Psychoacoustics

2nd lesson

Tones and Sounds

Definition: Sound is a vibration that typically propagates as an audible wave of pressure, through a transmission medium such as a gas, liquid or solid.

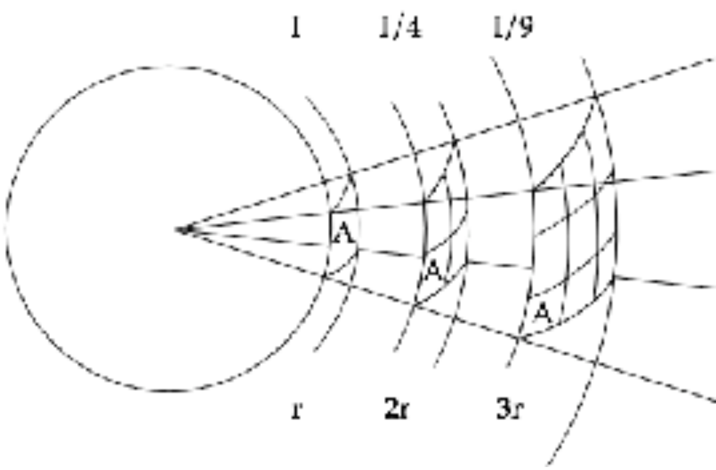
Simple and complex tones

- We are surrounded by air. Sound propagates in air spherically from the source as a longitudinal wave (movement of the molecules parallel to the direction of propagation), as opposed to vibrating strings where we speak of transverse waves (because the movement of the string is at right angles to the propagation direction of the wave) ,

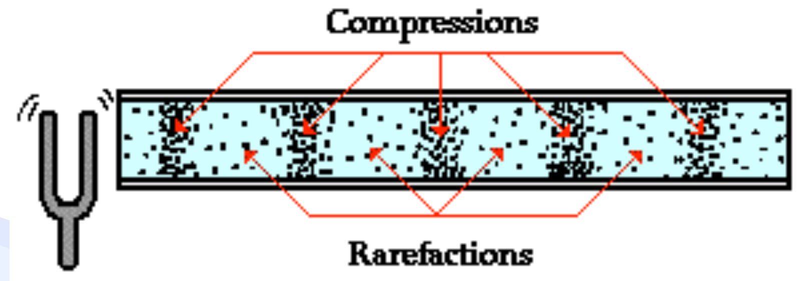
- Sound has a velocity of 344 m / sec in air at 20°C. In other media it propagates faster (for example, the Mickey Mouse effect in helium) or slower.

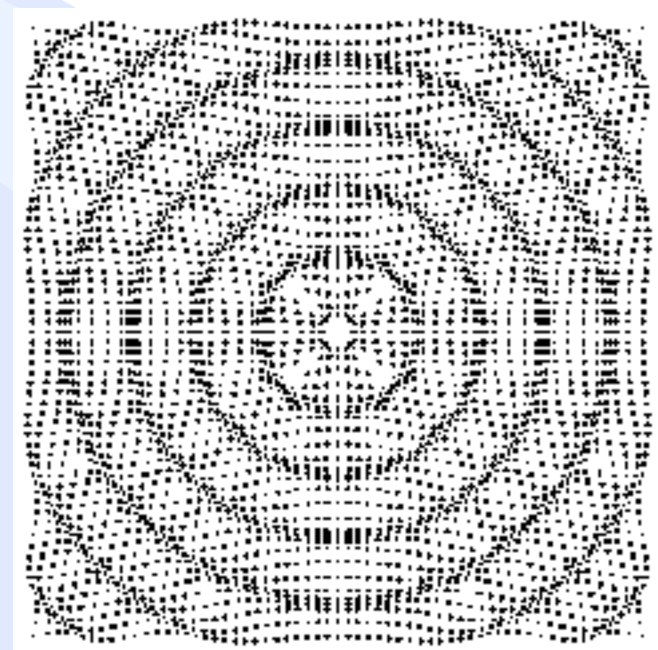
- The intensity of the sound decreases as a function of the distance (inverse-square law).

- The transmission of sound over air and the ear is approximately linear, i. e. free of distortions. The sound propagating from musical instruments such as the piano, guitar or even gong is linear and can be represented as the sum of slowly decaying sine waves with different frequencies. We call these musical or complex tones.

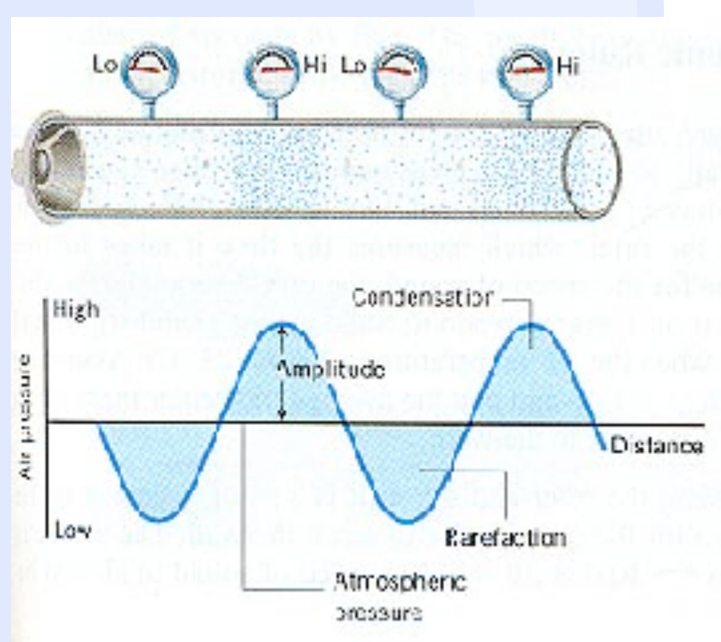


A tuning fork creates longitudinal waves, thus creating compressions and rarefactions of air.





For simplicity's sake, the longitudinal wave can be represented and conceptualized as a transverse wave.



Sinusoids

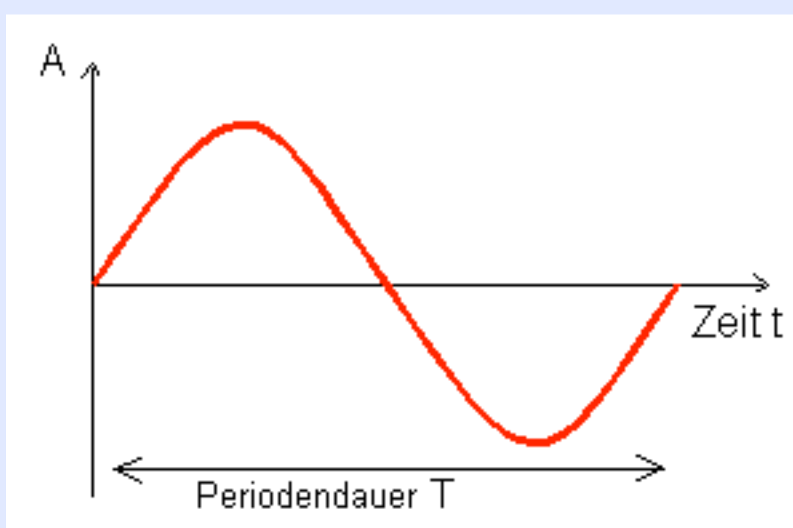
Since sound is based on vibrations, sound events can be represented and described by their waveform. The simplest form of vibration (complex sound effects are understood to be the sum of simple vibrations) exists with the sinusoidal oscillation obtained with a “mathematical” pendulum or with certain sound sources, e.g. a tuning fork. If one plots the course of a sinusoidal oscillation over time, one obtains a typical waveform, which is clearly described by the quantities:

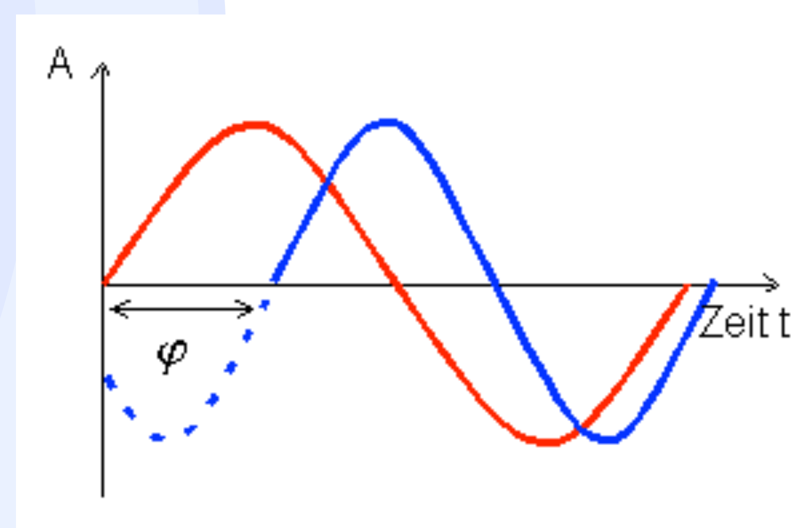
- Period **T**: duration of a cycle of vibration
- Amplitude **A**: Maximum displacement of the vibration
- Phase **ϕ**: Starting point of the oscillation, or temporal shift of two oscillations in respect to each other

For simplicity’s sake, frequency f is used instead of the period T to describe the number of oscillations per second. This is obtained by taking the inverse of the period:

- Frequency **f :** **f** = 1/**T** : Number of oscillations per second. The unit of frequency is Hertz [Hz]

Sound events caused by sinusoidal vibrations are called pure tones.



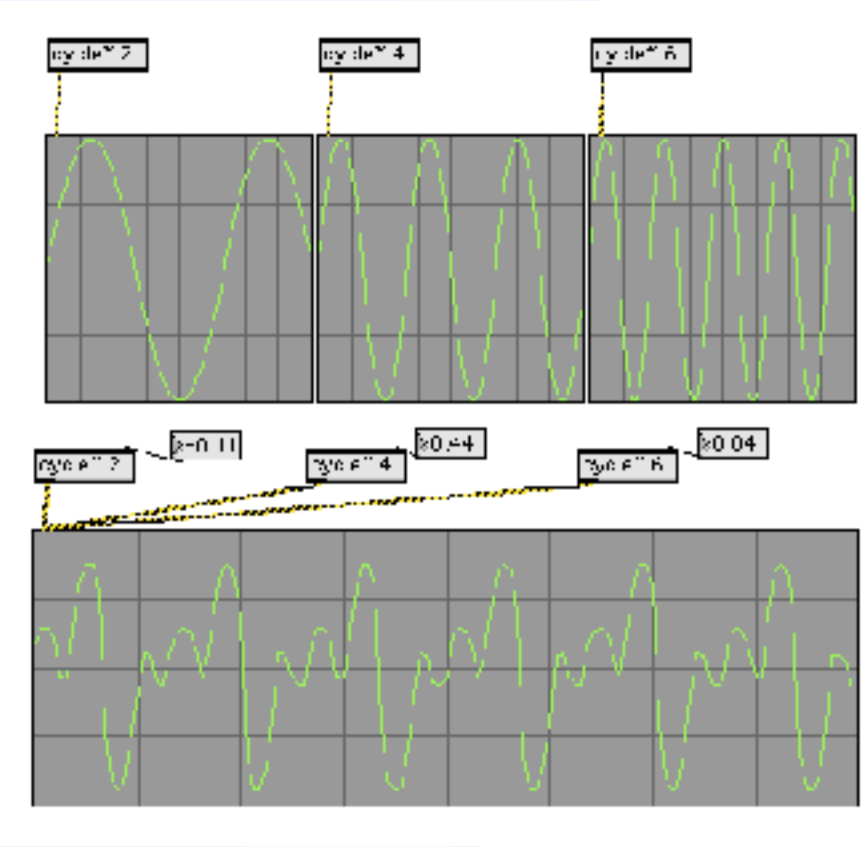


Tones and sounds

A non-sinusoidal sound event with a periodic waveform is caused by the superposition of several sinusoidal oscillations of different amplitudes and frequencies. The frequencies of the individual vibrations must be in an integer ratio. Sound events that fulfill this condition are called harmonic sounds.

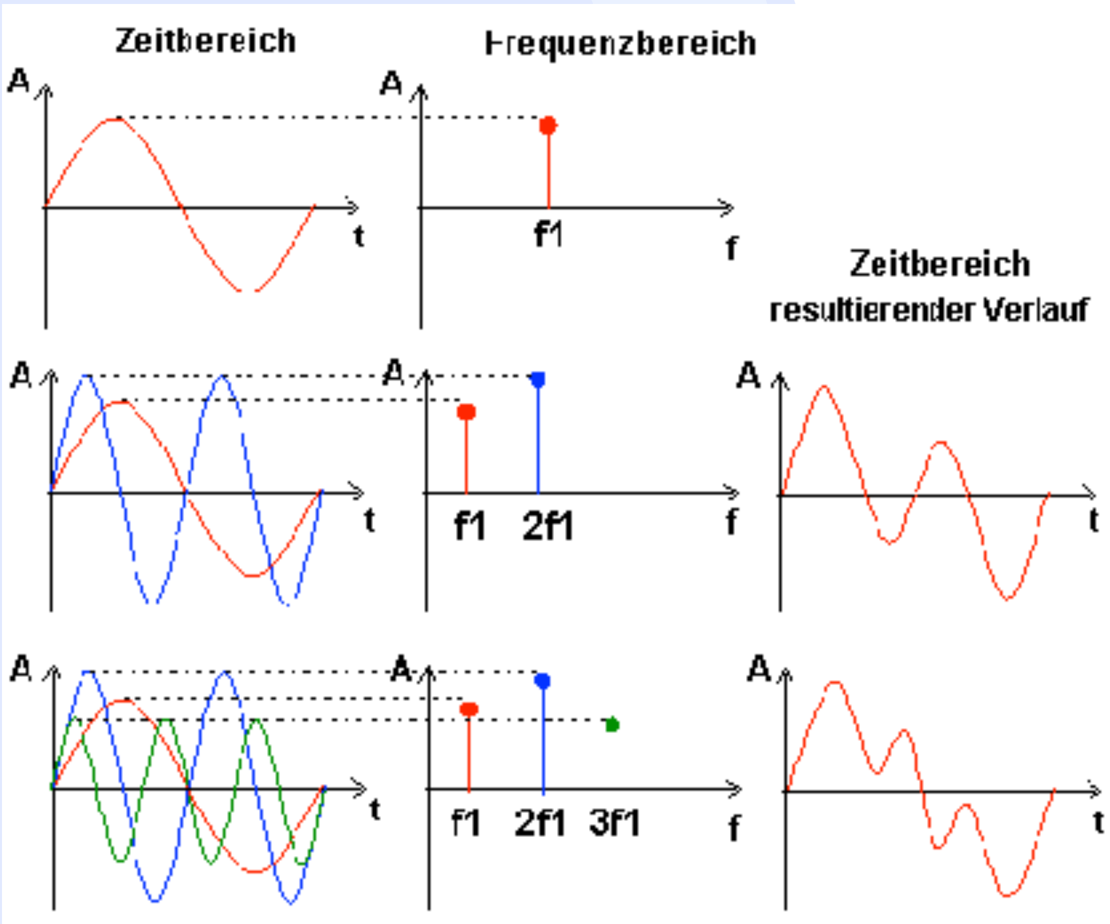
For harmonic sounds, the lowest frequency is called the **fundamental**. The overtones with integer multiples of the fundamental frequency are called partials or harmonics. From this it can be seen that the tones produced by musical instruments are, physically speaking, waveforms.

This can be demonstrated by the example below. Note how the resulting vibration resulting from the superimposition of sinusoids produces the same pitch as the fundamental.



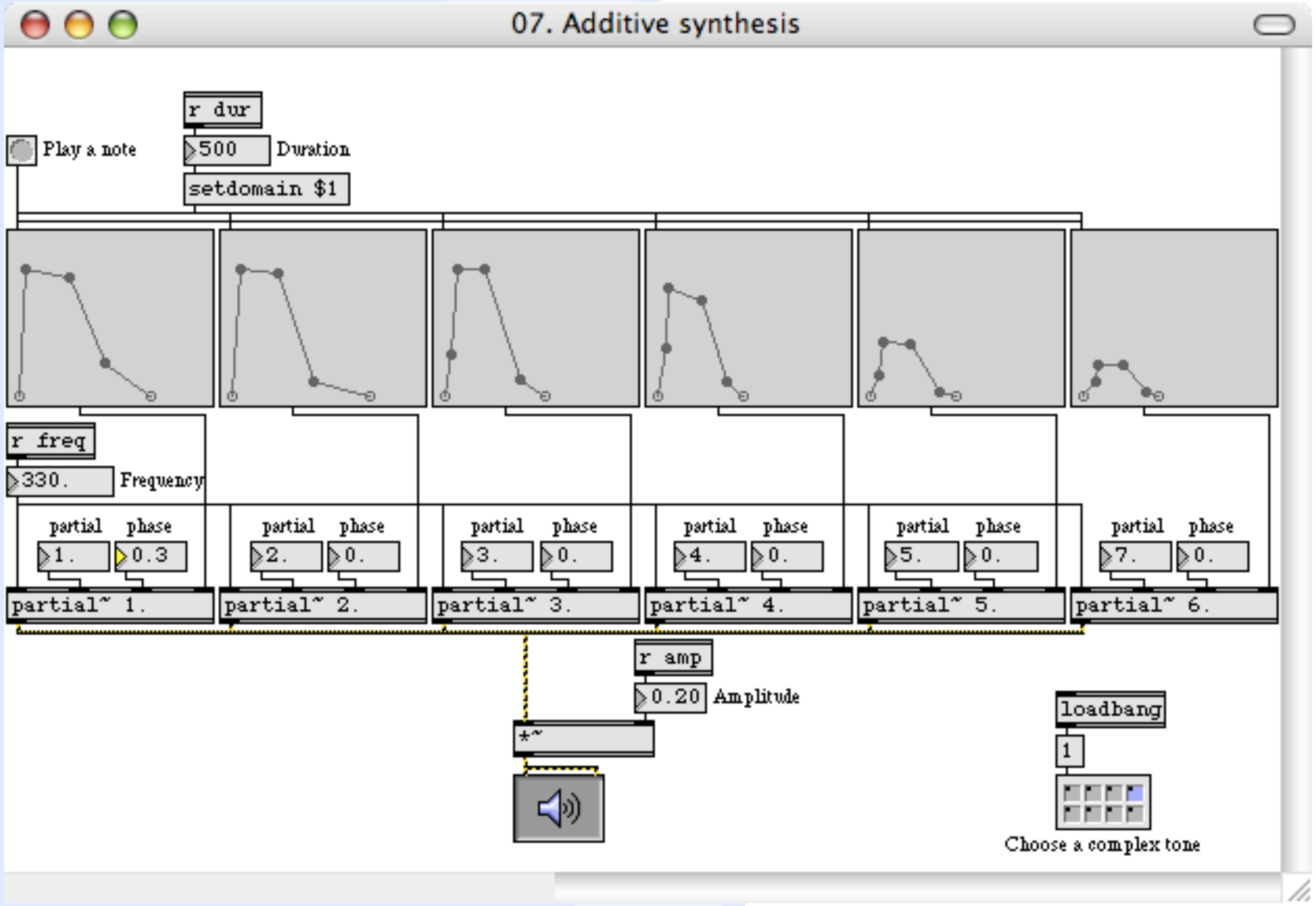
Representation as frequency spectrum

Each periodic vibration can be represented as a superposition of sine waves of different amplitudes and frequencies.
If one plots the amplitudes of the oscillations involved as a function of the frequency, one obtains a representation which is referred to as frequency spectrum (in short: spectrum).
In the spectrum, the amplitude of each partial oscillation is represented by a line of corresponding magnitude as a function of its frequency. The relationship between the temporal oscillation profile and the spectrum should be clarified by the adjacent drawing.
The representation of vibrations through the spectrum is called representation in the frequency domain. In analogy to this we refer to this a representation in the time domain.
Pure tones and sounds can be used as a discrete spectrum, i. be represented as a spectrum with individual lines. Noise, on the other hand, has a continuous spectrum. The representation through the spectrum is an important tool for describing sounds, as each sound event has a characteristic spectrum.



Additive synthesis

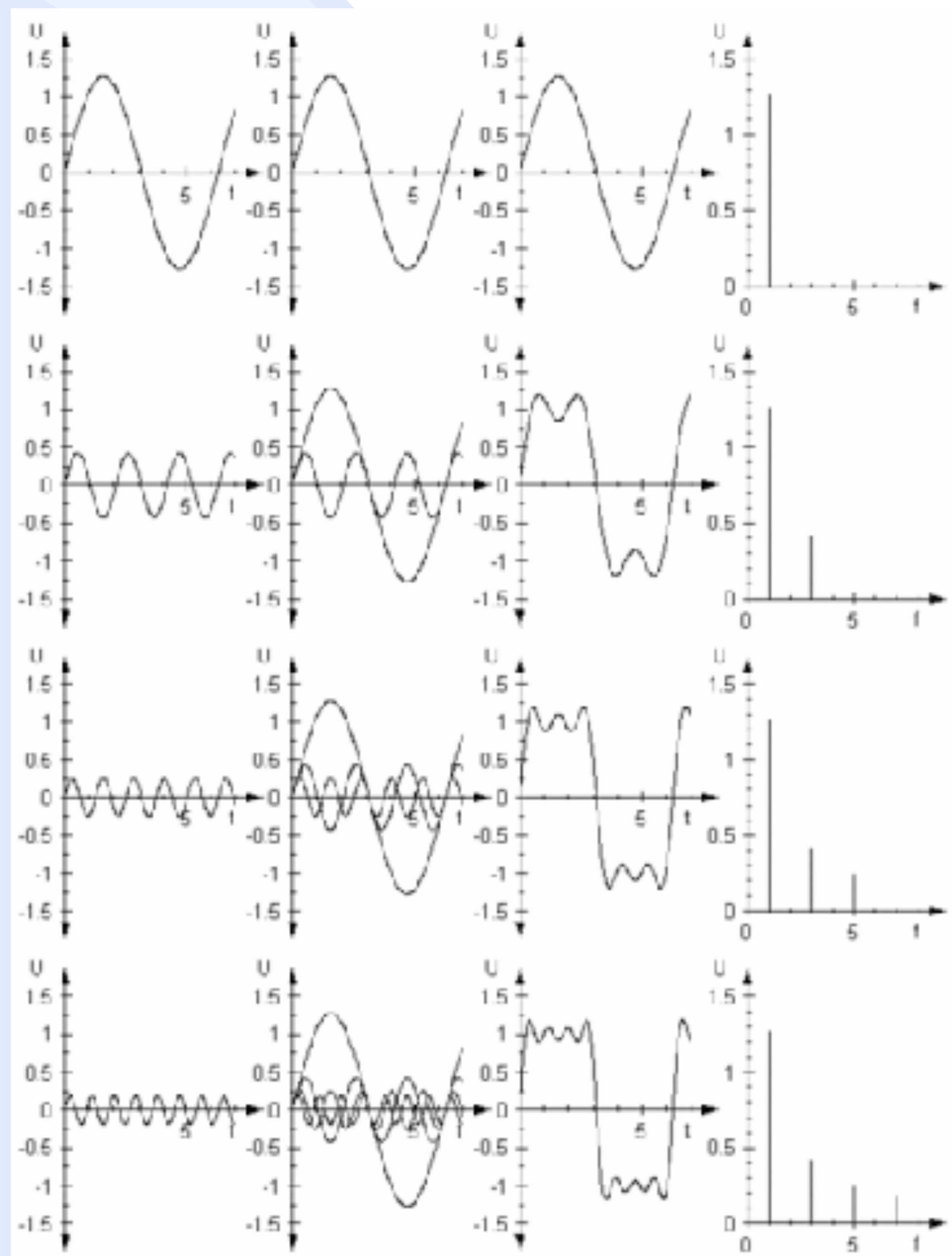
If we know the spectral composition of a sound (its partials and the evolution of the amplitudes in time), then the characteristics of the instrument can be simulated by additive synthesis.



Fourier analysis/transformation

Theorem of Fourier: Every periodic vibration can be described as the sum of cosine and sine waves. For example, the approximation of a square wave by a following function:

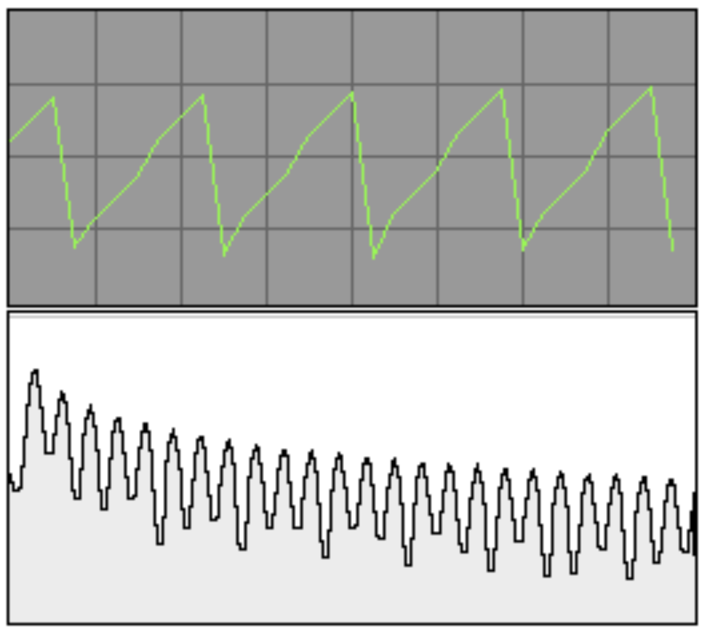
$$u(t) = \frac{4U_S}{\pi}\left(\sin\omega t + \frac{1}{3}\sin(3\omega t) + \frac{1}{5}\sin(5\omega t) - \frac{1}{7}\sin(7\omega t) - \frac{1}{9}\dots\right)$$



Spectrogram and sonogram

Simple representation of the spectrum of a sawtooth oscillation

Spektrogram:

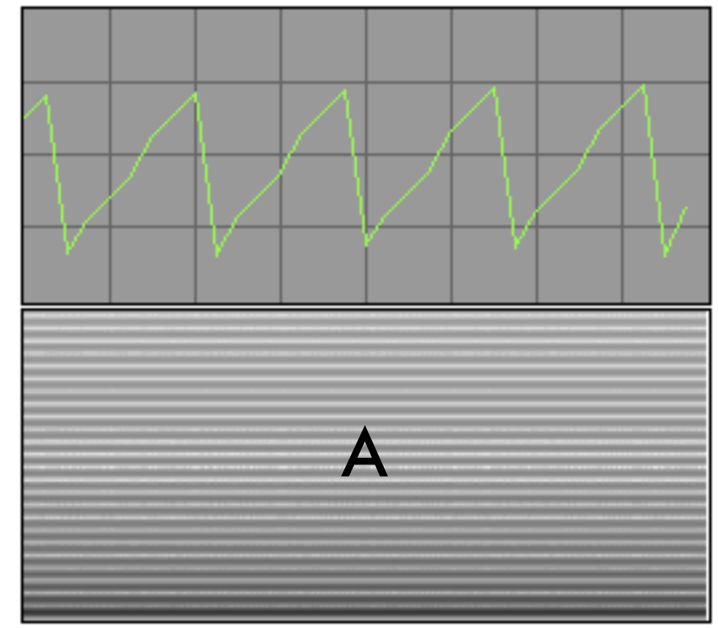


A

F (0 - 5000 Hz)

Sonogram:
Amplitude is represented by gray value

F



t (msec)

Waterfall representation of a complex spectrum