Introduction to Audio Synthesis

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Primary Characteristics of Sound

Before describing how a synthesizer functions or creates sound, it is important to understand the major aspects of sound and how they interact.

Pitch / Frequency

Timbre / Tone

Loudness / Amplitude

Pitch / Frequency

Frequency is determined by the amount of time it takes for a sound wave to repeat or ‘cycle’.
This is often noted as the number of cycles per second or ‘Hertz’ (Hz).

Pitch refers to the same idea as frequency, from a musical perspective.
A standard Western musical tuning is A - 440 Hz. Meaning that the musical note, ‘A’, is referenced at 440 cycles per second.

An octave, either up or down is either double or half of the Hertz.

A - 220 Hz | A - 440 Hz | A - 880 Hz
C - 264 Hz | C - 528 Hz | C - 1056 Hz - This is ‘Just Intonation’

Pitch / Frequency

Below is an example of oscillators tuned to C - 132 Hz, C - 264 Hz, and C - 528 Hz, respectively.

Timbre / Tone

Timbre is the characteristic of sound that distinguishes two sounds of the same frequency. This is dependent upon the actual wave shape of the sound.

Basic waveforms like the sine, triangle, sawtooth, and squarewave are all examples of simple timbral changes.

The image to the right is an example of a sine wave.

Timbre / Tone

Below is an example of a triangle, sawtooth, and square wave at C - 264 Hz.

Timbre / Tone - Periodic or Aperiodic?

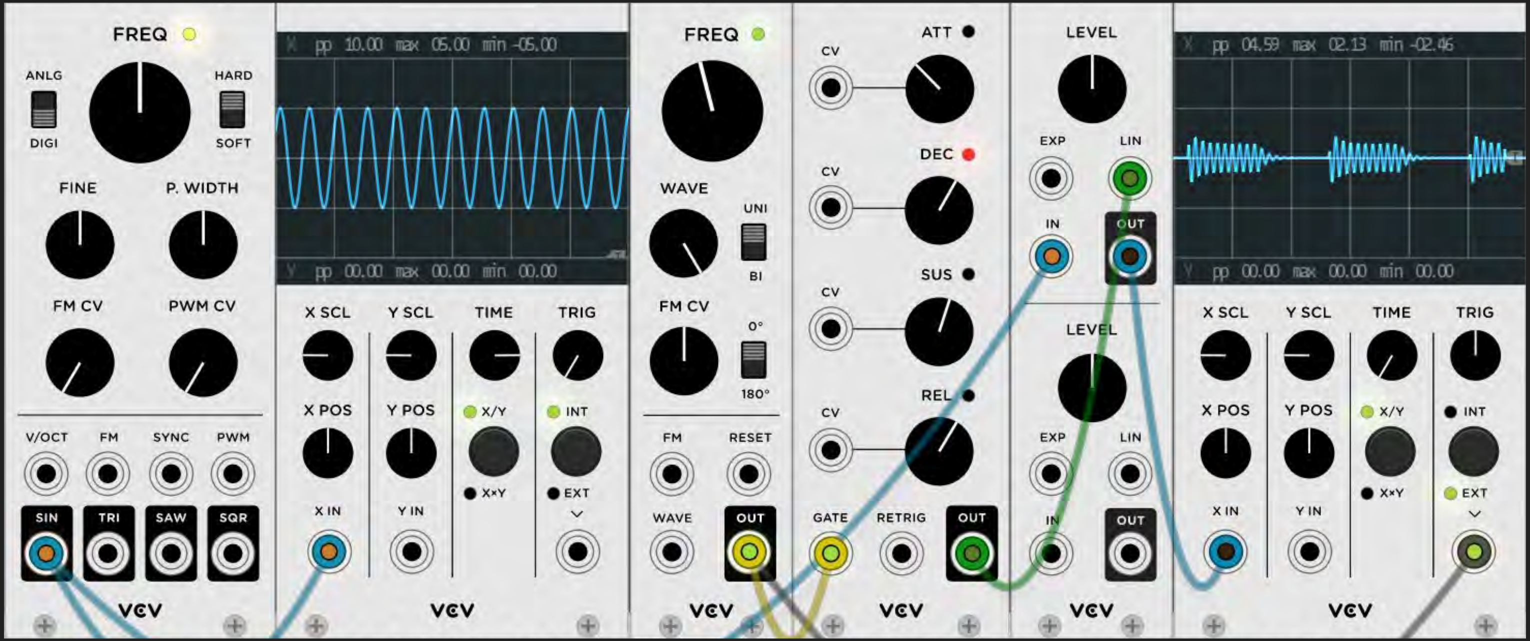
The previous examples have all consisted of ‘periodic’ sound waves. A periodic sound is a continuous or repeating waveform.

Where an ‘aperiodic’ wave is a one-shot or sound with a beginning and end.

The distinction between periodic and aperiodic is not concerned with the type of waveform. Either can be as simplistic or complex as one wants.

Timbre / Tone - Periodic or Aperiodic?

In this example, we created an aperiodic wave by modulating the amplitude. The second scope displays the aperiodic wave created from the original periodic.



Loudness / Amplitude

Loudness is measured in decibels and refers to the exponential listening response of the human ear and the perceived difference in volume or amplitude.

Whereas amplitude is, perhaps, best described with the actual current or voltage being delivered to a monitor or loudspeaker.

For Eurorack and VCV Rack standards, our amplitude ranges anywhere from +/- 0v to +/- 10v. So a sound with maximum output volume (direct) will have, roughly, +/- 10v and a sound that is half as loud (technically) may exist around +/- 5v.

Loudness / Amplitude

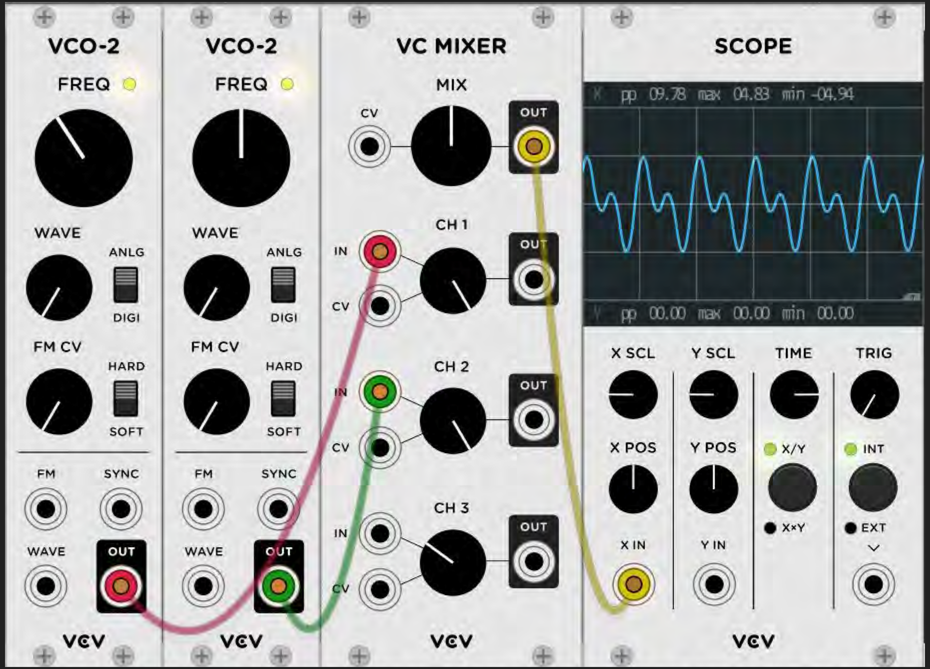
Below is an example of a sound wave with the same timbre and pitch at differing amplitudes.

Forms of Synthesis

The two major classifications of audio synthesis are described as either ‘additive’ or ‘subtractive’.

Additive synthesis utilizes the combination of multiple waves at varying frequencies to shape a sound.

Subtractive synthesis utilizes the removal of frequencies in order to shape sound.



Forms of Synthesis - Additive

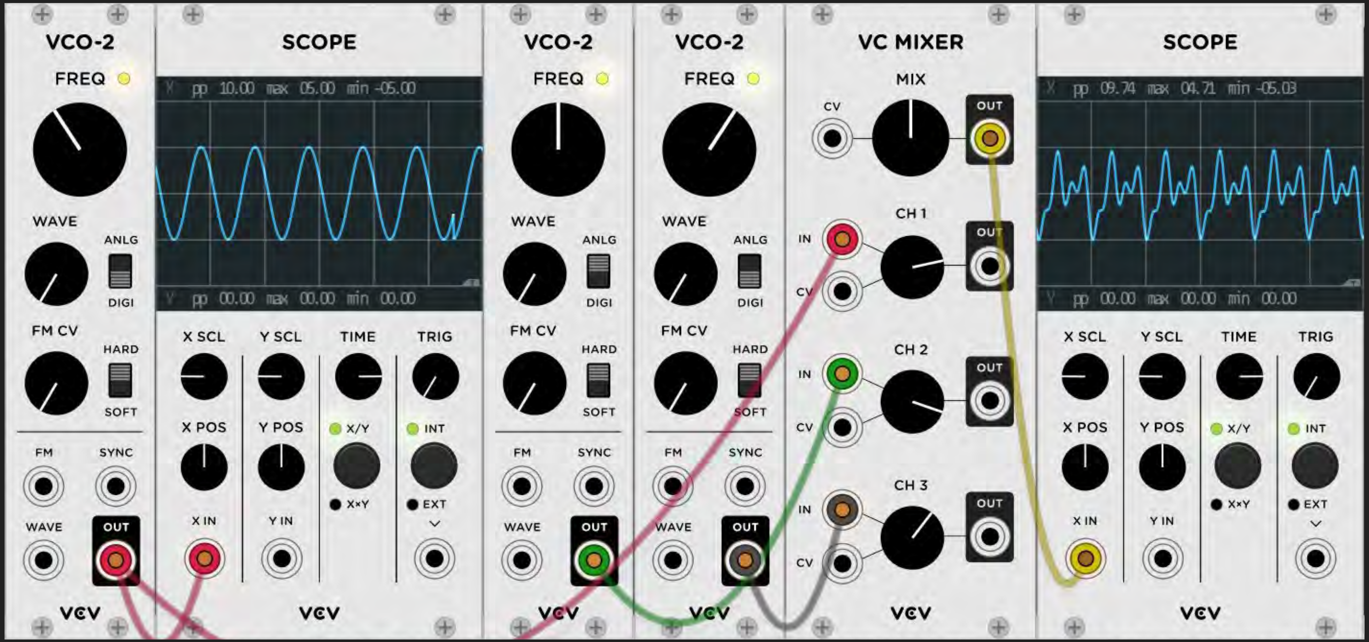
Additive synthesis, to further explain, starts with the lowest frequency also known as the ‘root’ or ‘fundamental’ frequency.

From there, additional waves are used to construct the sound. These are known as ‘overtones’ or ‘harmonics’.

By combining any number of sine waves, we can approximate practically any sound imaginable.

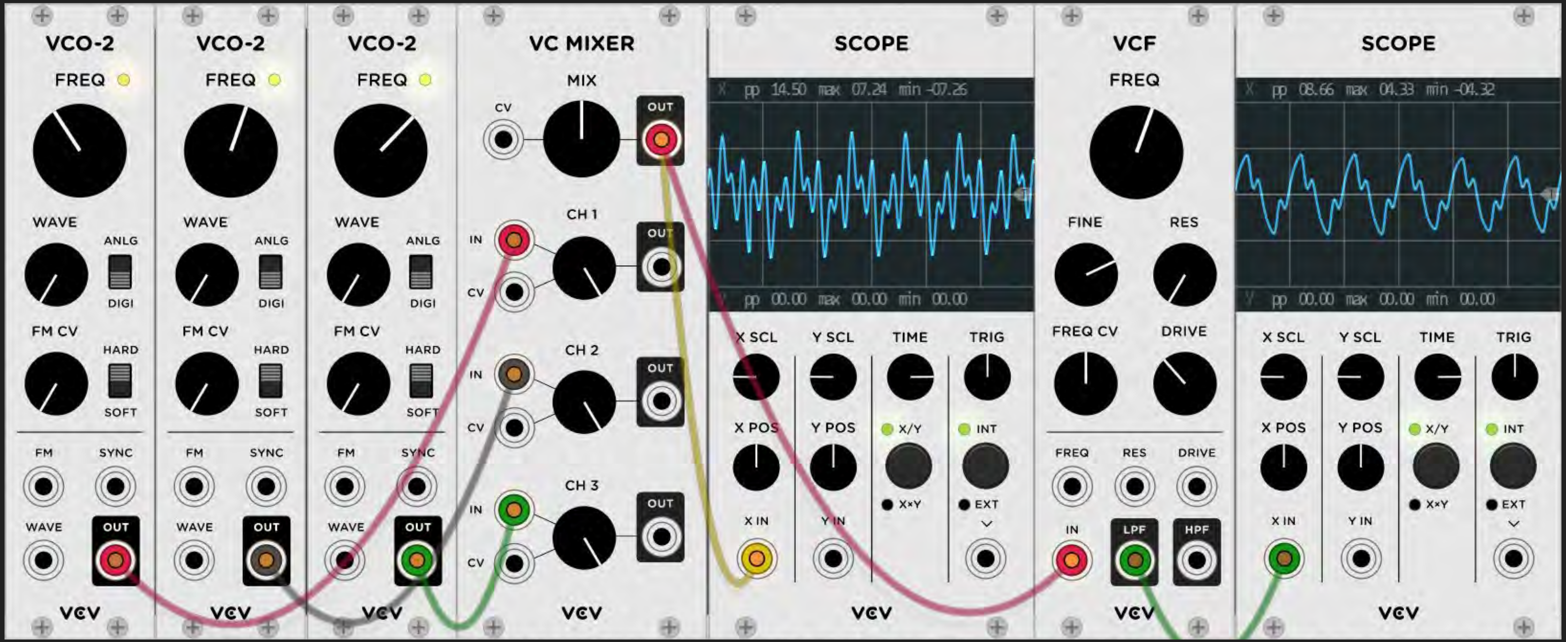
Forms of Synthesis - Additive

Below is a simple example of additive synthesis with 3 sine waves at different octaves.



Forms of Synthesis - Subtractive

Below is an example of subtractive synthesis utilizing a low-pass filter (LPF).



The Synthesizer Voice

There are three primary audio routing components to a synthesizer’s voice.

Voltage Controlled Oscillator (VCO)

Voltage Controlled Filter (VCF) - This may be any type of filter, though Low-pass Filters (LPF) are the most common.

Voltage Controlled Amplifier (VCA)

The Synthesizer Voice

Often they are chained in one of these two fashions.
VCO > VCF > VCA or VCO > VCA > VCF

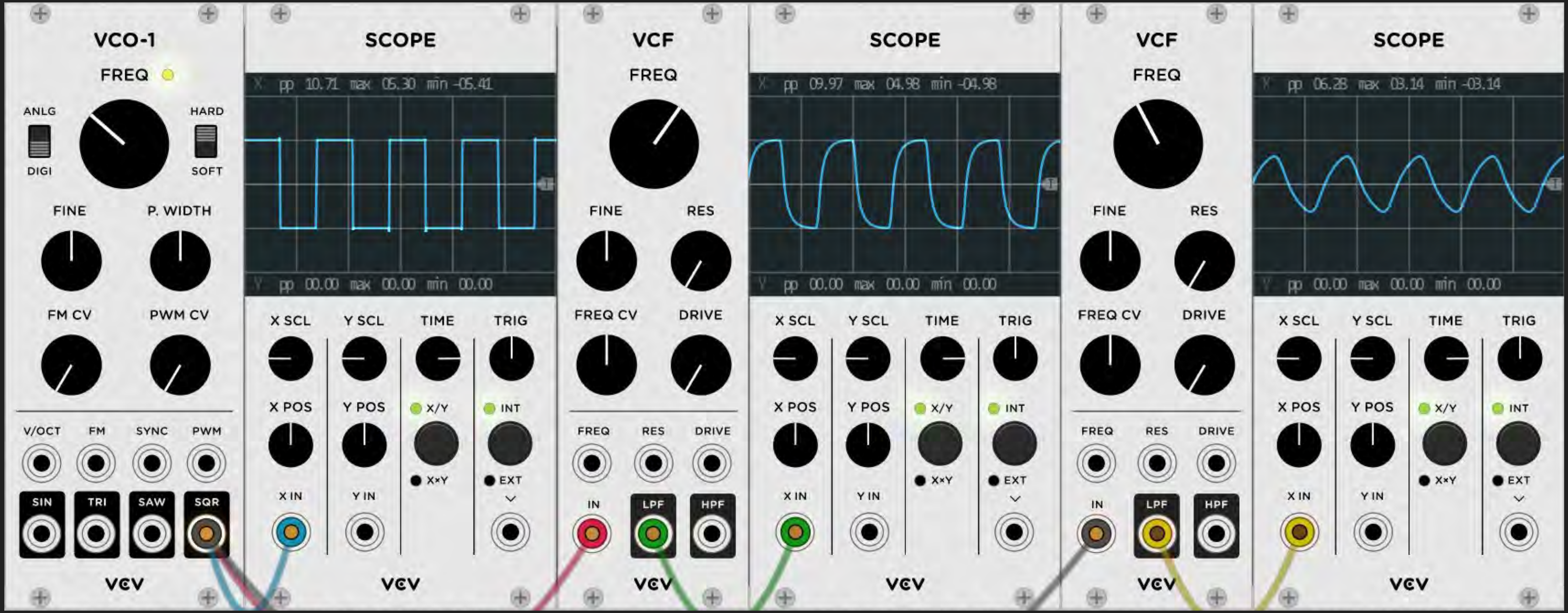
The Synthesizer Voice - VCO

The simplest form of VCO would be the square wave generator. Though our simplest sound wave is a sine, the square is the simplest form of oscillation to produce electronically.

This is achieved through alternating high and low voltages. A unipolar oscillator would produce 0v to +10v, but in this case we see that our signal is bipolar and travels from - 5v to + 5v.

The Synthesizer Voice - VCO

By utilizing a slew or LPF, effectively we increase the amount of time required to rise or fall from low to high voltages. This then changes the shape of our wave.



The Synthesizer Voice - VCF

The filter in synthesis is similar to the 1-band equalizer in audio recording or production technologies.

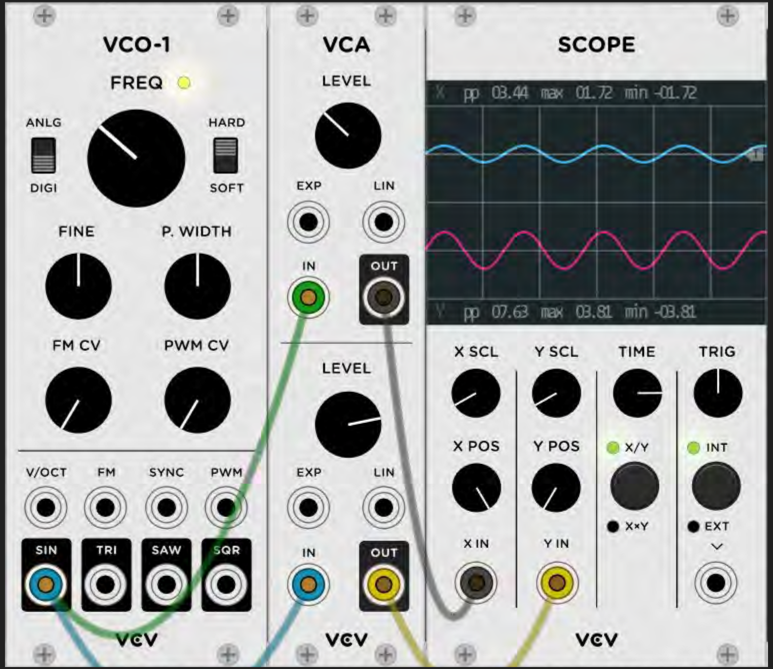
A LPF is a single band that removes frequency information above its threshold. While a high-pass filter (HPF) is the opposite; removing frequency information below the desired threshold.

On the VCV Rack - Fundamental VCF, both LPF and HPF options are available simultaneously.

The Synthesizer Voice - VCA

As we saw with the aperiodical example, a VCA is utilized to control the amplitude of a sound over time. However, by itself, the VCA only sets a static level for its output.

To enable the VCA to modify the amplitude over time, we need to send a control signal or voltage (CV) to either of its inputs. Labelled 'EXP' and 'LIN' on the VCV Rack - Fundamental Dual VCA.



Control Voltages

There are many ways to provide control voltage (CV) to the voice of the synthesizer. These are some of the standard generators.

Low Frequency Oscillator (LFO)

Envelope Generator (EG)

Sample & Hold / Random Voltages

Keyboard / Touchpads

Step Sequencers

Control Voltages - LFO

The low frequency oscillator (LFO), is effectively the same as a VCO. The only difference is the Hertz range of the LFO.

Typically, a VCO runs between the audible spectrum for human hearing. Being 20 Hz to 20 kHz.

A LFO runs below the point of audio (0.01 Hz to 20 Hz) and into the lower register of hearing (~200 Hz).

Control Voltages - LFO

On the VCV Rack - Fundamental LFO-1, we can see the LFO has the following controls:

Frequency control, CV inputs for frequency modulation (FM), pulse width control, pulse width modulation (PWM) input, reset input, and two switches for polarity and phase.

The LFO is a CV generator that is capable of being modulated by CV as well. These controls is where we begin to break away from the fundamental waveforms.

Control Voltages - LFO

Below is both an example of a LFO receiving FM and a square wave LFO with pulse width changes.

Control Voltages - EG

A standard form of envelope generator (EG) is the ADSR envelope.

A - Attack
D - Decay
S - Sustain
R - Release

To enable an EG, a gate is required. These can be generated with a square wave LFO, keyboard, or step sequencer.

Control Voltages - EG

As depicted in the image, the four stages of ADSR activate depending on the length of the gate received.

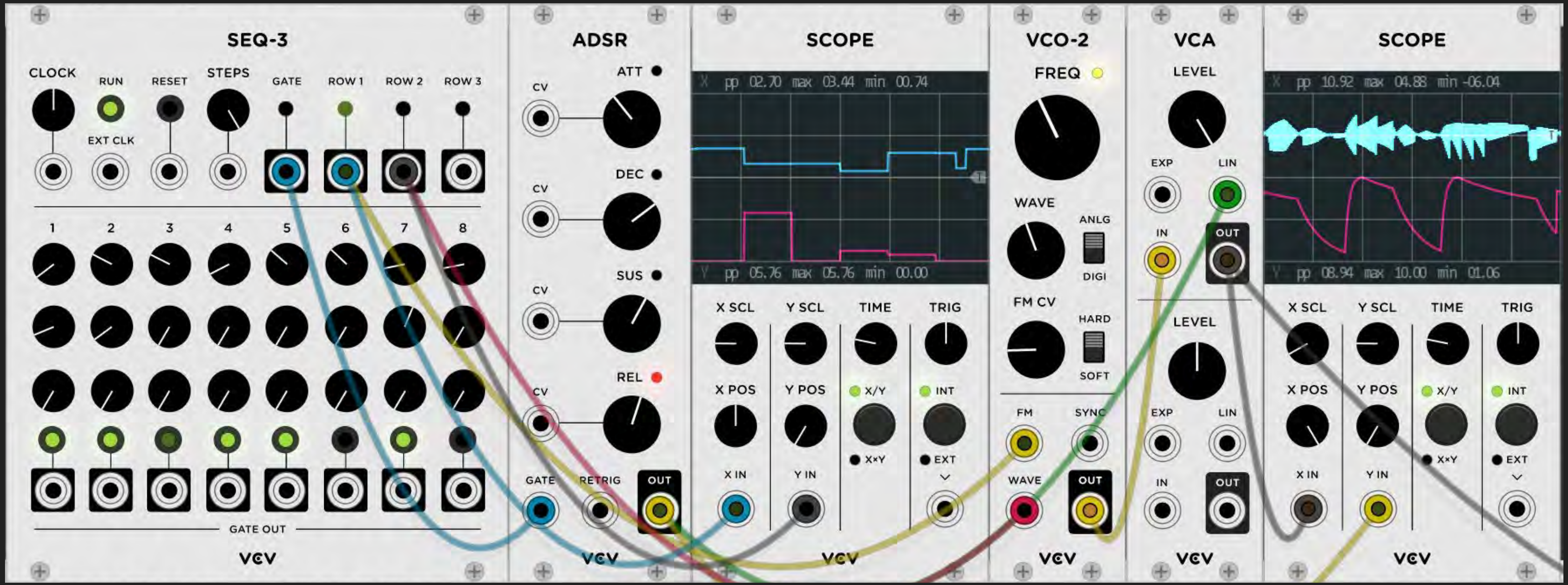
The attack begins when the gate first rises. After the attack has reached + 10v, the decay stage begins. Lowering the height to the voltage determined by the sustain. This is held until the gate falls. After, the release stage activates; falling the rest of the way to 0v.

Control Voltages - EG + VCA

In conjunction with a VCA, the EG is the standard method to modulate amplitude over time. This could also be used with a filter.

Control Voltages - Sequencers

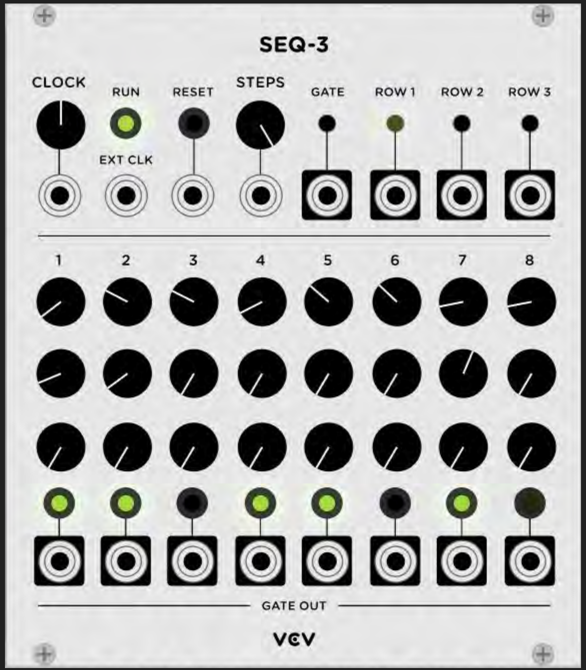
With the VCV Rack - Fundamental SEQ-3, we can generate a more rhythmic pattern than a LFO with both gates and unipolar voltages.



Control Voltages - Sequencers

A basic step sequencer has at least a clock or gate input to tell it when to move from one step to another. The VCV Rack - Fundamental SEQ-3 has an internal clock and rate control. This translates to beats per minute (BPM).

Each time the clock produces a high voltage, the sequence moves forward. This sequencer has a variable step count, between 1 and 8 steps.



Control Voltages - Sequencers

On a standard step sequencer, we might only have a single row of values to select. These values are output and sent to a variety of things, but typically the frequency CV input on your VCO is the place to start.

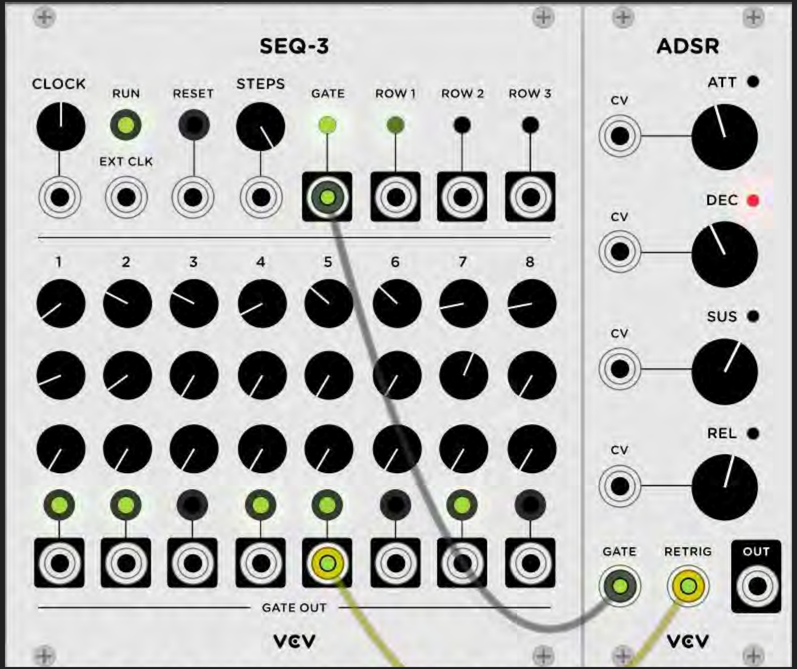
This input is often labelled 1v/o for ‘1 volt per octave’. Utilizing a sequencer, we can send CV to the VCO in order to create a movement in pitch. The 1v/o input is the most accurate for tuned changes.

Control Voltages - Sequencers

In addition to the CV sequence, we have a gate sequence and individual gate outputs per step.

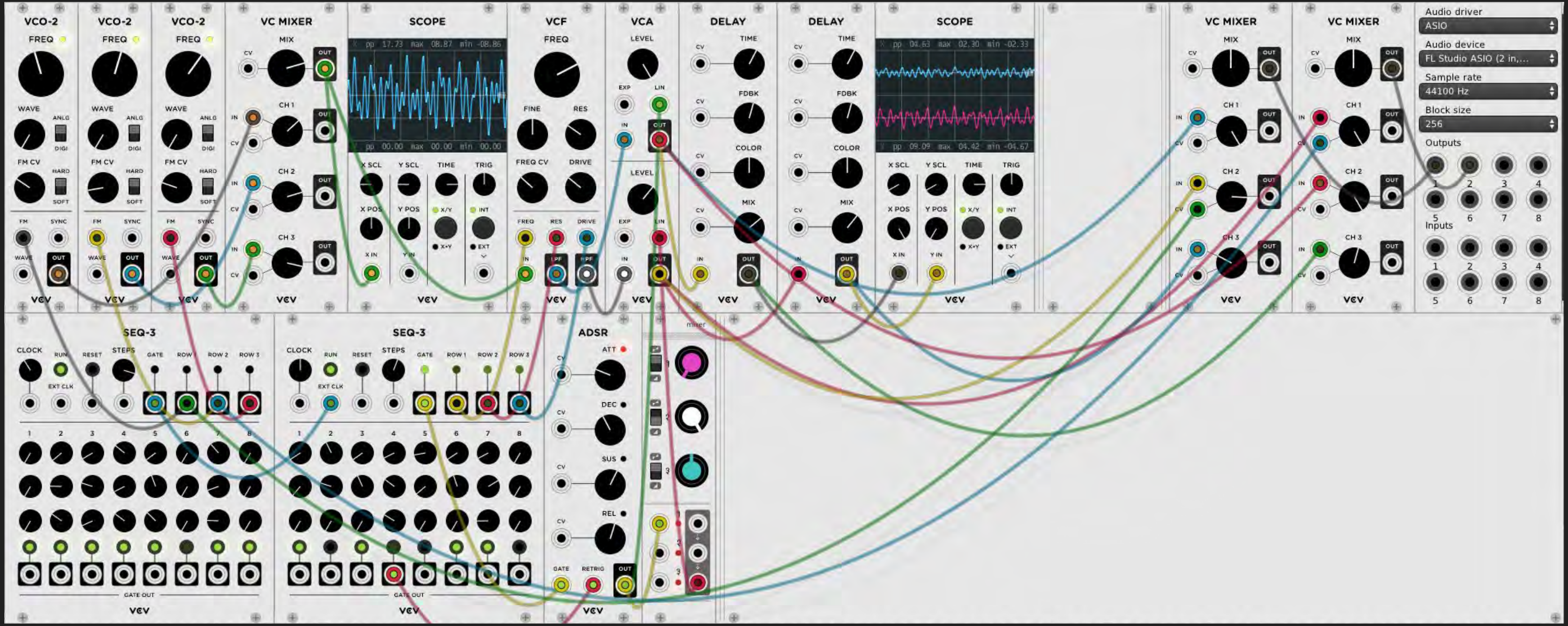
These can be used to drive EGs or reset LFOs, even clock additional sequencers!

Here we see the main gate sequence activating an EG while the individual gate output on step 5 ‘retriggers’ the EG.



Experimenting with Synthesis

Some of the best ways to get to know how a synthesizer works is to simply patch away and see how things interact!



References

Belt, Andrew. *VCV Rack v0.5.0*. 2017.

Crombie, David. *The Complete Synthesizer: A Comprehensive Guide*. PDF. 1984.