Sound Synthesis

Fundamentals of artificial sound generation
(or: how to comprehend a synthesizer)

Artur Twardowski

About me

Artur Twardowski

ARTURO DURO 'EL ROMPEDOR'

Programmer since 2001

working in Mobica since 2014

Interested in music since ever

creating music since 2004

user of LMMS since 2016

2004 – 2006: Music MasterWorks
2006 – 2009: trackers
2009 – 2016: FL Studio
2016 – 2022: LMMS

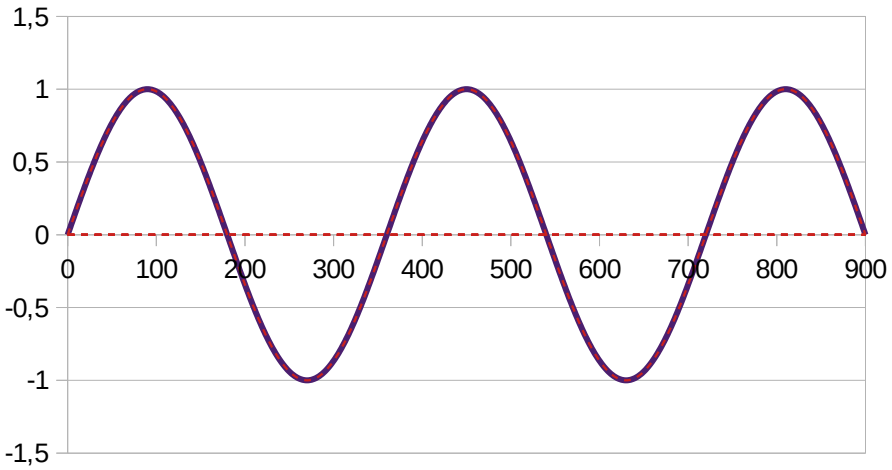
About this presentation

- Pure, but dull analog oscillations
  - Additive synthesis
  - Envelopes
- Impure, but interesting analog oscillations
  - A bit of maths ;)
  - Subtractive synthesis
  - Filters
- Pure, but harsh digital oscillations
  - Frequency modulation synthesis

Vibrators ;)

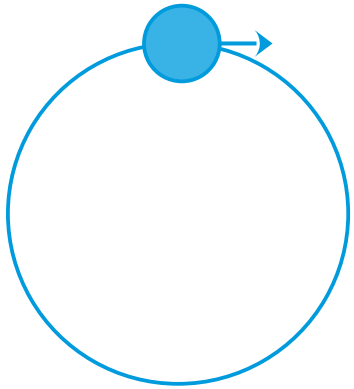
Sources:
https://pl.wikipedia.org/wiki/Skrzypce#/media/Plik:Violin_VL100.jpg
https://pl.wikipedia.org/wiki/Pianino#/media/Plik:Pianino_Legnica_inside.jpg
https://pl.wikipedia.org/wiki/Organy#/media/Plik:Organy_Wo%C5%BAniki.jpg

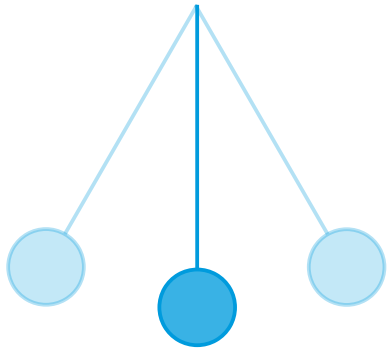
A fundamental oscillation



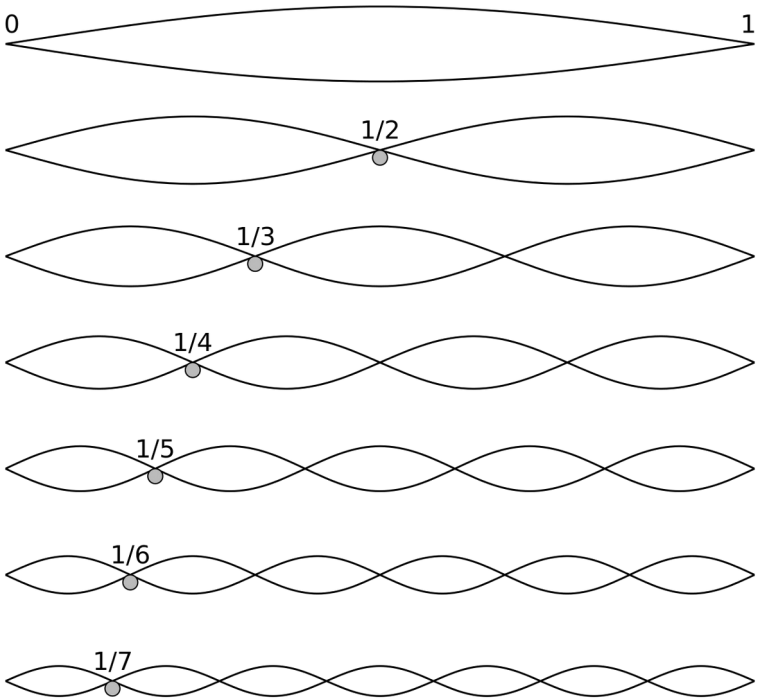
Sine wave

y=sin(x)

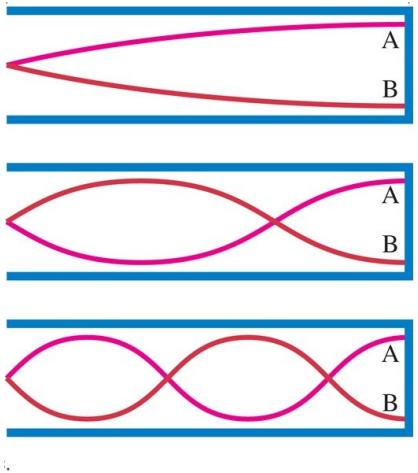




Standing wave

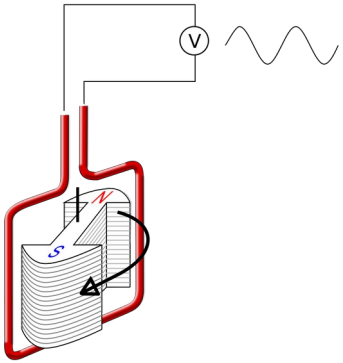


Harmonic frequencies
(overtones)

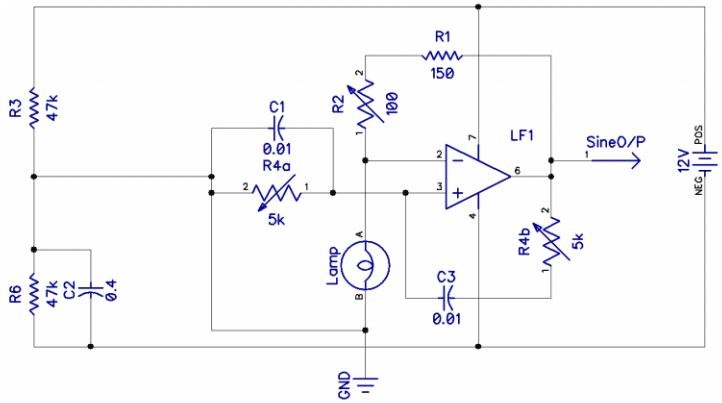


Sources:
https://pl.wikipedia.org/wiki/Harmoniczna#/media/Plik:Harmonic_partials_on_strings.svg
https://www.acs.psu.edu/drussell/demos/standingwaves/standingwaves.html

Oscillator



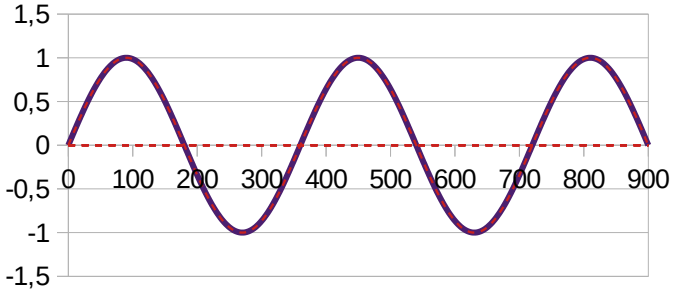
Source: https://en.wikipedia.org/wiki/Alternator#/media/File:Alternator_1.svg



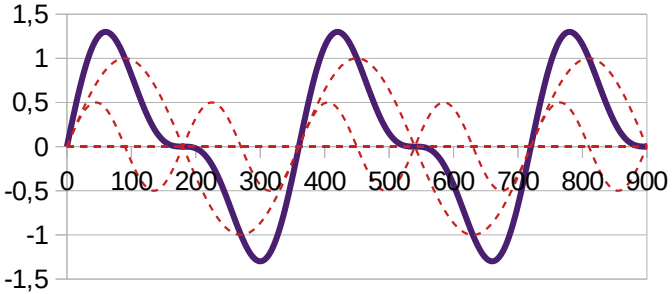
Wien Bridge Oscillator

Source: https://www.circuitbasics.com/sine-wave-generators/

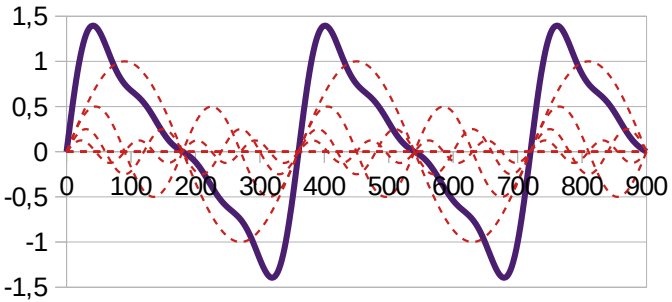
Additive synthesis



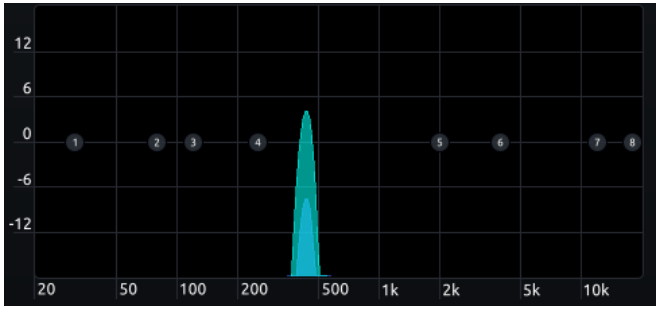
Sine wave y=sin(x)



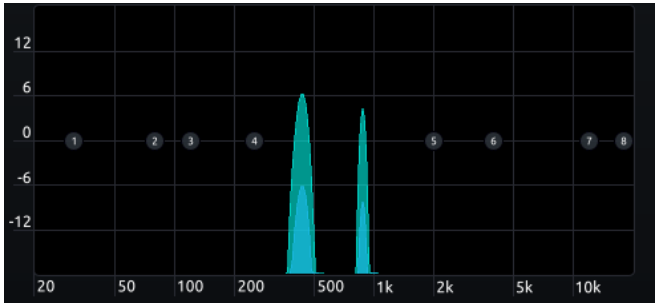
y=sin(x) + 0.5sin(2x)



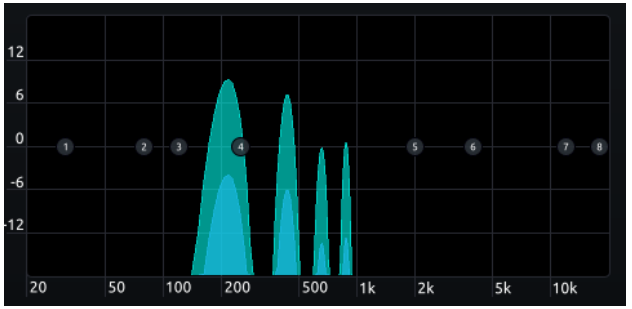
y=sin(x) + 0.5sin(2x)
+ 0.25sin(3x) + 0.125sin(4x)



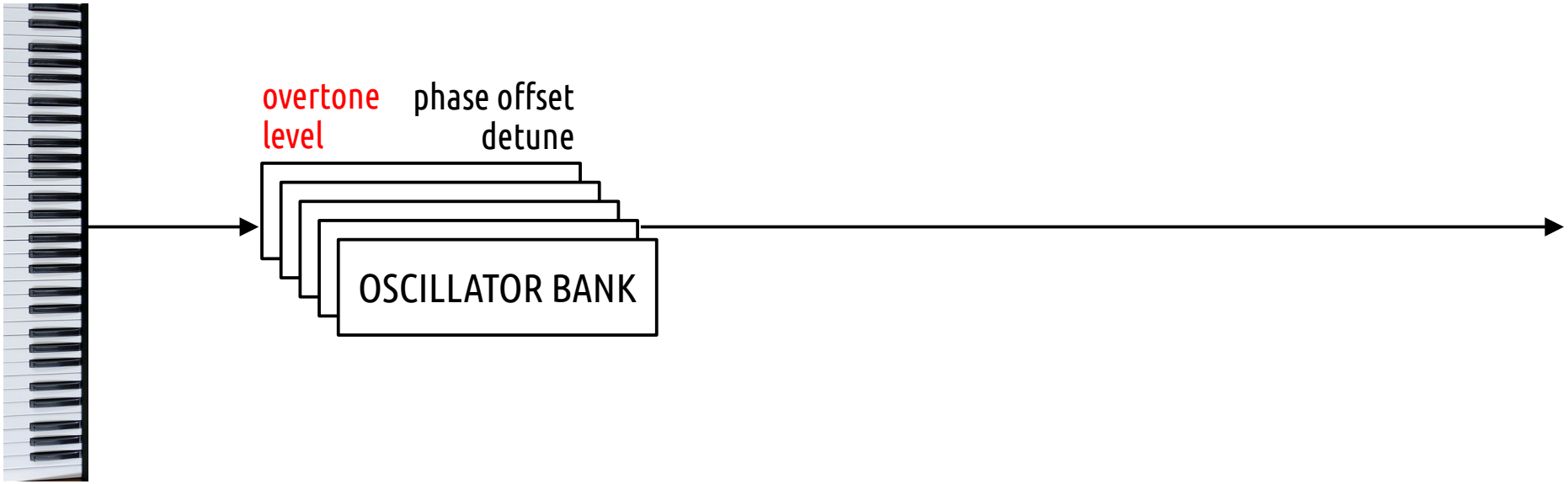
a^1=440 Hz (A4)



(phase shifts deliberately omitted)



Additive synthesis



Additive synthesis - demo

LMMS built-in additive synth

Overtone selection

Waveform

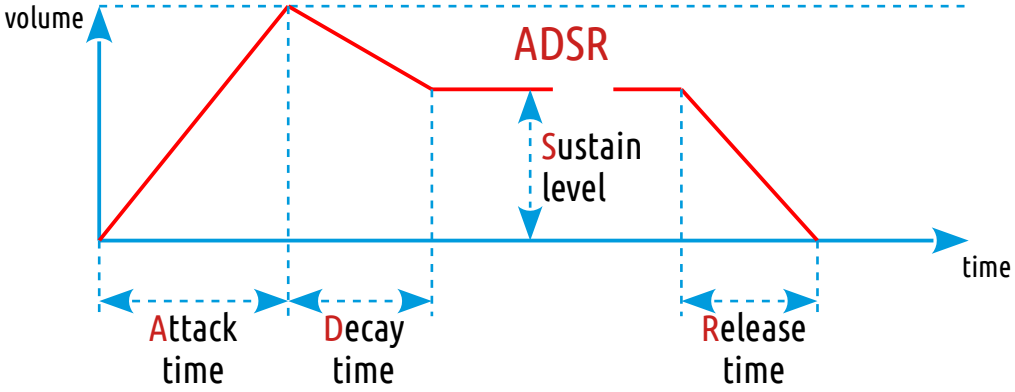
Overtone level

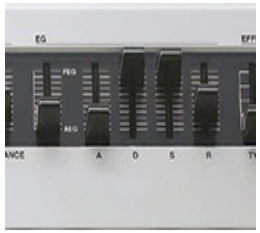
Panning

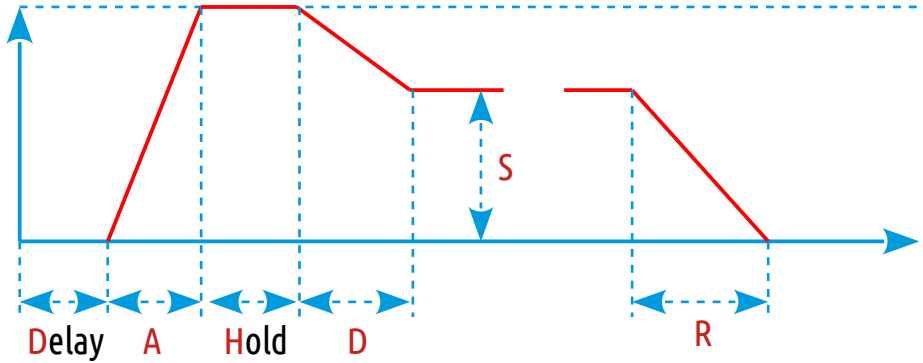
Detune

0 dB	= 1
-3 dB	= ½
-6 dB	= ¼
-9 dB	= ⅛
-10 dB	= 1/10
-20 dB	= 1%
-30 dB	= 1‰
-60 dB	= 1 ppm

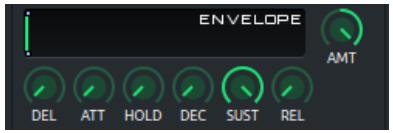
Envelope



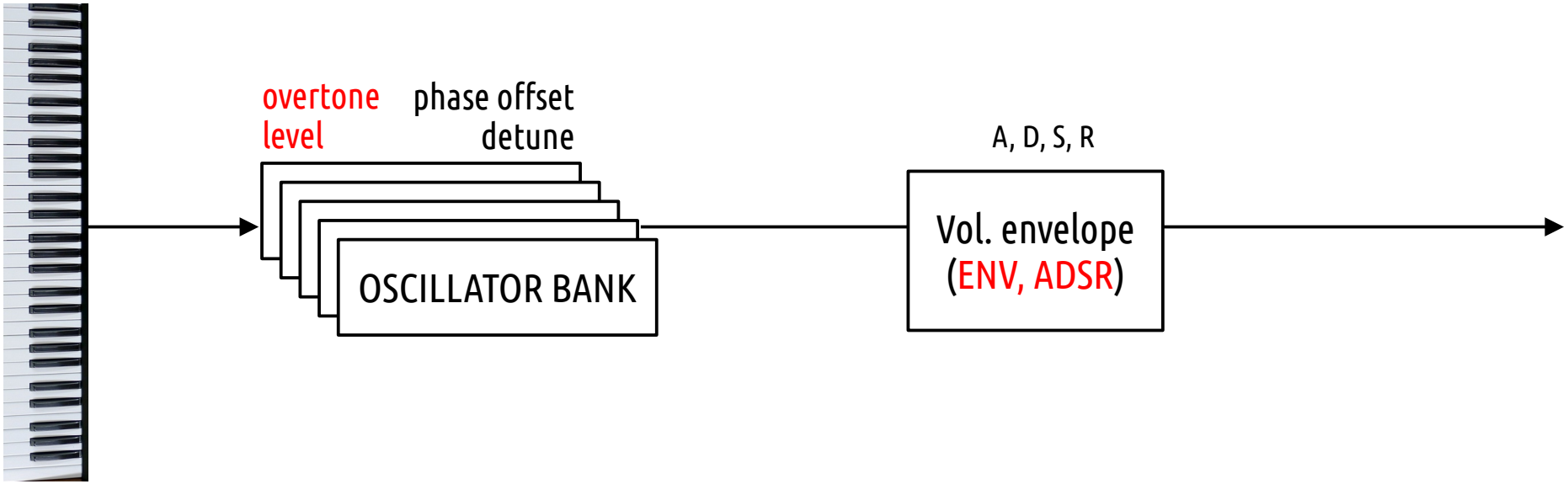




Zero envelope:
All times set to 0 (A, D, R, delay, hold, etc.)
All levels set to max (S)



Additive synthesis



Demonstration - Additive synthesis with envelope

Additive synthesis - problems

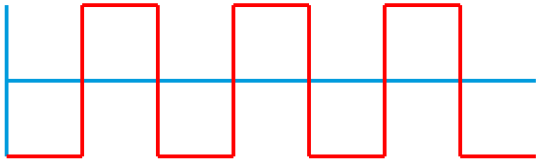
Good sine wave generator is difficult to build

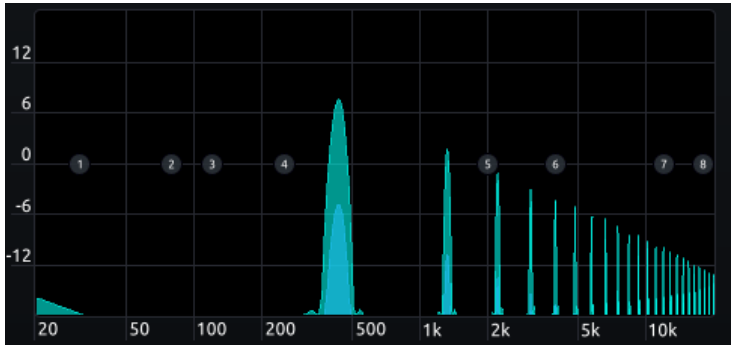
Multiple generators needed for single voice

Still limited number of overtones

Maybe there is a better solution...

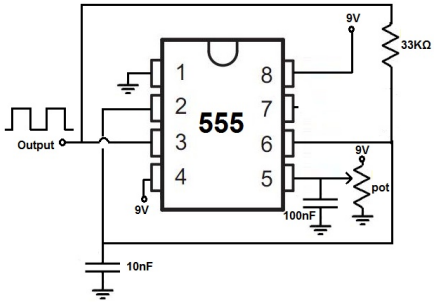
Square wave





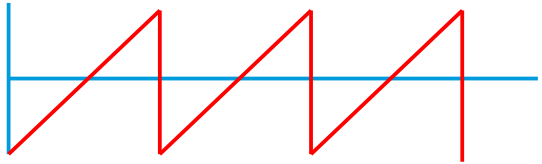
$$y = \sin(x) + \frac{1}{3}\sin(3x) + \frac{1}{5}\sin(5x) + \frac{1}{7}\sin(7x) + \ldots$$

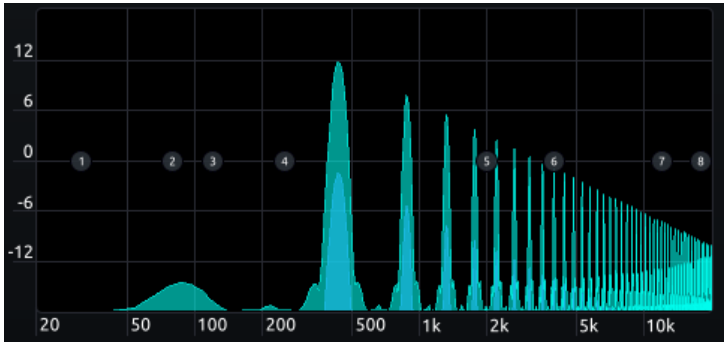
$$y = \sum_{n=1,3,5,\ldots} \frac{1}{n}\sin(nx)$$



Source: http://www.learningaboutelectronics.com/Articles/Voltage-controlled-oscillator-VCO-circuit-with-a-555-timer.php

More waveforms

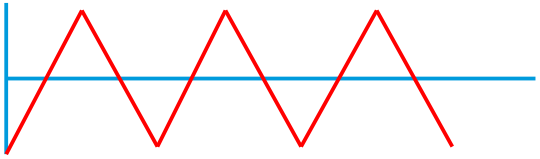


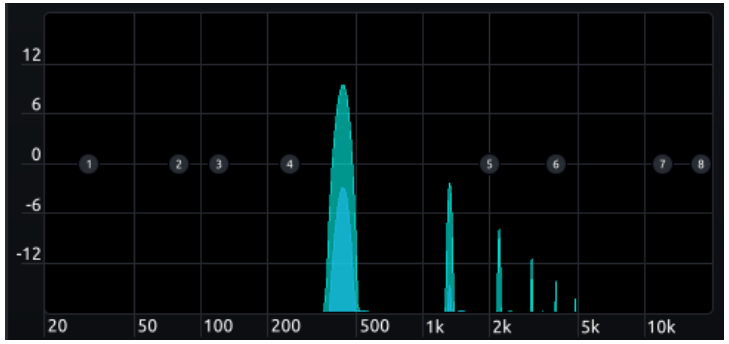


Sawtooth wave

$$y = \sin(x) + \frac{1}{2}\sin(2x) + \frac{1}{3}\sin(3x) + \frac{1}{4}\sin(4x) + \ldots$$

$$y = \sum_{n} \frac{1}{n}\sin(nx)$$



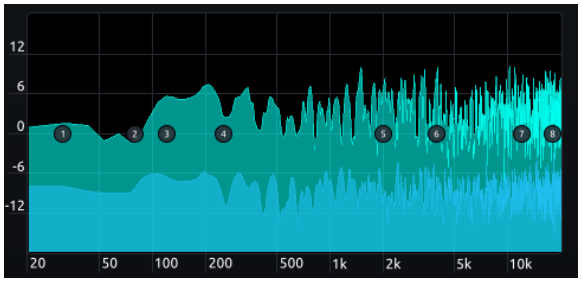


Triangular wave

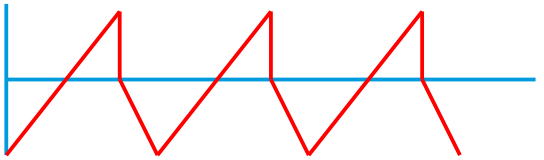
$$y = \sin(x) + \frac{1}{9}\sin(3x) + \frac{1}{25}\sin(5x) + \frac{1}{49}\sin(7x) + \ldots$$

$$y = \sum_{n=1,3,5,\ldots} \frac{1}{n^2}\sin(nx)$$

Even more waveforms

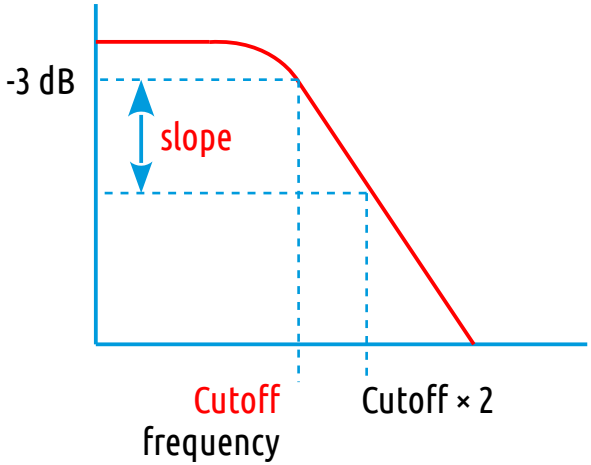


White noise

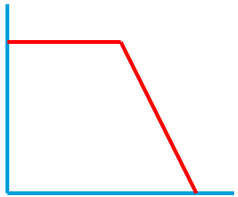


Moog sawtooth-triangle

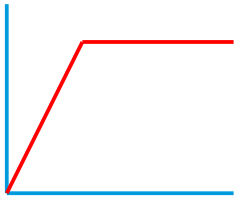
Filters



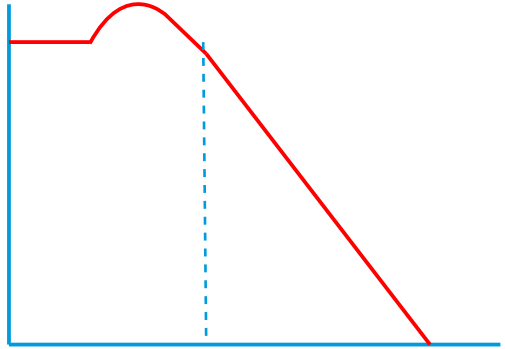
Slope: dB/oct (or dB/dec)



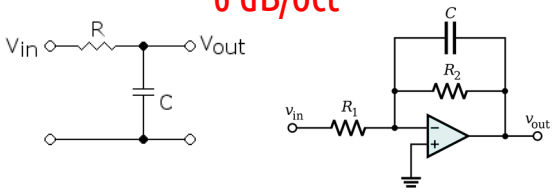
Low-Pass Filter



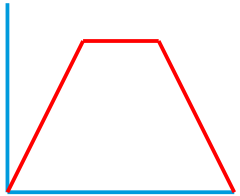
High-Pass Filter



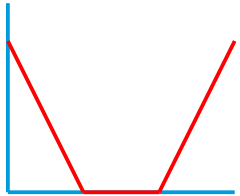
6 dB/oct



Source: https://pl.wikipedia.org/wiki/Filtr_dolnoprzepustowy



Band-Pass Filter

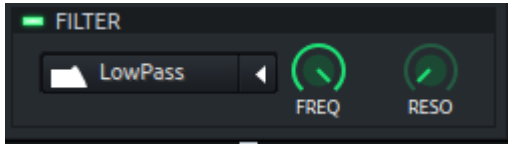


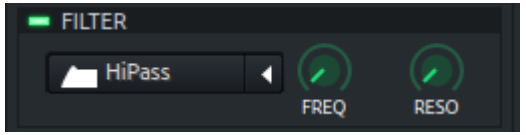
Notch Filter

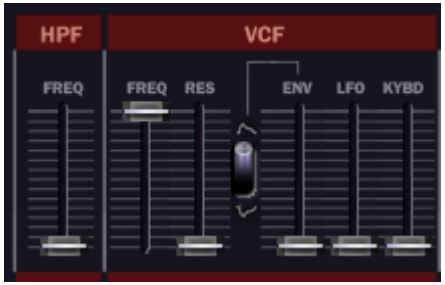
All-Pass Filter

Filters

Zero filter:
Resonance to minimum
Cut-off frequency:
- for LPF: maximum
- for HPF: minimum
ENV, LFO, etc. - usually to minimum





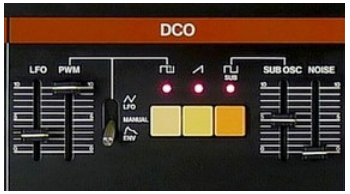


Subtractive synthesis

key (note)
velocity
pressure (aftertouch)

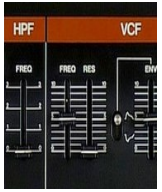
waveform(s)
levels

Oscillator
(OSC, DCO)



cutoff frequency
resonance

Filter
(VCF)



A, D, S, R

Envelope
(ENV, ADSR)

Subtractive synthesis

key (note)
velocity
pressure (aftertouch)

waveform(s)
levels

Oscillator
(OSC, DCO)

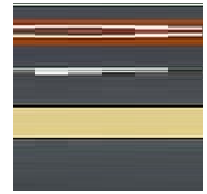
cutoff frequency
resonance

Filter
(VCF)

A, D, S, R

Vol. envelope
(ENV, ADSR)

Other effects
(chorus, reverb,
equalizer, etc.)



waveform
frequency
phase

Low frequency
oscillator
(LFO)

A, D, S, R

Filter envelope

Subtractive synthesis – hardware

Minimoog

Yamaha CS-15

Roland Juno-60

Yamaha reface CS

Demonstration - Subtractive synthesis

Free VST by Togu Audio Line – U-NO-62
Recreation of Roland Juno-60

Tuning knob, master volume, pitch bends, some extra controls, chorus.

Oscillators:
- sawtooth
- square wave with PWM
- square wave sub-bass
- white noise

PWM can be controlled with LFO or volume envelope

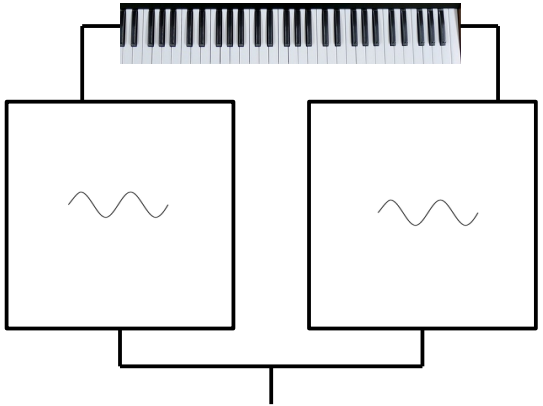
Filters:
- HPF with adjustable cutoff frequency
- LPF with adjustable cutoff freq and Q

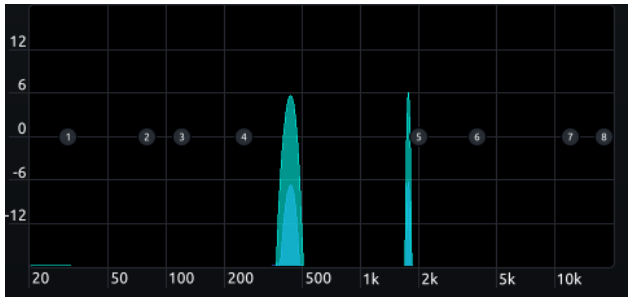
LPF's cutoff freq can also be controlled by LFO or volume envelope

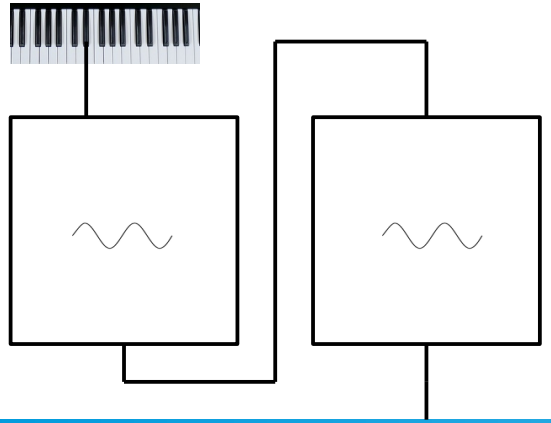
1 envelope, for volume (can control PWM and filter cut-off as well).

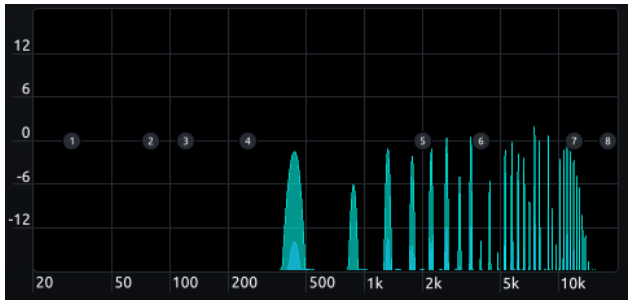
We can turn the envelope into gate

Frequency Modulation synthesis

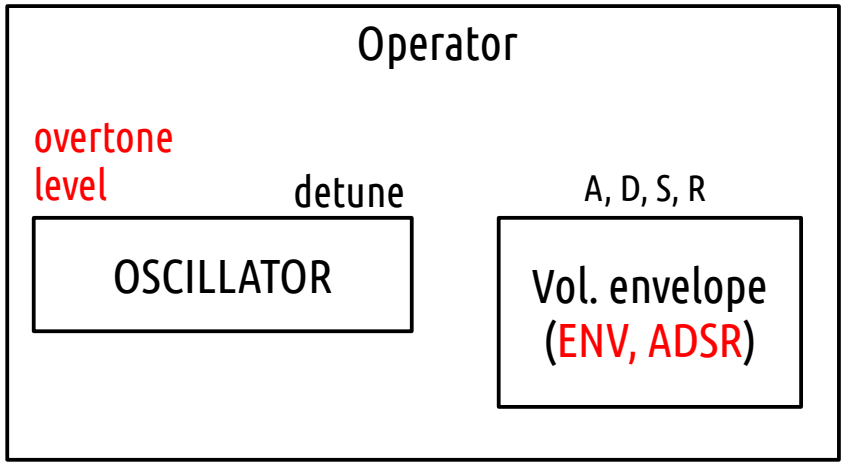




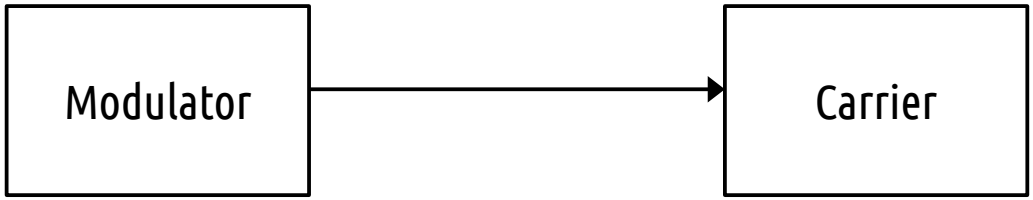




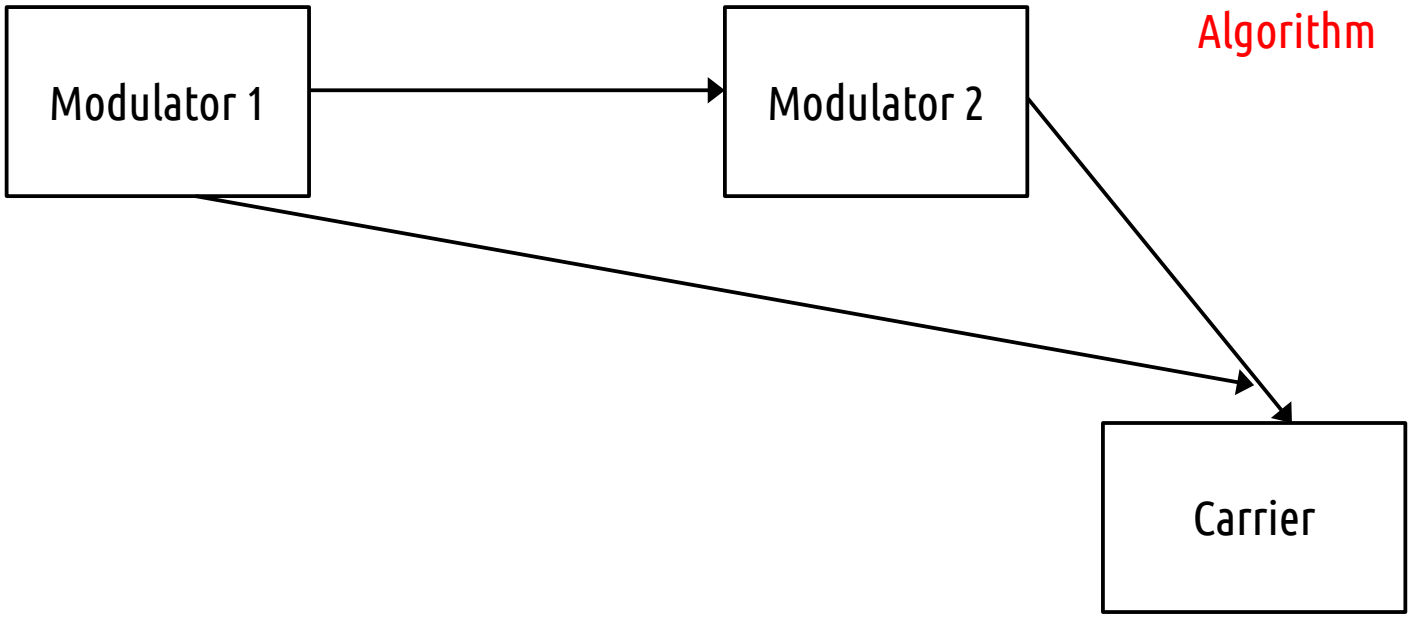
Frequency Modulation synthesis



Frequency Modulation synthesis

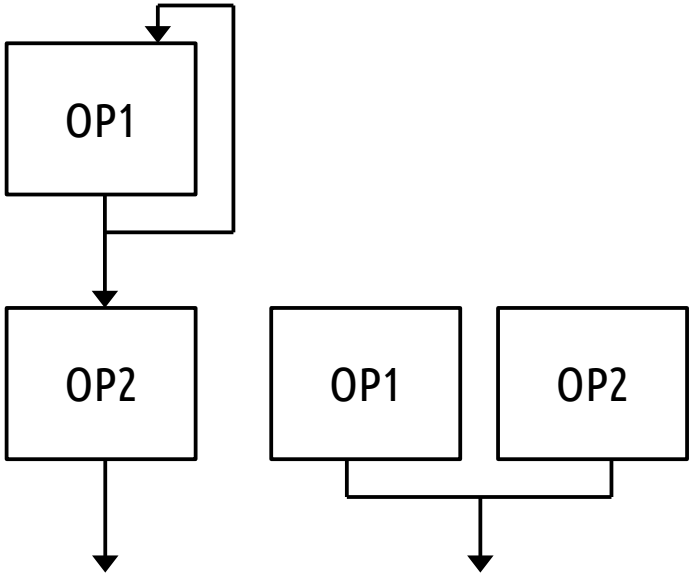


Frequency Modulation synthesis

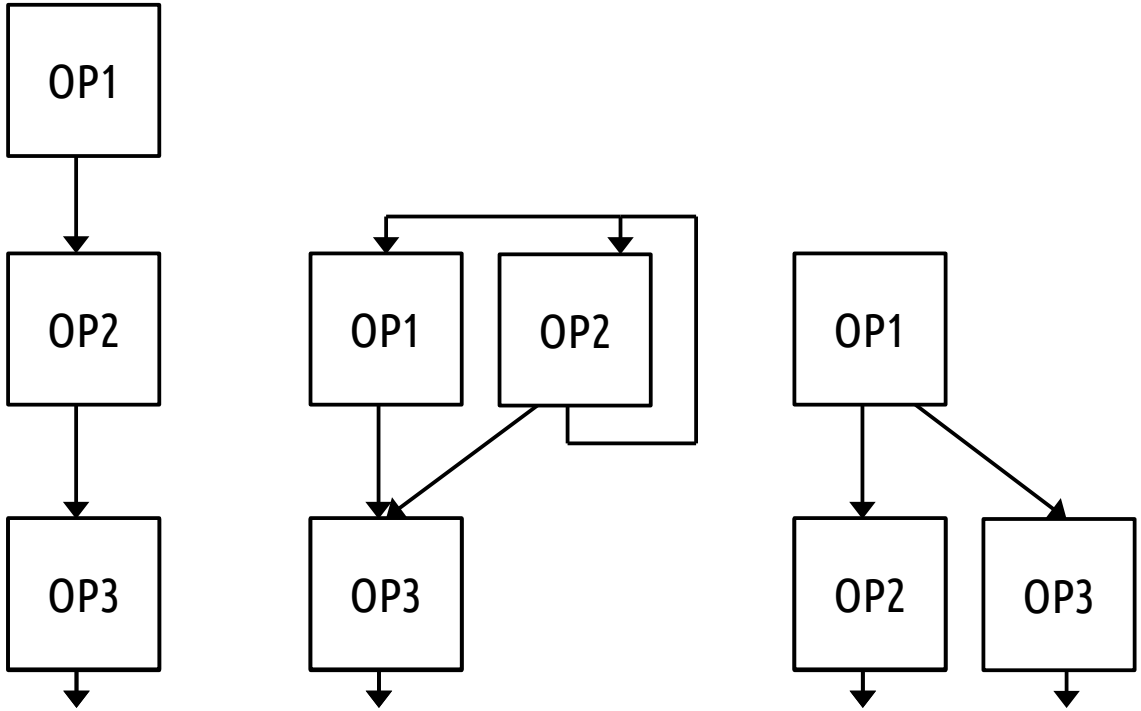


Frequency Modulation synthesis – examples of algorithms

two-operator FM synth



three-operator FM synth



FM synthesis – hardware

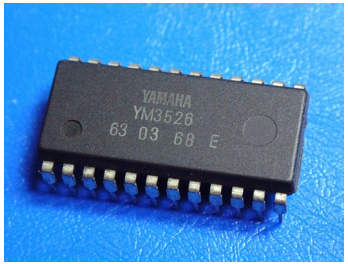
Yamaha DX7

6-operator

Yamaha reface DX

4-operator

Yamaha OPL



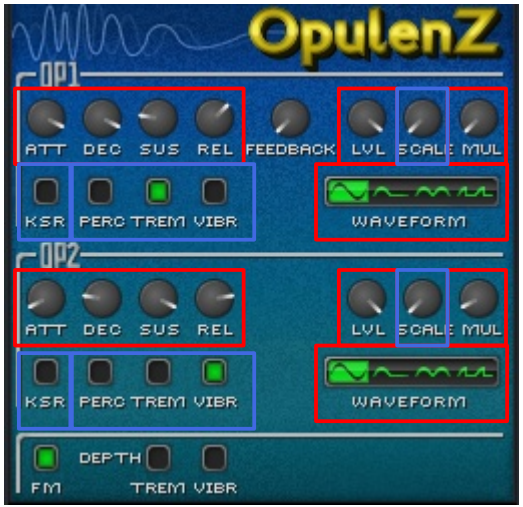
OPL – YM3526 – Sound Expander for C64
OPL2 – YM3812 – AdLib/SoundBlaster
OPL3 – YMF262 – SoundBlaster 16

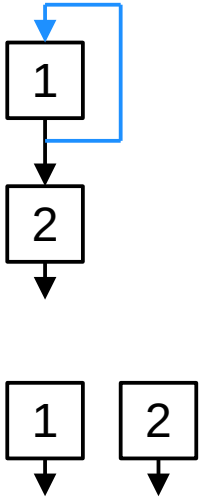
2-operator

Sources:
https://upload.wikimedia.org/wikipedia/commons/f/f7/Yamaha_DX7IID.jpg
https://pl.yamaha.com/pl/products/music_production/synthesizers/reface/reface_dx.html
https://en.wikipedia.org/wiki/Yamaha_OPL#/media/File:Yamaha_YM3526.png

Frequency Modulation synthesis - demo

LMMS built-in two-operator FM synth inspired by OPL2 (Yamaha YM3812).





Separate volume envelope for each operator

4 waveforms to choose from:
sine, half-sine, absolute sine, quarter sine

Level adjustment for each operator

Frequency adjustment for each operator

Adjustable keyboard scaling

Percussive mode for each operator (removes sustain phase).

Vibrato and tremolo for each operator and for master signal.

More synthesis

- Phase Distortion synthesis
- Sampling (sample-based synthesis)
- Wavetable
- Vector synthesis
- Granular synthesis
- Physical modelling synthesis

Questions?