

CTP431: Fundamentals of Computer Music

Digital Sound Synthesis



Graduate School of
Culture Technology

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Category of Sound Synthesis

- Abstract sound synthesis
- Sample-based synthesis
- Physical modeling

Abstract Sound Synthesis

- Use unit generators (oscillators) and modifiers (filters)
 - Highly parametric and programmable
 - Additive: a collection of sine oscillations
 - Subtractive: harmonic oscillator (sawtooth, square) + filter
 - Modulation: frequency modulation
 - Distortion: sine + distortion



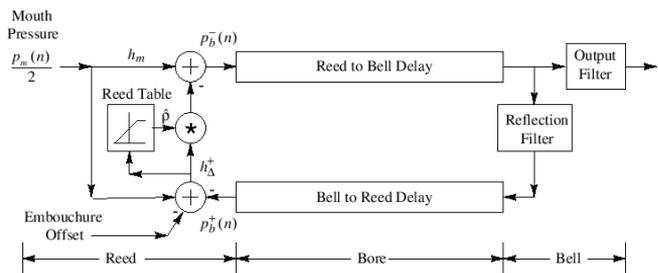
Sample-based Synthesis

- Use recorded samples
 - Require large memory
 - Natural tones but not flexible: pitch shifting by resampling
 - Concatenative synthesis: e.g. singing voice synthesis
 - Granular Synthesis



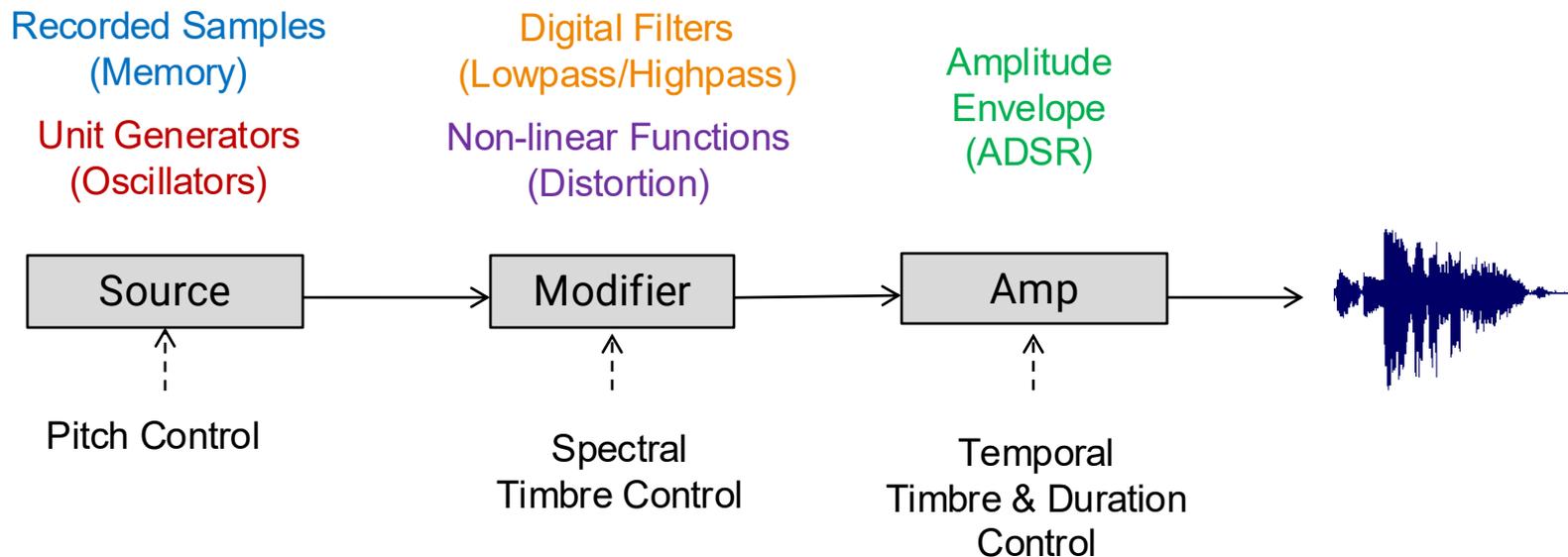
Physical Modeling sSynthesis

- Imitate the physical phenomenon of vibrating objects
 - Numerical modeling of wave equations: e.g. finite difference
 - Digital waveguide: efficient model based on delaylines
 - Physically interpretable parameters



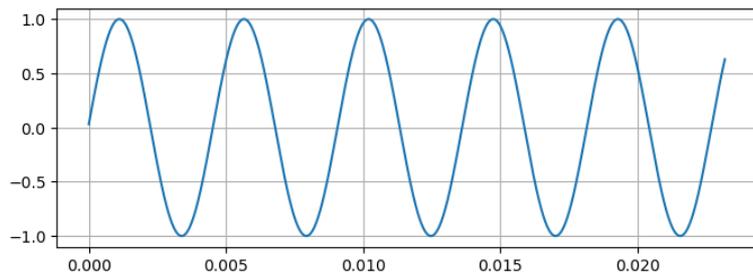
Tone Generation on Computer

- General framework

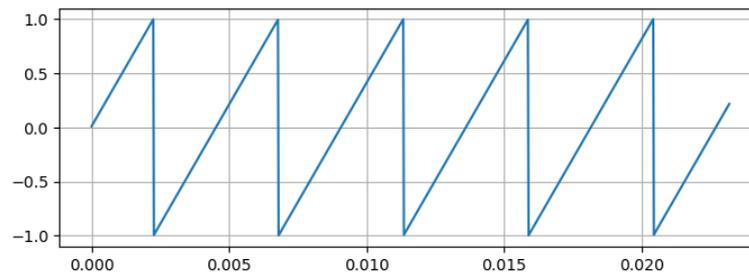


Unit Generators

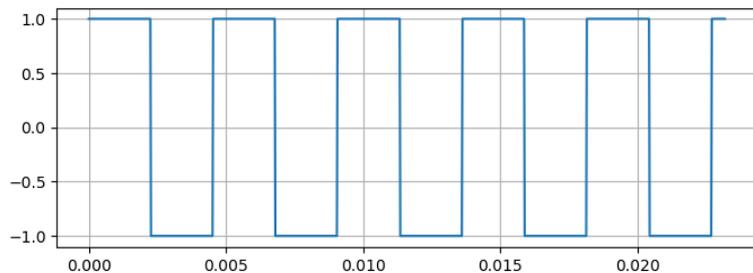
- Generate oscillators with classical waveforms
 - Parameters: frequency, pulse width (square osc)



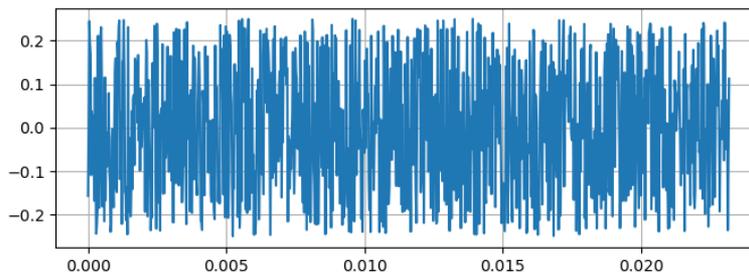
Sine



Sawtooth



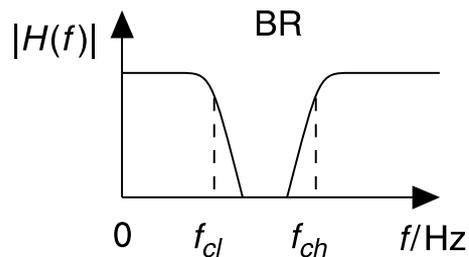
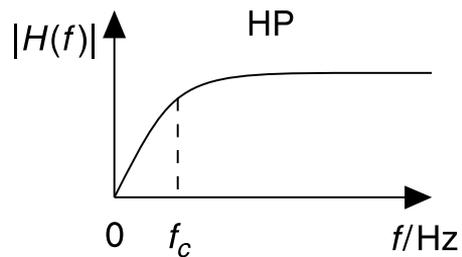
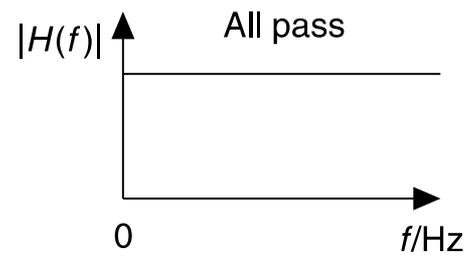
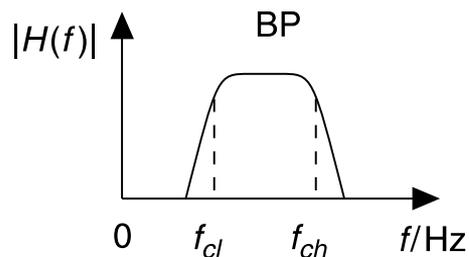
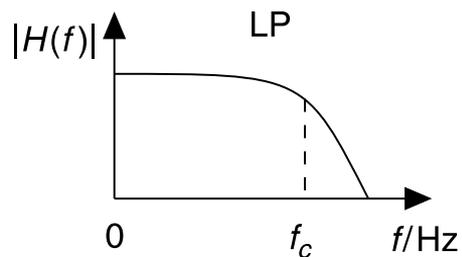
Square



Noise

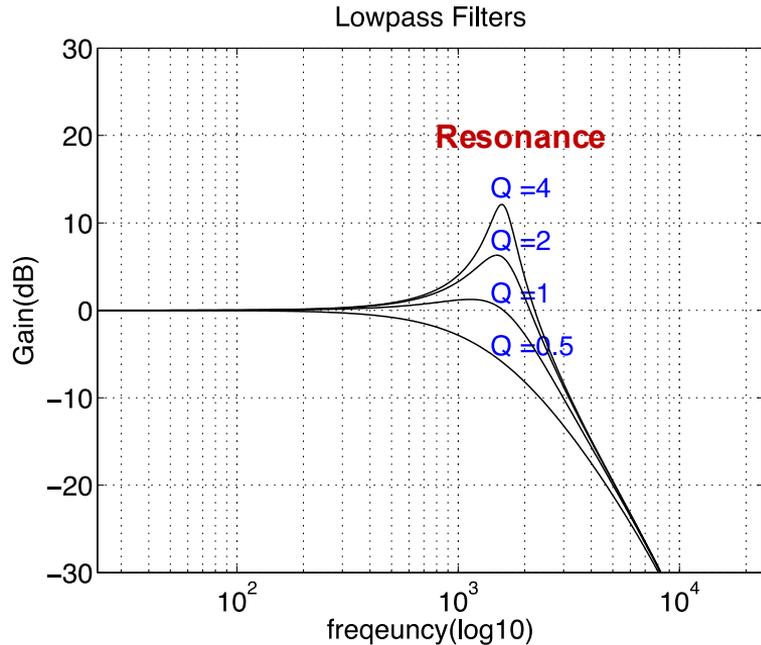
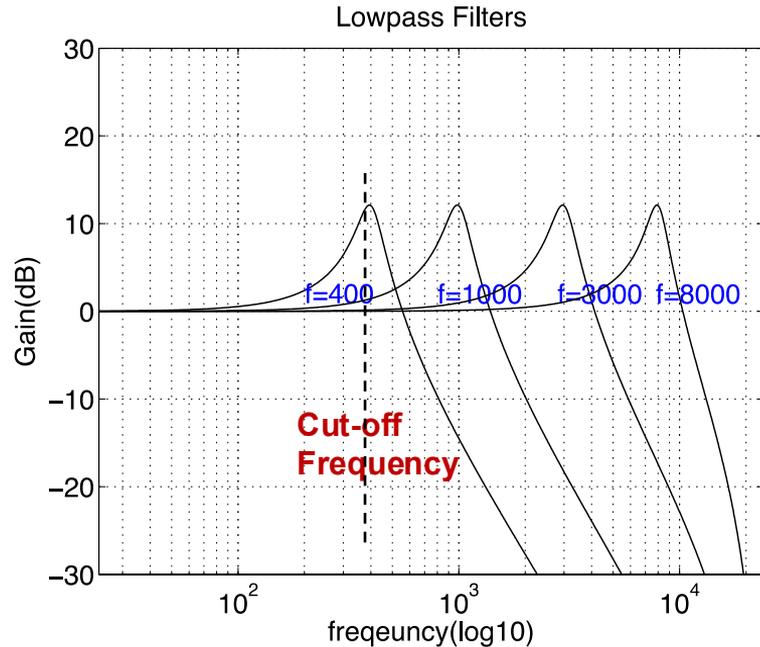
Filters

- Control the frequency response of the source signals
 - Types: lowpass, highpass, bandpass, bandreject (notch)
 - Parameters: cut-off/center frequency, Q



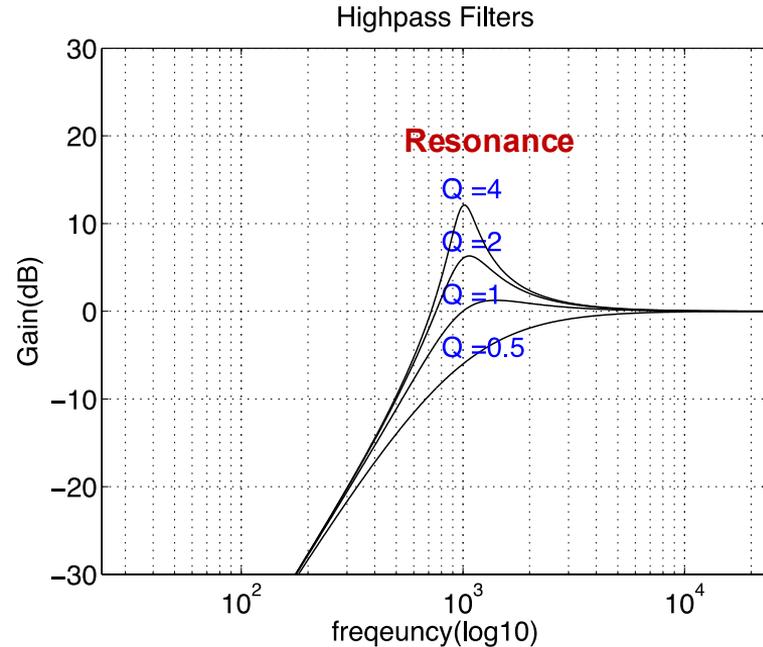
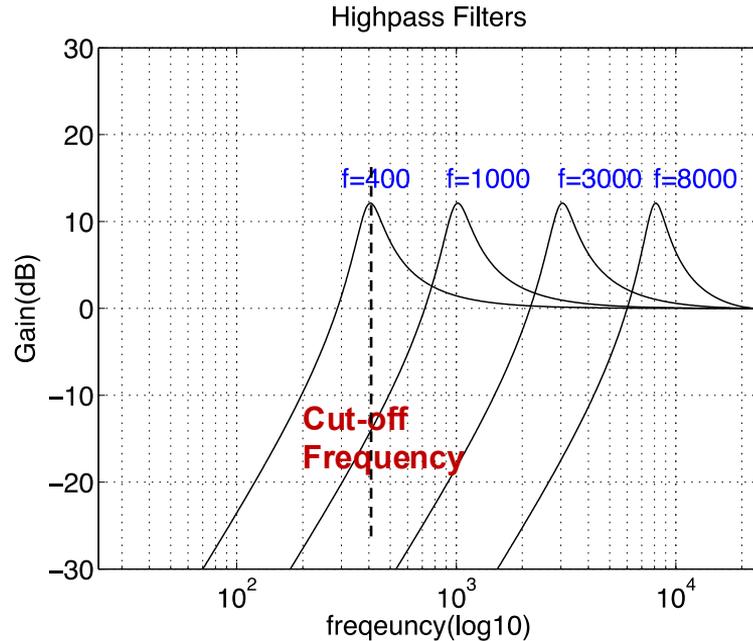
Resonant Lowpass Filter

- Suppress high-frequency content
 - With a resonance at the cut-off frequency



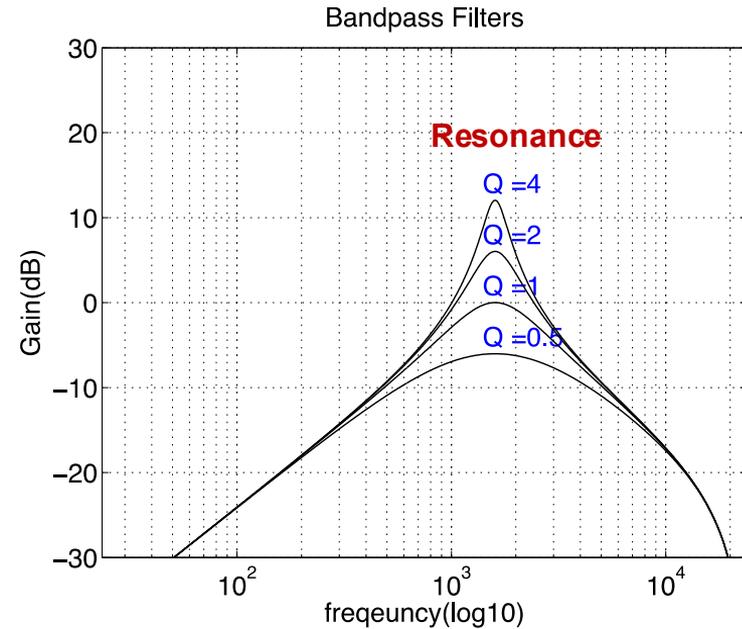
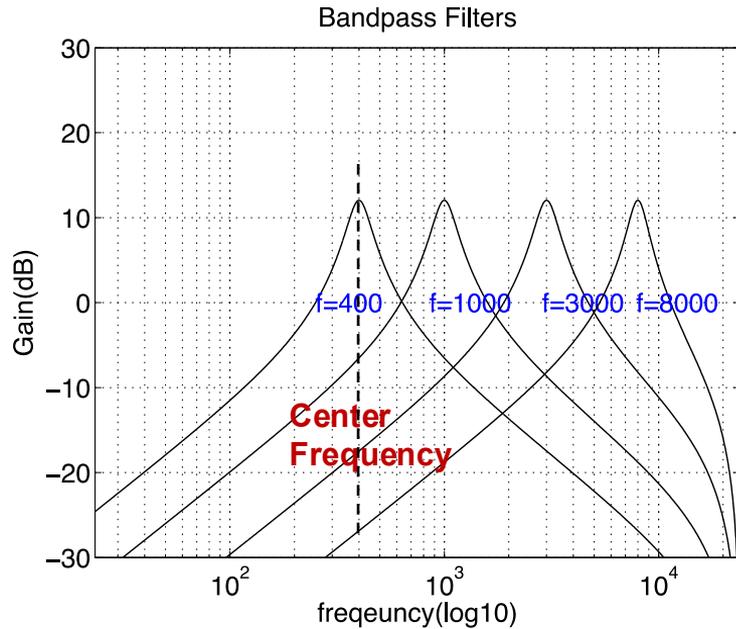
Resonant High-pass Filter

- Suppress low-frequency content
 - With a resonance at the cut-off frequency



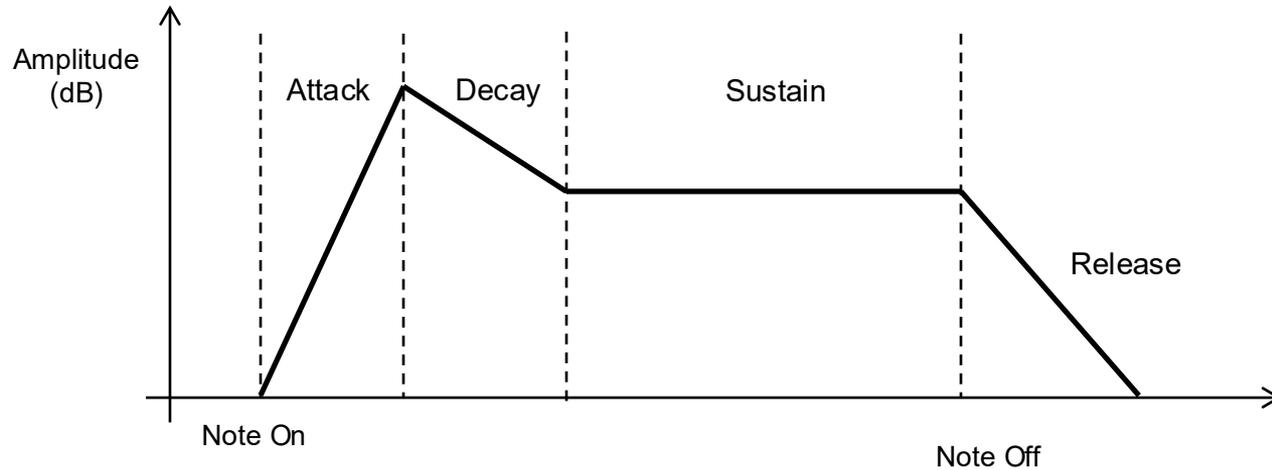
Bandpass Filter

- Suppress both low and high frequency content
 - Preserve the content around the center frequency



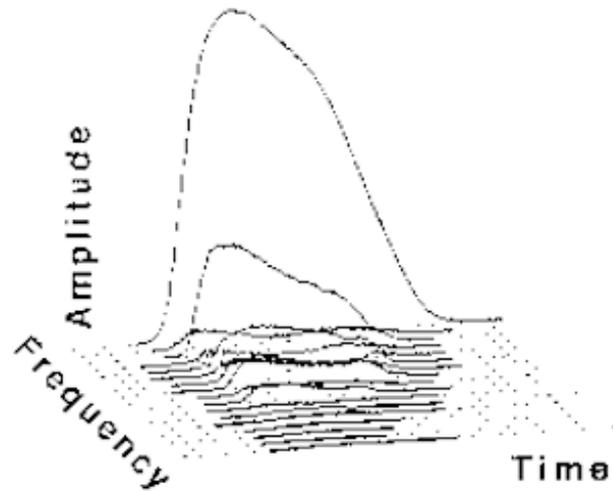
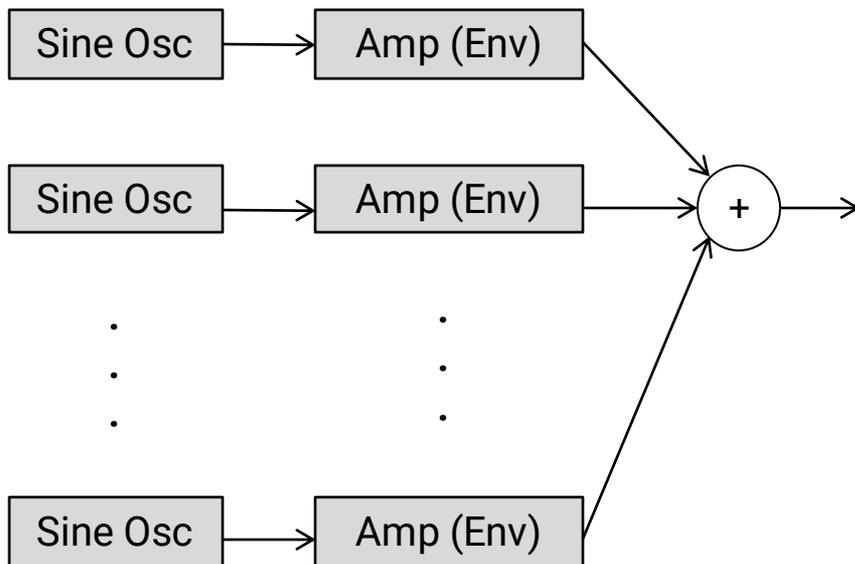
Amplitude Envelop Generator

- ADSR curve
 - Attack time, decay time, sustain level, and release time



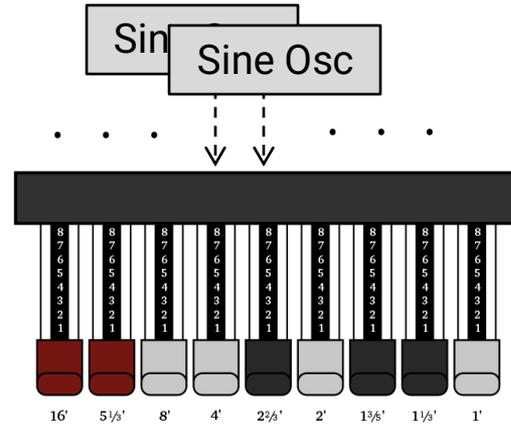
Additive Synthesis

- Synthesize sounds by adding multiple sine oscillators
 - The frequencies of sine oscillators are arbitrary: synthesize inharmonic tones



Hammond Organ

- Drawbars
 - Control the levels of individual tonewheels: harmonic sine oscillators

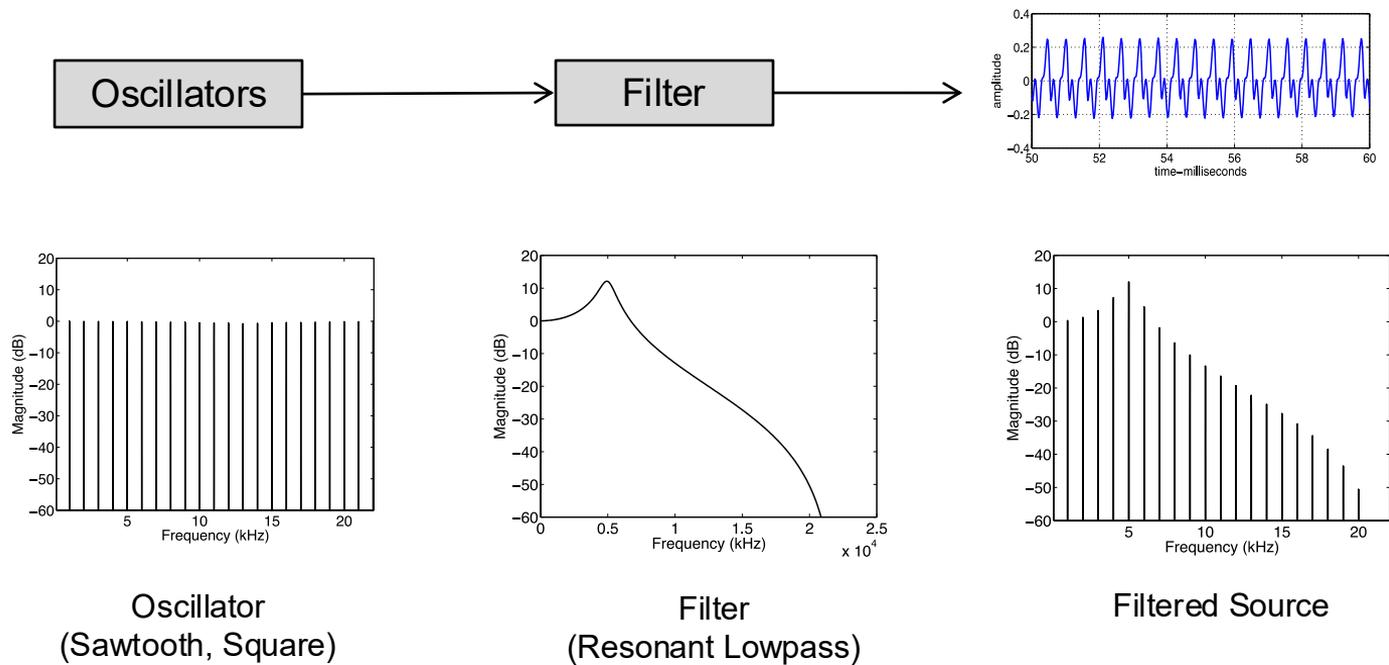


Examples

- Organ
 - <https://www.vdveen.net/webaudio/hammond/hammond.htm>
- Bell
 - <https://aatishb.com/synthesine/examples/bell-additive/index.html>

Subtractive Synthesis

- Synthesize sounds by filtering wideband oscillators



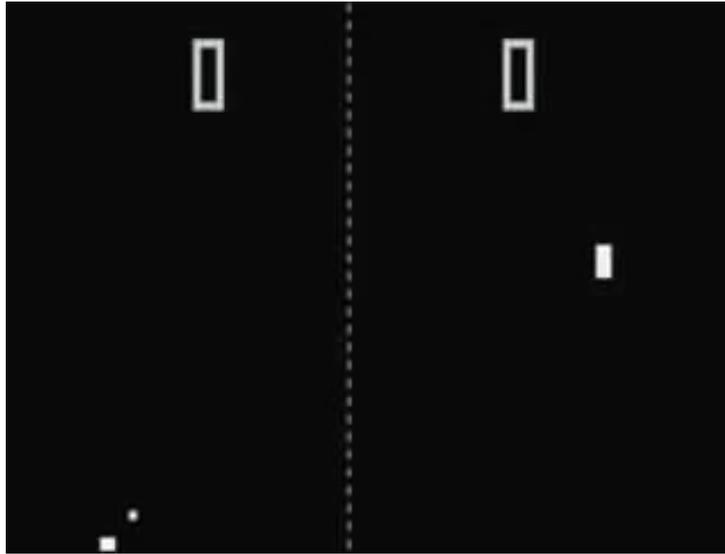
MiniMoog

- Analog synthesizer



Retro Game Sounds

- Atari Pong (1972): the “beep” sounds
 - Early game sound effect
 - Use existing square waveforms in the circuit



Nintendo Entertainment System Chiptunes



<https://www.youtube.com/watch?v=la3coK5pq5w>

Drum Machine

- Rhythm machine
 - Unique electronic drum kit sound and step sequencer



Roland TR-808

<https://www.youtube.com/watch?v=GZeVAR7d9TA>

Web version

<https://io808.com/>

Examples

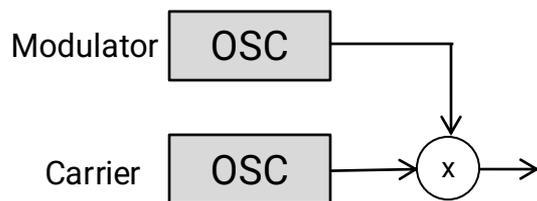
- Web Audio Demos
 - <http://aikelab.net/websynth/>
 - <http://nicroto.github.io/viktor/>
 - <https://www.vdveen.net/webaudio/minimoog/mm.htm>
- Well-known sounds
 - SuperSaw
 - Leads
 - Pad
 - Bass
 - 8-Bit sounds (80's game)
 - TR-808 (Drum machine)

Modulation Synthesis

- Modulation is originally from communication theory
 - Carrier: channel signal, e.g., radio or TV channel
 - Modulator: information signal, e.g., voice, video
- Types of modulation synthesis
 - Amplitude modulation (or ring modulation)
 - Frequency modulation
- Decreasing the frequency of carrier to hearing range can be used to synthesize sound
 - Generate new sinusoidal components
 - Modulation is non-linear processing

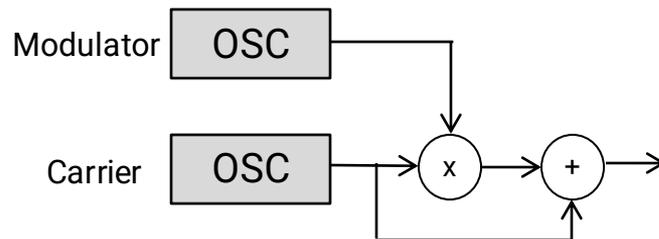
Ring Modulation / Amplitude Modulation

- Change the amplitude of one source with another source
 - Slow change: tremolo
 - Fast change: generate a new tone



$$a_m(t)A_c \sin(2\pi f_c t)$$

Ring Modulation

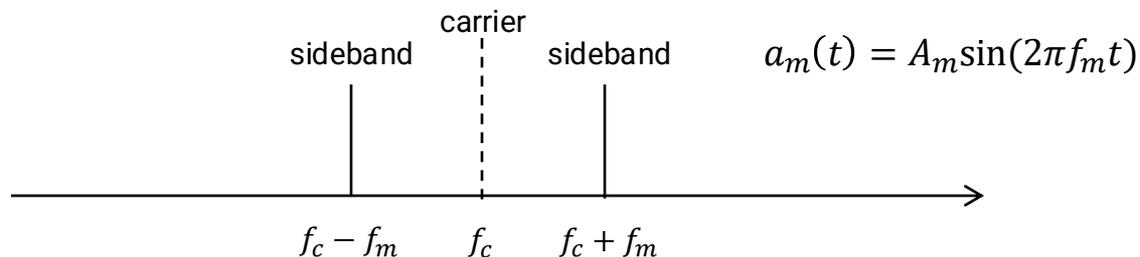


$$(1 + a_m(t))A_c \sin(2\pi f_c t)$$

Amplitude Modulation

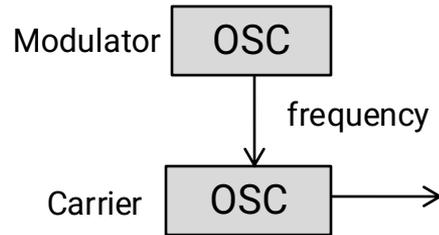
Ring Modulation / Amplitude Modulation

- Frequency domain
 - Expressed in terms of its sideband frequencies
 - The sum and difference of the two frequencies are obtained according to trigonometric identity
 - If the modulator is a non-sinusoidal tone, a mirrored-spectrum with regard to the carrier frequency is obtained



Frequency Modulation

- Change the frequency of one source with another source
 - Slow change: vibrato
 - Fast change: generate a new (and rich) tone
 - Invented by John Chowning in 1973 → Yamaha DX7



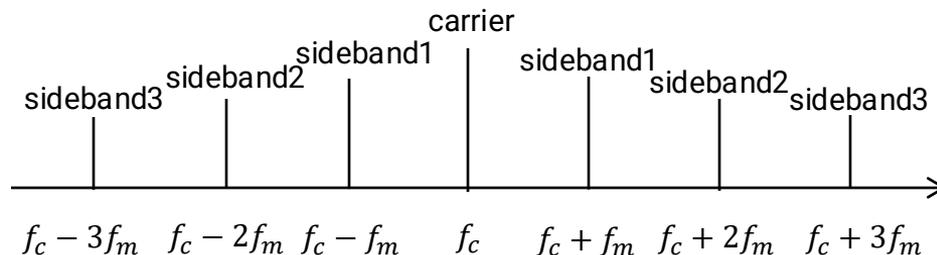
$$A_c \sin(2\pi f_c t + \beta \sin(2\pi f_m t))$$

$$\beta = \frac{A_m}{f_m} \quad \text{Index of modulation}$$

Frequency Modulation

- Frequency Domain
 - Expressed in terms of its sideband frequencies
 - Their amplitudes are determined by the Bessel function
 - The sidebands below 0 Hz or above the Nyquist frequency are folded

$$y(t) = A_c \sum_{k=-\infty}^{\infty} J_k(\beta) \cos(2\pi(f_c + kf_m)t)$$



Frequency Modulation

- Bessel Function

$$J_k(\beta) = \sum_{n=0}^{\infty} \frac{(-1)^n \left(\frac{\beta}{2}\right)^{k+2n}}{n!(n+k)!}$$

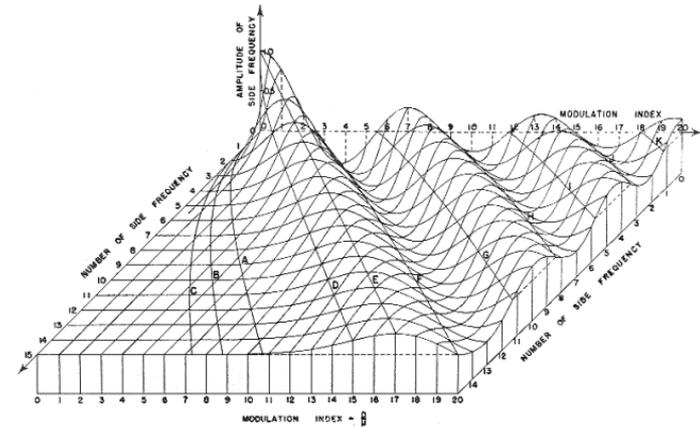
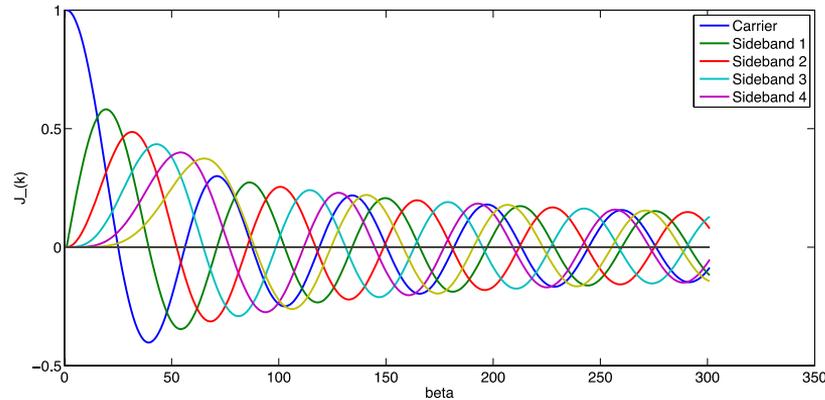
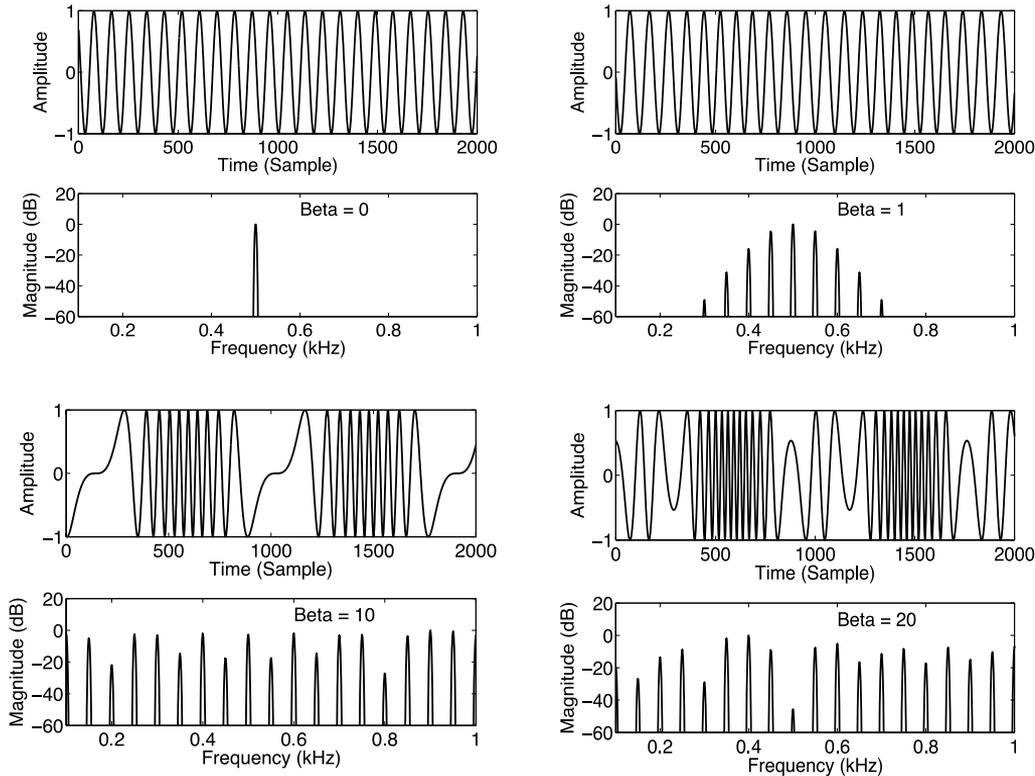


Fig. 4—Side-frequency amplitudes.

The Effect of Modulation Index



$$f_c = 500, f_m = 50$$

Examples

- Sound Examples

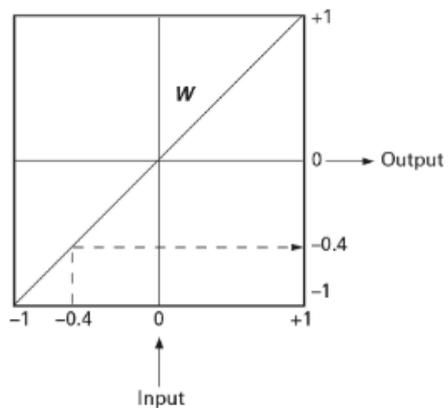
- Bell
- Wood
- Brass
- Electric Piano
- Vibraphone

- Web Audio Demo

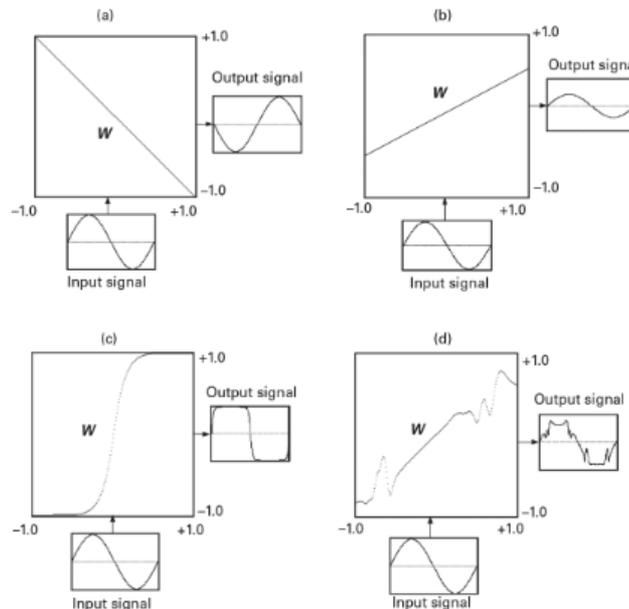
- <http://www.taktech.org/takm/WebFMSynth/>

Waveshaping Synthesis

- Generate a rich sound spectrum by distorting a sine waveform by shaping a new waveform by a non-linear transfer function
 - Also, called “distortion synthesis”



x-to-y mapping



Waveshaping Synthesis

- Examples of transfer function: $y = f(x)$

- $y = \frac{x'}{1+|x'|} \rightarrow x' = g \cdot x$

- g is the gain and it controls the harmonics

- Chebyshev polynomial: $T_{k+1}(x) = 2x \cdot T_k(x) - T_{k-1}(x)$

- $T_k(\cos(x)) = \cos(kx)$

- T_k generates the k th harmonics

- Any harmonic distribution can be generated with a combination of T_k

- $5T_1(x) + T_2(x) + 4T_3(x) + 3T_5(x)$

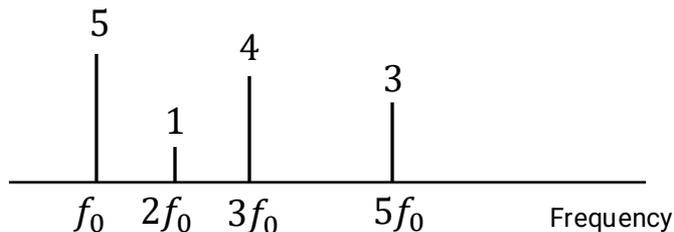
$$T_0(x) = 1$$

$$T_1(x) = x$$

$$T_2(x) = 2x^2 - 1$$

$$T_3(x) = 4x^3 - 3x$$

...



More resources

- <https://learningsynths.ableton.com/en/playground>
- <https://learningmusic.ableton.com/index.html>