

MUSC 4820/5820 Digital Music Techniques 001

Week 11: Sound Synthesis 3 – Operations and Modulations



College of Arts & Media

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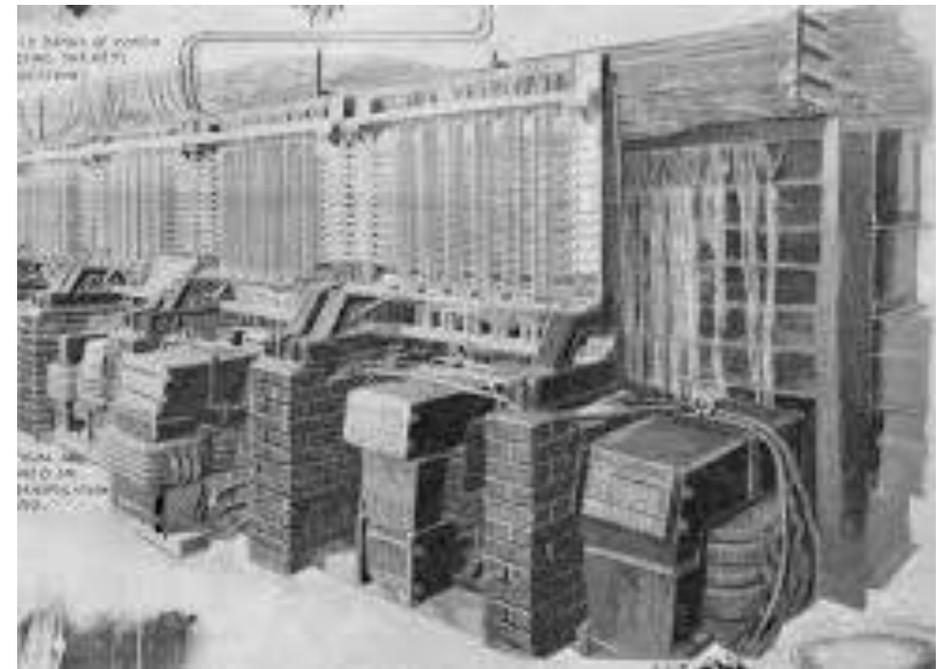
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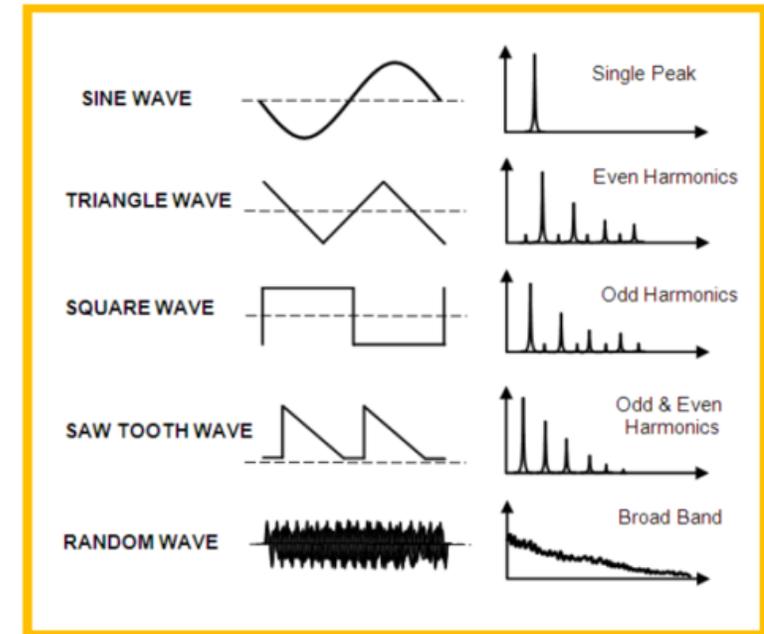
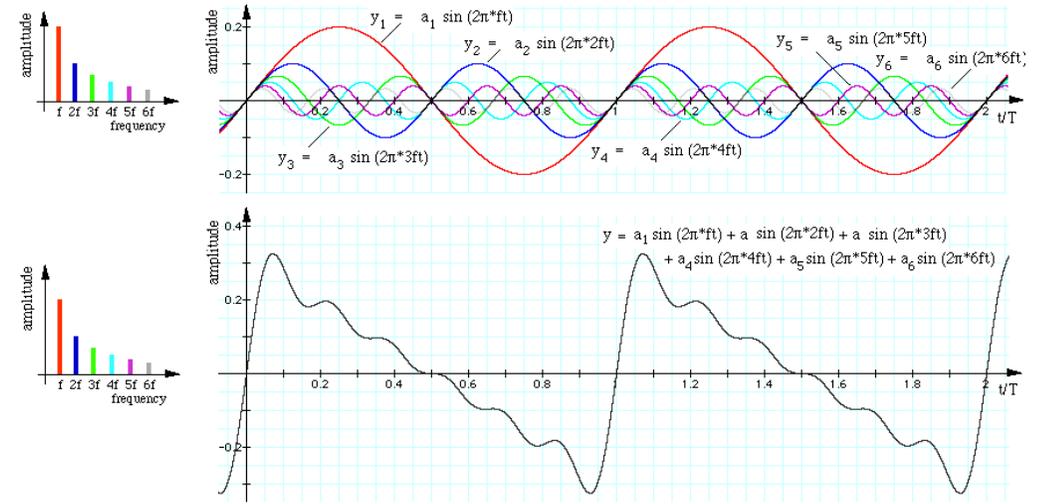
Overview of Sound Synthesis

- 1906, “Telharmonium”, the 1st and largest sounds synthesizer
- 1940s, the invention of the stored program electronic digital computer opened the way for the present era
- 1957, Bell Lab, the first experiments in sound synthesis by computer, using a giant IBM 704 computer (MUSIC I program)
- Musical computer programming languages
- 1960s, the first UGen (Unit Generators) Concept was coined by Max Mathews ,using MUSIC III program.
- UGens are signal processing modules like oscillators, filters, and amplifiers – we are still using this concept nowadays
- Time varying and Static synthesis methods: Envelopes, Ugens, and Patches
- Current types of sound synthesis: [waveform synthesis](#); modulation synthesis; physical modeling and formant synthesis; graphic synthesis, stochastic synthesis, spatial synthesis, and many more
- Using software for sounds synthesis in real-time and non-real-time
- Fourier Transfer Theory: Sound analysis and re-synthesis theory (From time domain to frequency domain)



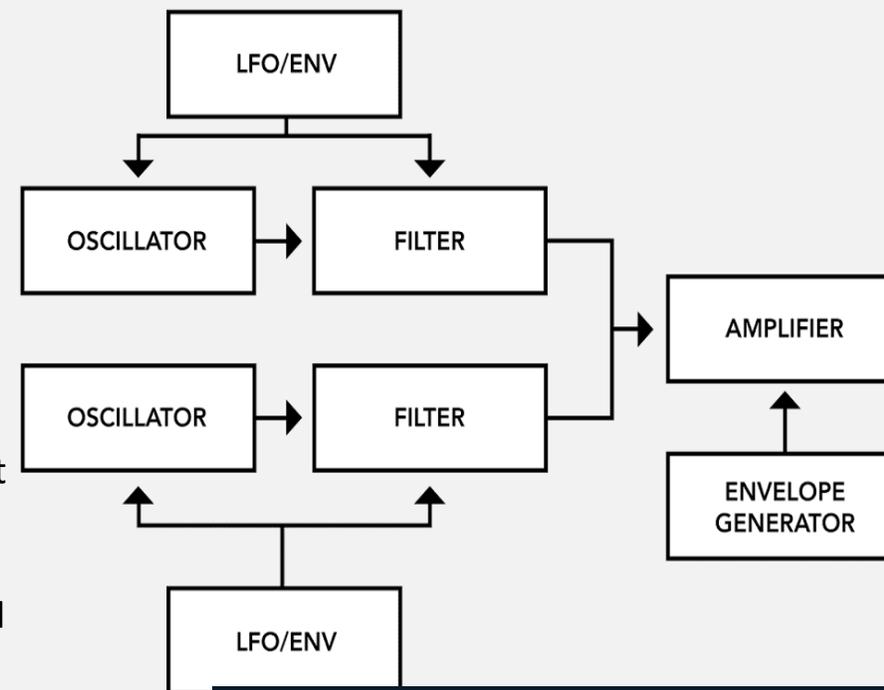
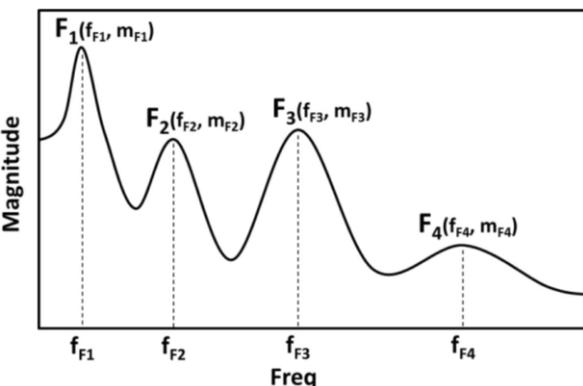
Additive Synthesis

- **Sound Analysis methods to find a sound's key elements** : Short-time Fourier Transform (STFT), Fast Fourier Transform (FFT), and spectrum analysis
- Then, a system combines all the sine waves' frequencies and their proportions varying in time in that particular sound to recreate the original sound –this called resynthesis
- Another good use of Additive synthesis is to add partials through time – this give very subtle sound transformations to enrich the compositional purpose – e.g. evolving pads or drone sounds
- One of the earliest sound synthesis techniques – needs a lot of tone generator, VCAs, Envelopes, and/or LFOs to achieve fine control and manipulation, so it can be very **expensive and inefficient** !!!
- Also, for analog modules, pitch drifting in n oscillator is common, so the **pitch could be lack of accuracy**

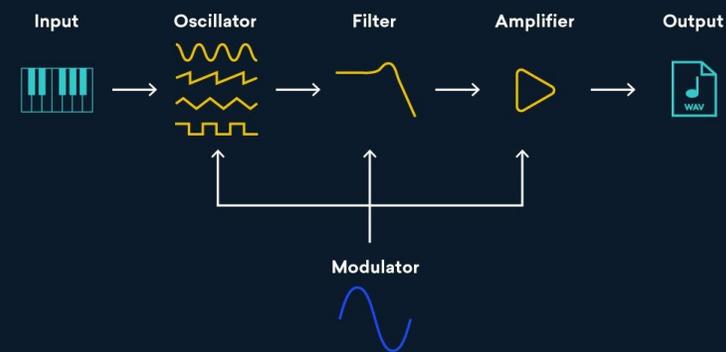


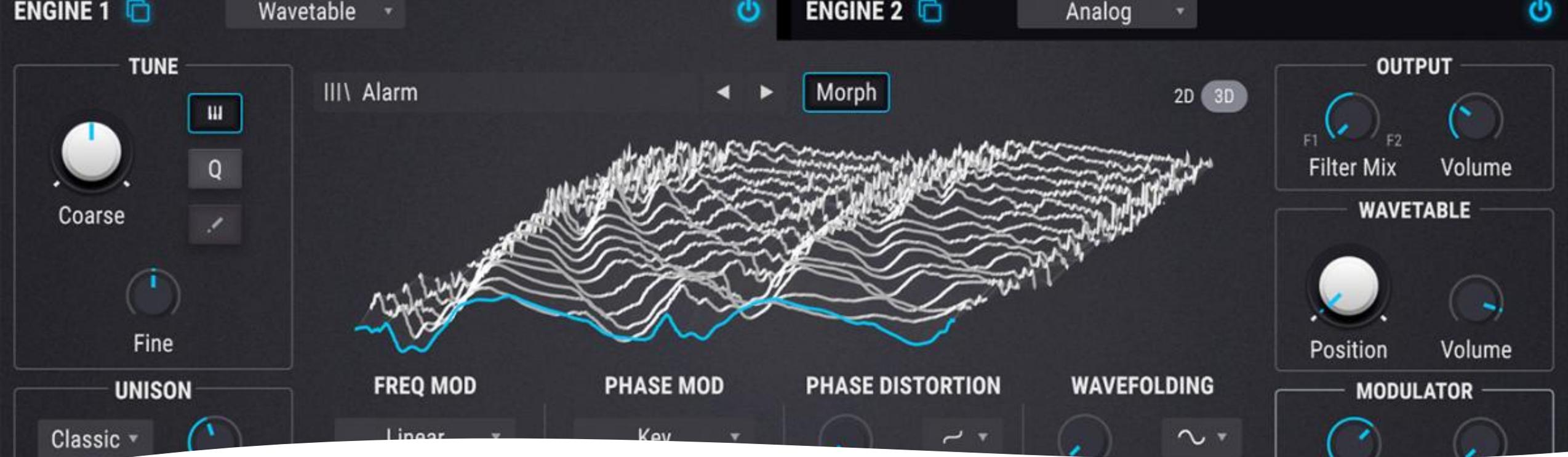
Subtractive Synthesis

- **Sound Analysis methods to find a sound's key elements** : Short-time Fourier Transform (STFT), Fast Fourier Transform (FFT), formant analysis (pitch and amplitude)
- Then, a system usually generates a noise signal to further sculpture the noise with a series of filters - this often is called filter banks and envelopes to recreate the desired sonic results.
- Some of the physical modeling techniques involve subtractive synthesis
- Another good use of Subtractive synthesis is the Vocoder and speech synthesis – e.g. evolving pads or drone sounds (bandpass filters are mostly common for speech synthesis)



Subtractive Synthesis





Wavetable Synthesis

- **Multiple wavetable synthesis:** wavetable crossfading and wave stacking
- **Wavetable crossfading** creates sounds that mutate from one source to another over time
- **Wavetable Stacking** is a simple and effective variation on additive synthesis. In this method, each sound event results from the addition of several waveforms (typically 4-8 on commercial synthesizer). The difference between wavetable stacking and classical additive synth is that the latter uses only sine waves while wavetable stacking uses complex wave forms.
- There are other more mathematical intensive wavetable synthesis such as Wave Terrain synthesis and time-varying Wave Terrain synthesis that need to calculate orbits and scan terrains, which is widely used in software/digital sound synthesis.

Sample Processing/Manipulation Methods (High-level Organizations for Sonic Grains)

- Editing the audio file length
- Volume level controls and dynamic processors
- Low-fi samplers
- Play back direction
- Pitch shifting and controls
- Looping
- Sample and hold
- Sample slicing and time stretching (granular synthesis)
- Frequency (filtering) and time effects (delay, reverb, chorus, flanging, phasing...) processing; both (Convolution, distortion...)
- Adding voice count (polyphony)
- Use other control voltage sources and modifiers to modulate/modify samples (ADSR, LFOs, and sequencing controls... 😊)
- Spectral control/processing
- MIDI controls (e.g. velocity layers)
- Round-robin switching techniques
- Key switching to change play styles or switch between sample sets
- Scripting (combines concepts of Physical Modeling and Behavioral Modeling with the Multi-Vector/Phase-Synchronous Sample-Morphing technique) e.g. [Swam Instruments](#)
- Advance mapping for custom systems
- Combine the above and be creative!!!

Granular Synthesis

Granular Synthesis

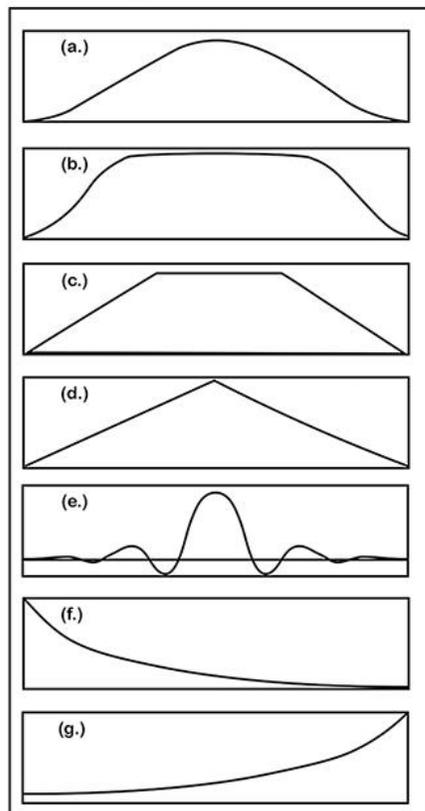


Figure 3.2 Grain envelopes.
(a) Gaussian. (b) Quasi-Gaussian.
(c) Three-stage line segment.
(d) Triangular. (e) Sinc function.
(f) Expodex. (g) Rexpodec.

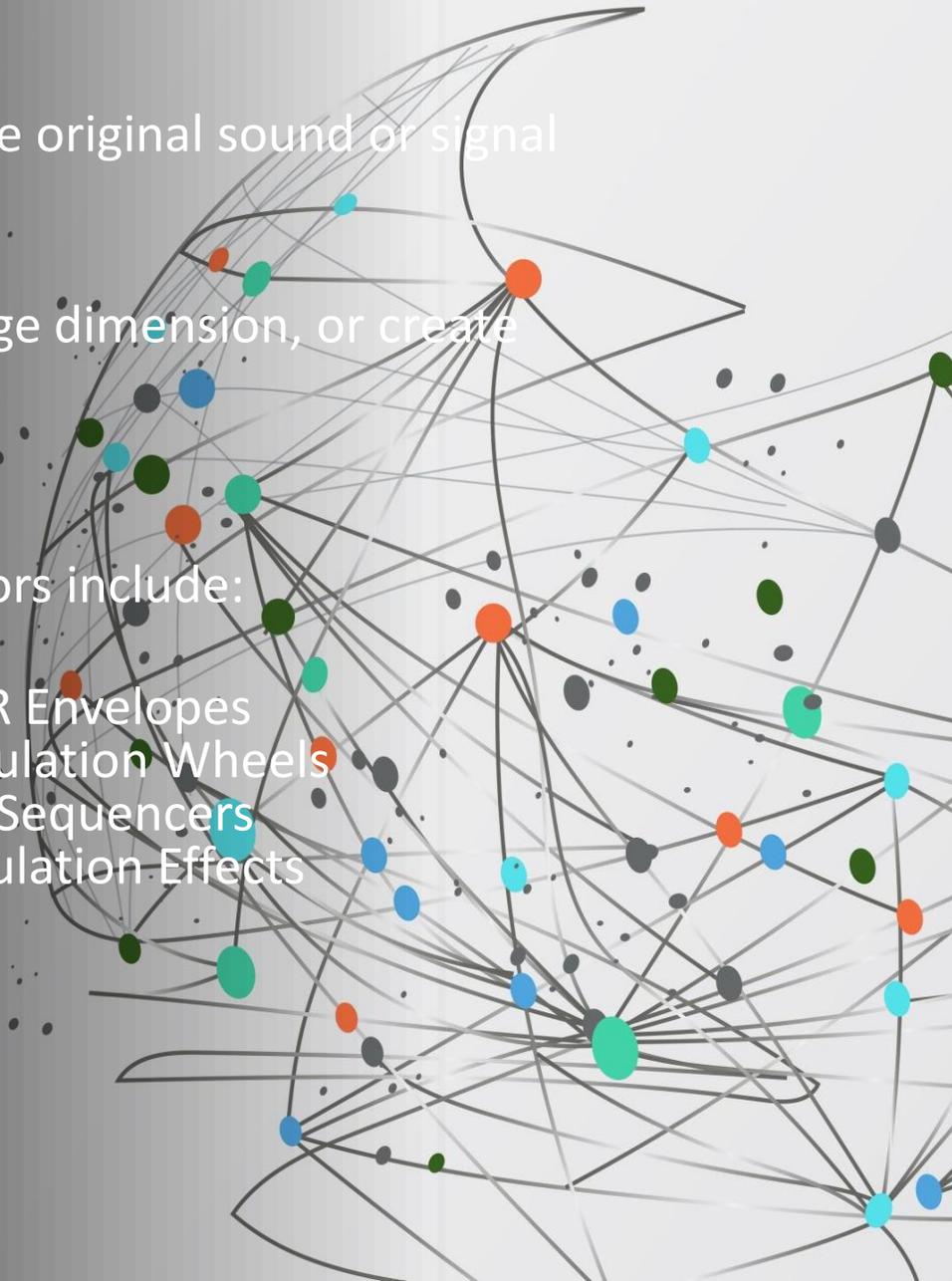
- **Particle systems and Sonic grains**
- The composer **Iannis Xenakis (1960)** was the first to explicate a compositional theory for grains of sound.
- Then **Curtis Roads** developed the first computer-based implementations of granular synth at UCSD (1974) and MIT (1981).
- Then, a system combines all the sine waves' frequencies and their proportions varying in time in that particular sound to recreate the original sound –this called resynthesis
- Grain Generator (A sinewave oscillator and an envelope generator, or simply using samples at a sample/microsound-level) that generate one or more streams of grains with a period between each grain (the speed of the grain-generation determines the pitch or non-pitch)
- Synchronous, Quasi-synchronous, and Asynchronous Granular Synth: Pitch static, pitch varying, and non-pitch granular synths
- High-level granular organizations
- Time granulation of sampled sounds

What is Modulation?

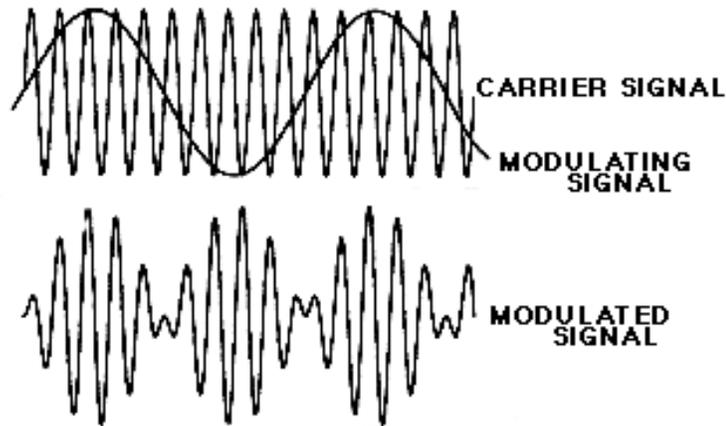
- A Modulator is an audio or any Signal that changes (modifies) the original sound or signal (Carrier) over time.
- Modulating a sound can add a sense of movement, add or change dimension, or create depth.
- Modulators can be used to:
 1. Change the frequencies of a sound
 2. Alter the gain or volume
 3. Change the position of a filter on a sound
 4. Move controls on effects and instruments
- Any signal can be modulated by any other signal 😊

Common Modulators include:

1. LFOs
2. ADSR Envelopes
3. Modulation Wheels
4. Step Sequencers
5. Modulation Effects



Modulation In Sound Synthesis



- Modulation requires a “Source Signal” called a Modulator that controls another signal called the “Carrier Signal”. For example, LFO (a Source Signal, also called “modulator”) was applied to the oscillator or the original signal (carrier). Essentially, the Synth’s original sound wave is the **Carrier Signal!**
- For AM (Amplitude Modulation) and FM (Frequency Modulation), the carrier signal is always there nonmatter how many sideband frequencies would be created – this is the theory behind the whole AM and FM radio signal transmission.
- Some modulators, like the LFO or envelopes, produce a signal... but they do not produce an audible sound. The job of the Modulator is to change the original sound, not produce one itself. **HOWEVER**, you can always use an audio rate signal as a modulator, complex spectrum will be created this way – this is also why we often use a sine wave as a modulator because complex waveform modulator created too complex modulation results - this sometimes sounds very noisy

Modulation Effects

Modulation Effects are a group of effects, some of which you may have never considered a Modulator.

They include:

1. LFO
2. Chorus
3. Flanger
4. Phaser
5. Auto Pan
6. **Tremolo (AM)**
7. **Vibrato (FM)**

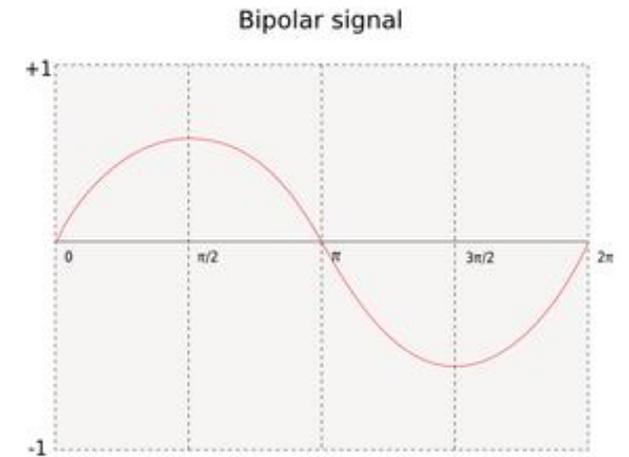
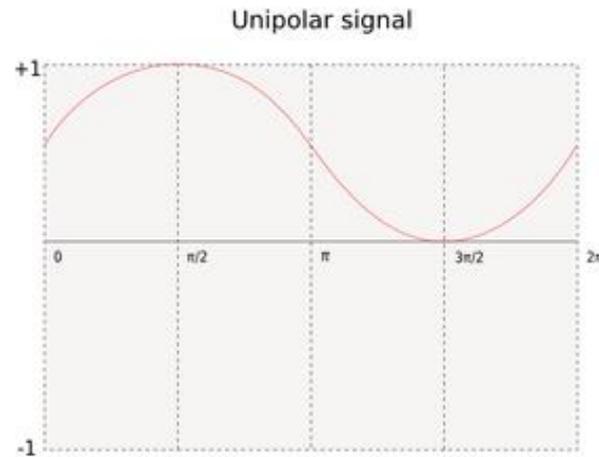
All of these are considered Modulators because they add:

- movement, width, depth, or change the character of the original sound.

Additionally, we can take an existing audio file (samples) and shape it and give it more movement (modulation)!

Modulation Synthesis

- **Bipolar and Unipolar Signals**
- **Rectifier**
- **Carrier Signal**
- **Modulator/ modulation signal**
- **Modulation Index**
- **Cross-modulation modules – Warps**



Amplitude Modulation

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Where:

carrier frequency in Hertz is equal to $\omega_c / 2\pi$
 C is the carrier amplitude
 ϕ is the phase of the signal at the start of the reference time

??

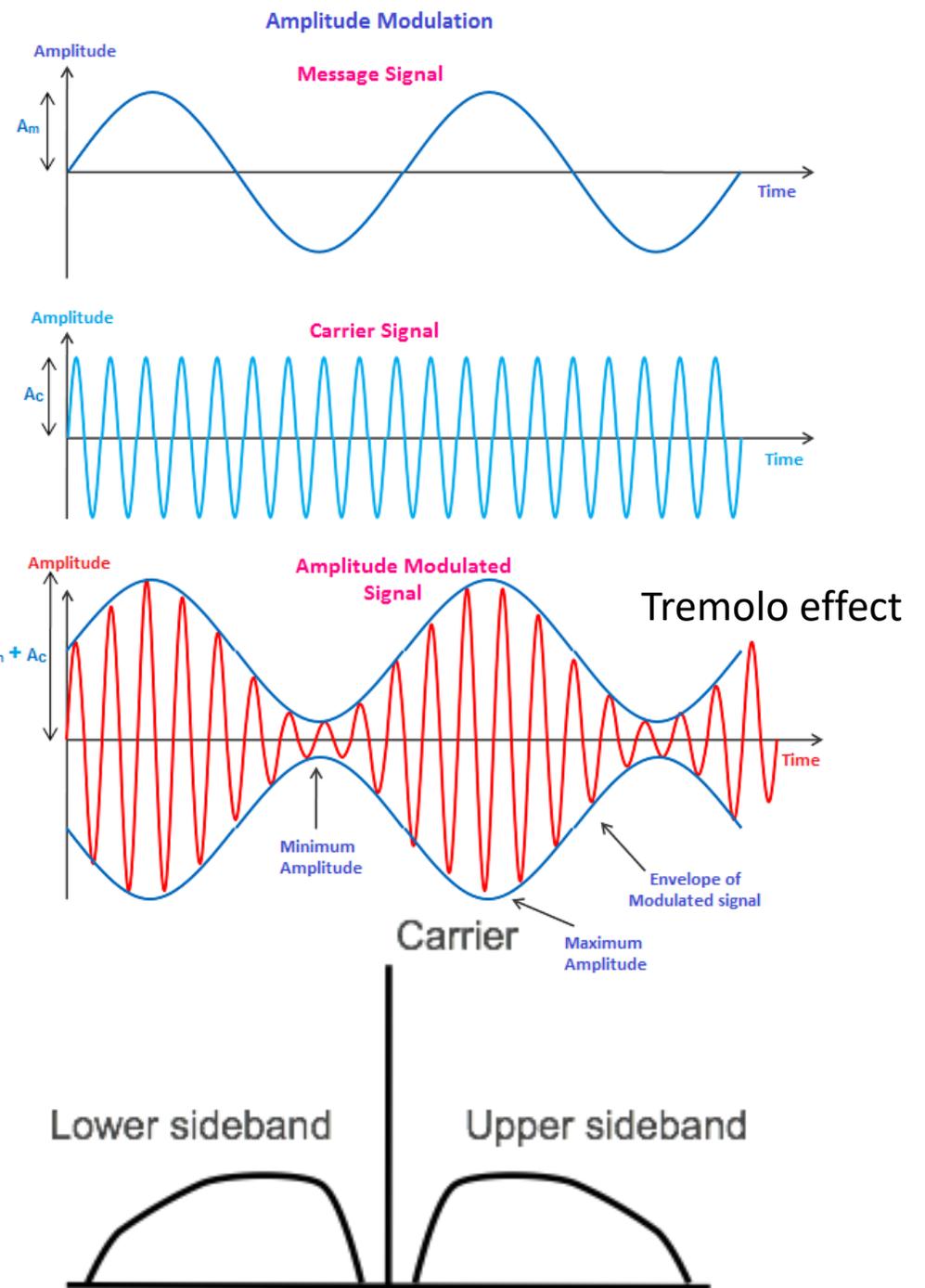
Where:

modulating signal frequency in Hertz is equal to $\omega_m / 2\pi$
 M is the carrier amplitude
 ϕ is the phase of the signal at the start of the reference time

??

Where:

The constant A is required as it represents the amplitude of the waveform.

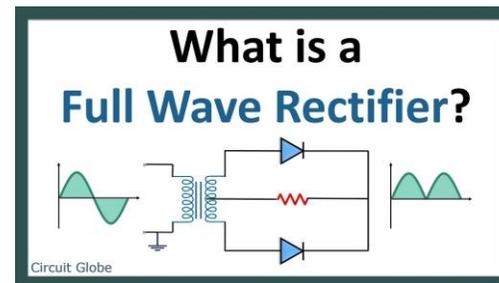
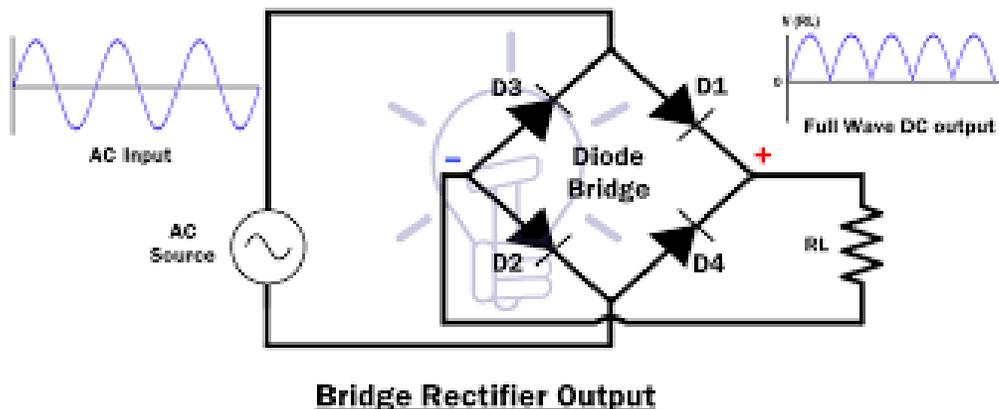


Ring Modulation

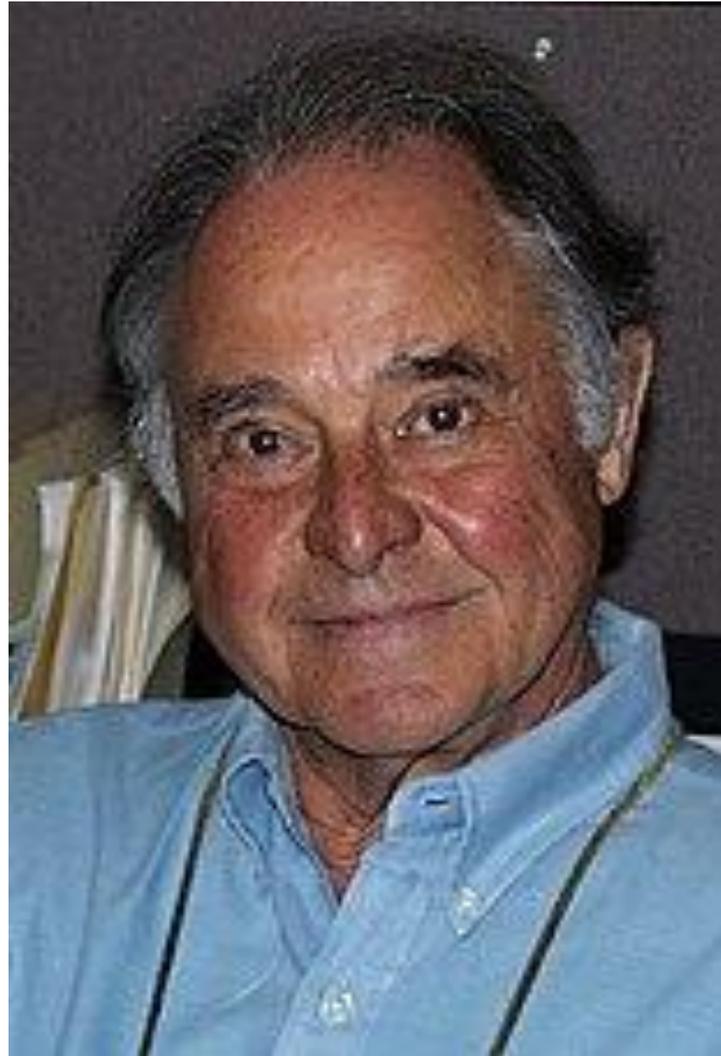
- A **ring modulator** is an electronic device for ring modulation. The function derives its name from the fact that the [analog circuit](#) of [diodes](#). The circuit is similar to a [bridge rectifier](#)
- The difference with ring modulation is that neither of the input signals, carrier or program, appear at the output.

$$y = A_m \cdot \cos(f_c) \cdot \cos(f_m) = A_m \cdot \frac{\cos(f_c + f_m) + \cos(f_c - f_m)}{2}$$

- Convolution in the time domain is the multiplication in the [frequency domain](#)
- **convolution** is a [mathematical operation](#) on two [functions](#) (f and g) that produces a third function that expresses how the shape of one is modified by the other.
- Therefore, the output waveform contains the sum and difference of the input spectral components.



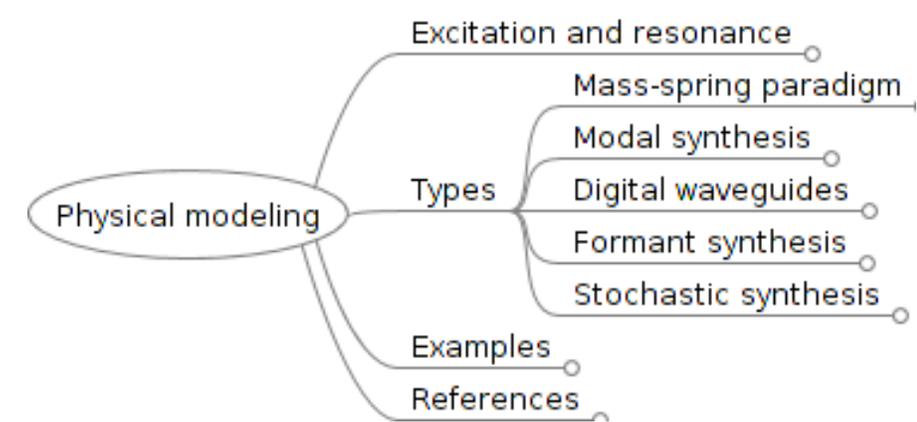
Frequency Modulation



- The FM-method published in 1973 by John Chowning (Born in 1937), the founder of CCRMA (Center for Computer Research in Music and Acoustics) at Stanford University, also the inventor of YAMAHA DX-7
- FM has the basic formula form **$e=A\sin(\alpha t+I\sin\beta t)$**
- where **e** is the deviation of the wave from its position of rest,
- **t** is time,
- **A** is the maximum deviation (amplitude)
- **α** and **β** are the periods (frequencies) of the carrier and the modulation waves, respectively.
- Vibrato Effect
- Multiple-Carrier FM
- Multiple-Modulator FM (parallel and series)
- Feedback FM: YAMAHA's patent to solve uneven amplitudes of the harmonic partials

Physical Modeling

- **Physical modelling synthesis** refers to methods in which the waveform of the sound to be generated is computed using a mathematical model, a set of equations and algorithms to simulate a physical source of sound
- The first commercially available physical modelling synthesizer made using waveguide synthesis was the Yamaha VL1 in 1994.
- A book of Physical Modeling <https://ccrma.stanford.edu/~jos/pasp/>
- Physical Modeling is computationally more expensive
- Source separation and high-order spectrum analysis
- Some basic concept: Interactions between Excitation (exciters: the cause of vibrations–non-linear) and Resonance (resonators: frequencies that are resonating thus producing unique pitch and timbre – usually is linear for acoustic instruments – it can be harmonic or non-harmonic). Damping, feedback, boundary conditions, initial state, impedance (the resistance of striking force), are also the common parameters for generating a *wave equation* for physical modeling
- Mass-spring paradigm for string instrument. (model synthesis)
- Karplus-strong Synthesis for plucked string and Drum



Physical Subtractive Voice Synthesis Block Diagram

