally implemented using voltage controlled oscillators.




# Subtractive Synth Components




Keyboard:
- Each key press produces a different control voltage plus a trigger signal for envelope shapers.

Voltage Controlled Oscillators:
- VCO pitch controlled by voltage from keyboard.
- LFO used for tremolo/vibrato effects.

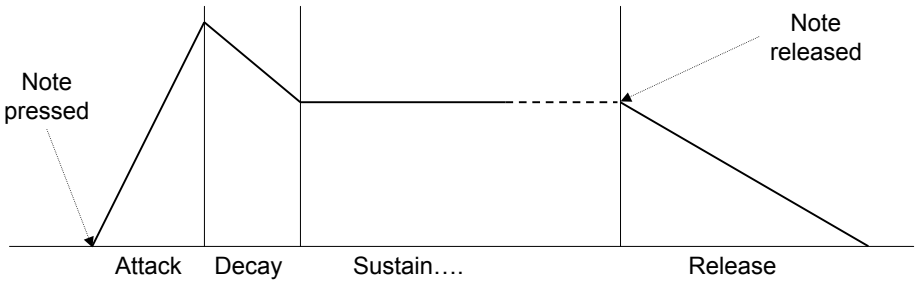
High Pass and Low Pass Filters:
- Removes unwanted harmonics from the audio signal.
- Cut-off frequency controlled by Env2 (and LFO).

Envelope Shapers:
- Produce time-varying control voltages to control filter operation and overall audio volume.

Voltage Controlled Amplifier:
- Shapes output audio, controlled by ADSR (and LFO).

# Envelope Shaper

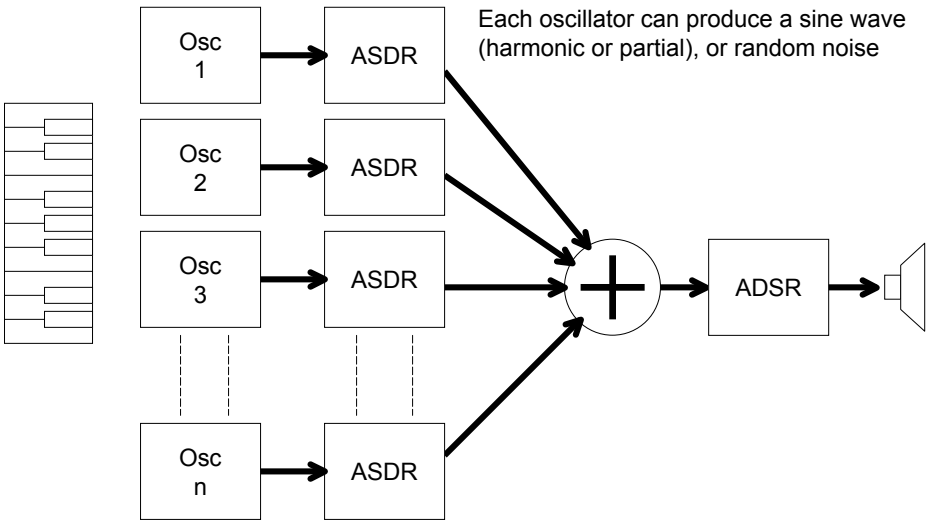
- An envelope shaper produces a time-varying output which is typically used to control the envelope of the generated sound.
- Triggered by pressing and releasing a note.
- Commonly has four phases:
  - attack, decay, sustain, release (**ADSR**).




# Subtractive Synths

- Moog and Mini-Moog synthesizers (1960s)
  - Pioneering subtractive synths using analogue voltage control.
- EMS VCS-3 (1969)
  - Featured on *Dark Side of the Moon.*
- Yamaha CS-80 (1976)
  - One of Japan's first synthesizers.
- Roland SH-101 (1980)
  - Monophonic bass synthesizer.

# Additive Synthesis




# Wave Table Synthesis

- Standard additive synthesis uses sine wave generators.
- A useful variation is **Wave Table Synthesis**, which replaces the sine wave generators by arbitrary waveforms.
- These waveforms are held in a storage area called a Wave Table (hence the name given to the technique).

## Additive Synths

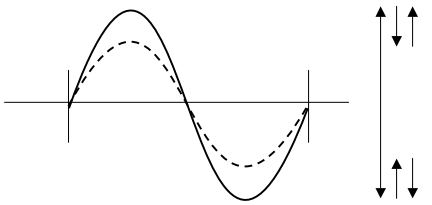
- Pipe (Church) organ (3rd century BC - present)
  - Uses tuned pipes as sound generators, flexibly coupled to one or more keyboards.
- The Telharmonium (1897)
  - Pioneered the idea of sound synthesis, using linked dynamos as wave generators.
- Hammond drawbar tone-wheel organ (1934)
  - Another electro-mechanical system which became a classic instrument.
- Kawai K5 (1987)
  - Digital additive synth, but with extra filtering for better sound control.

## Modulation Synthesis

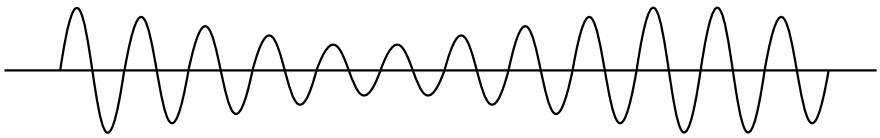
- Based on concepts from radio transmission.
- Distortion frequencies (modulations) are applied to a sine wave.
- Resulting output contains partials derived from the modulation frequencies.
- The output from one device can be used to modulate another, producing huge variety and complexity.

# Amplitude Modulation

Changing the amplitude of a sine wave

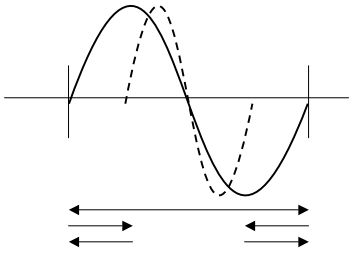


Increasing and decreasing amplitude

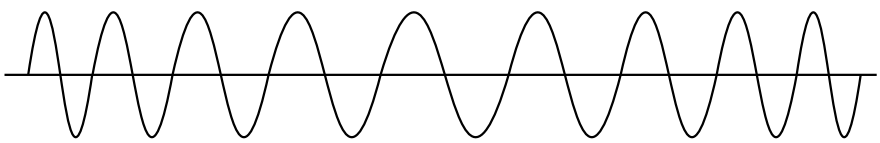


# Frequency Modulation

Changing the frequency of a sine wave

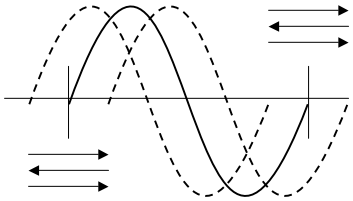


Increasing and decreasing frequency (*squeezing*)

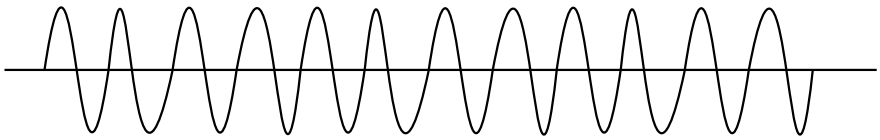


# Phase Modulation

Changing the phase of a sine wave

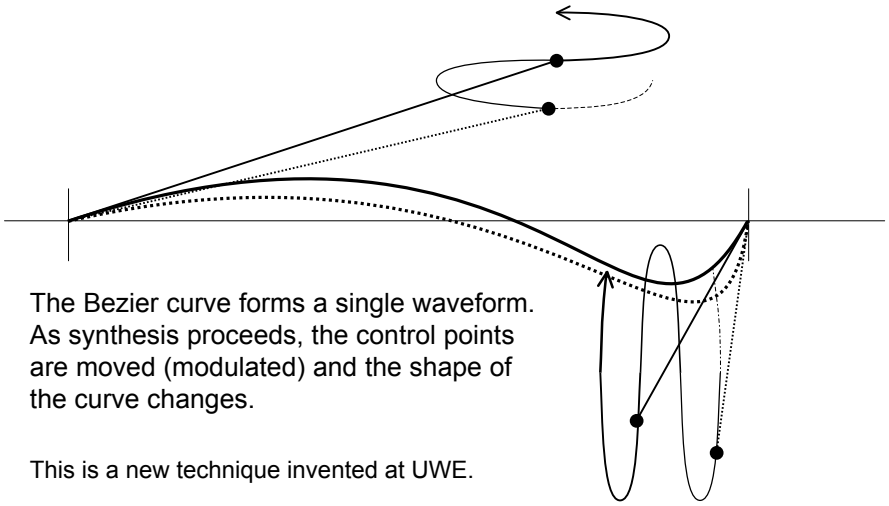


Increasing and decreasing phase (*wiggle*)



# Bezier Synthesis

Changing the controls points of a Bezier curve



The Bezier curve forms a single waveform. As synthesis proceeds, the control points are moved (modulated) and the shape of the curve changes.

This is a new technique invented at UWE.

# Side Bands

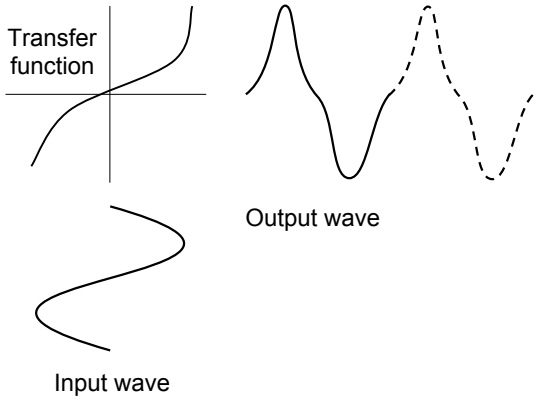
- The basis of all modulation techniques is that they add **side bands** (extra frequencies) to the original spectrum.
- Amplitude modulation:
  - Adds two side bands at ± the modulation frequency.
- Frequency and Phase modulations:
  - Adds a number of side bands at ± multiples of the modulation frequency.
- Bezier synthesis:
  - Has **four** modulation frequencies (not just one).
  - Adds a complex pattern of side bands not yet characterized.

# Modulation Synths

- Theremin (1917)
  - Pioneering electronic instrument which is still used today.
  - Not really a synth as it only has one voice.
- Yamaha DX7 (1983)
  - The classic FM synth which didn't use FM (it actually used PM) and became the sound of the 1980s.
- Numerous computer sound cards
  - FM became a standard (cheap) way of producing numerous almost-musical sounds for computer games.

# Wave Shaping Synthesis

- Wave shaping is a technique for *distorting* an input waveform using a **transfer function:**




# Wave Shaping Synth

- Casio CZ-101 (1985)
  - Used a variation of wave shaping called **Phase Distortion** synthesis.
  - The brand name on the box lacked credibility but many users regarded this as a great synth sometimes capable of rivalling the DX7.

# Granular Synthesis

- Generates a sequence of sound *grains*.
- Each grain is an extremely short (10-100 milliSecs) burst of sound.
- Grains are output in quick succession to produce a rapidly changing sound, which can be further filtered and envelope shaped.
- Grains are often controlled by a **Cellular Automaton** which produces a pseudo-random pattern.
- Incredibly difficult to control, but can produce some unexpected and exciting results.

# Physical Modelling

- A number of different techniques which attempt to duplicate instruments by simulating (modelling) the actions of the components within them:
  - Some instruments can be modelled using wave guide theory.
  - Other instruments might be modelled from the equations which describe the movements of their component parts.
- Can produce highly realistic simulations.
- Allows unreal instruments to be produced, such as a trumpet with a variable size bell.

# Physical Modelling Synths

- Yamaha VL-1 (1995)
  - First commercially available Physical Modelling synth.
  - Great for wind instruments.
  - Featured a breath controller.
- Korg Prophecy (1996)
  - Lead synth, also featured analogue synth emulation.