Human perception of sound

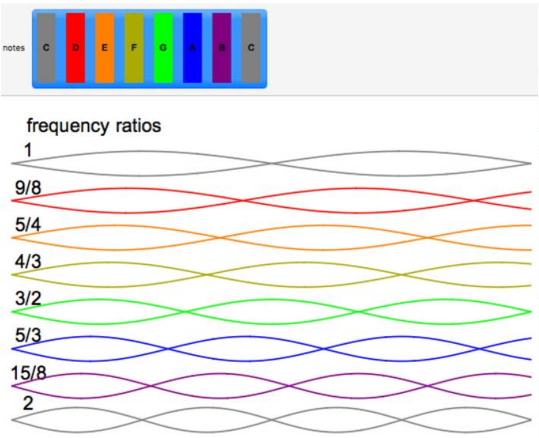
How the physical quantities that characterize the waves affect the perception of sound.

Quantity	Perception
Frequency	Sharp or severe sound
Amplitude	High or low volume
Spectrum	Timbre or harmony of sound

The frequency also has a minor influence on the perception of the volume or intensity of the sound. For example, low frequencies need more energy to be heard.

Frequency range	Type
20 – 500 Hz	Low
500 – 8000 Hz	Medium
8000 – 20000 Hz	High

The frequency in music is closely linked to musical notes. In fact, each note corresponds to a precise frequency.



	FREQUENCY (Hz)								
	OCTAVE								
NOTE	0	1	2	3	4	5	6	7	8
C		32.703	65.406	130.813	261.626	523.251	1046.502	2093.005	4186.009
C#/Db		34.648	69.296	138.591	277.183	554.365	1108.731	2217.461	4434.922
D		36.708	73.416	146.832	293.665	587.330	1174.659	2349.318	4698.636
D#/Eb		38.891	77.782	155.563	311.127	622.254	1244.508	2489.016	4978.032
E		41.203	82.407	164.814	329.628	659.255	1318.510	2637.020	5274.041
F		43.654	87.307	174.614	349.228	698.456	1396.913	2793.826	5587.652
F#/Gb		46.249	92.499	184.997	369.994	739.989	1479.978	2959.955	5919.911
G		48.999	97.999	195.998	391.995	783.991	1567.982	3135.963	6271.927
G#/Ab		51.913	103.826	207.652	415.305	830.609	1661.219	3322.438	6644.875
A	27.500	55.000	110.000	220.000	440.000	880.000	1760.000	3520.000	7040.000
A#/Bb	29.135	58.270	116.541	233.082	466.164	932.328	1864.655	3729.310	
B	30.868	61.735	123.471	246.942	493.883	987.767	1975.533	3951.066	

Distinctions

Sounds can first be distinguished in <u>PERIODIC</u> and <u>NON- PERIODIC</u>. In the former it is possible to distinguish an oscillation cycle which is repeated over time, while in the latter it is not (generally classified as noise).

- If a sound is periodic it will be possible to associate it with a set height and therefore, we will have a tone or a note as a sound perception
- In non-periodic sounds it is not possible to associate it with a set height because the brain cannot count oscillation cycles

In music both types are very important, as periodic sounds are used to create melody and harmony while non-periodic ones are mainly used for rhythm.

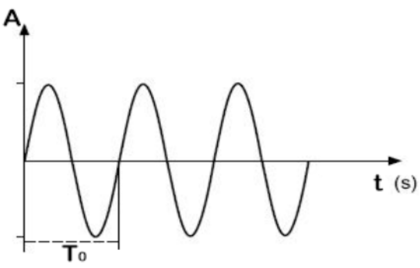
The main responsible for the height of a sound is the frequency. The frequency of a sound is the number of complete vibrations that the source makes in a second or alternatively the number of compressions and rarefactions that a particle of air undergoes in a second.

Not all sounds have a defined height! Height is a characteristic that results from the periodicity of a signal, that is, from the fact that the signal repeats the same pattern for a while.

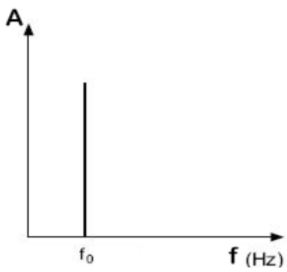
Difference between pure sound and complex sound

Pure sound also called ***tone***:

Consists of a single frequency and therefore described by a simple sine wave. The signal trend is very rounded, the period is composed of a single well-defined compression and a single rarefaction. Listening to a pure sound is not particularly interesting. In fact, pure sounds can be produced almost exclusively in the laboratory.



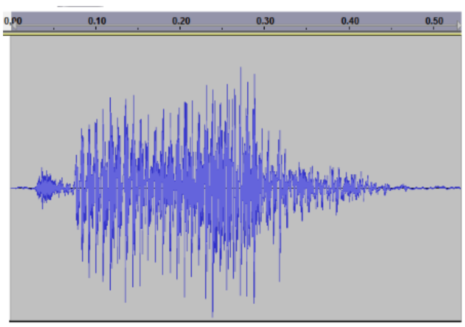
Waveform



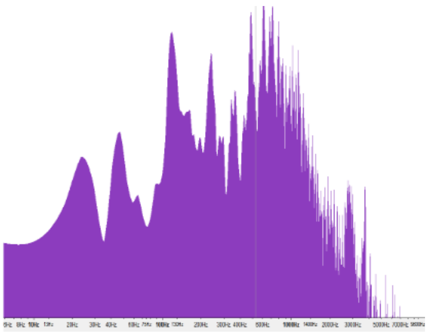
Spectrum(discrete)

A **complex sound**:

Consists of several summed frequencies. In a wave with an articulated course, more variety of compression and intermediate dilutions may be included in a single period. Our listening reveals the characteristic timbre of the sound-producing source and its surroundings.



Waveform



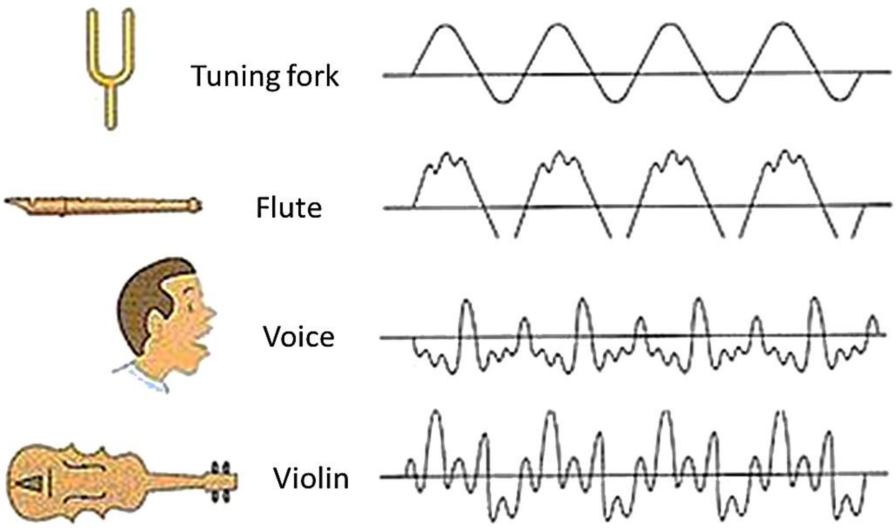
Spectrum(continuous)

In general, sounds in nature are complex and specific. The course is derived from the source's tone generation method.

The typical exception is the tuning fork, which produces a nearly pure sine sound.

Natural tone and timbre

In nature, there are no pure periodic signals. Traditional musical instruments produce sounds with significant periodicity phases. For instruments, it makes sense to talk about the feeling of height. The timbre is the perceptual parameter that best suits the waveform. Timbre is the characteristic of sound, in which two sounds can be distinguished at the same frequency, from different sources such as the sound of one instrument from another (e.g. flute and guitar). The timbre depends on the spectral content of the sound, which is composed of the sum of the sine components that can be examined by Fourier analysis.



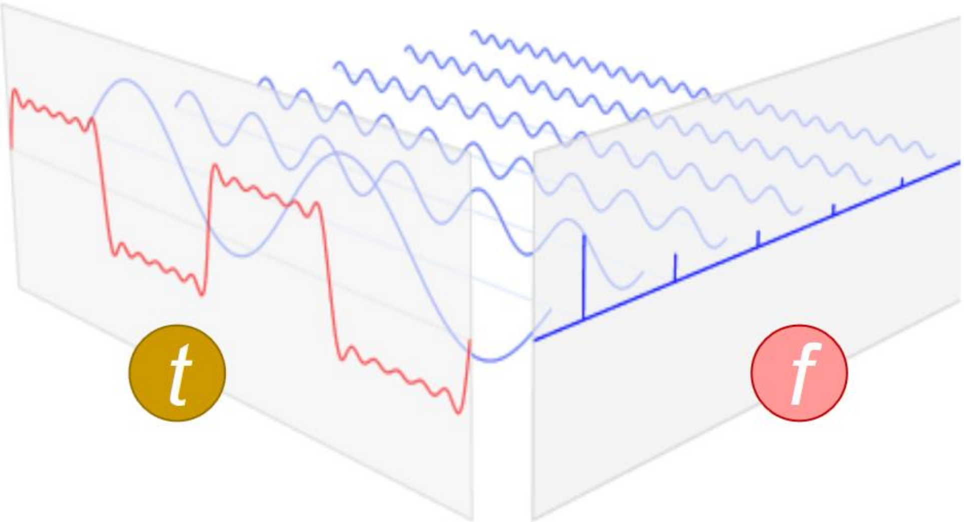
Fourier analysis

First focus is on the study of the spectral components that require Fourier analysis. The analysis of Fourier is an analytical method, which allows us to highlight in a signal many aspects related to the nature of sound that are not directly related to the representation in the time domain.

The differences between the time domain and frequency domain:

In physics, the Fourier transformation in wave mechanics represents the link between time domain and frequency domain. If signals are considered as a function of location instead of time signals, the

Fourier transformation represents a link between the spatial domain and the spatial frequencies or wavenumbers present in the frequency domain.

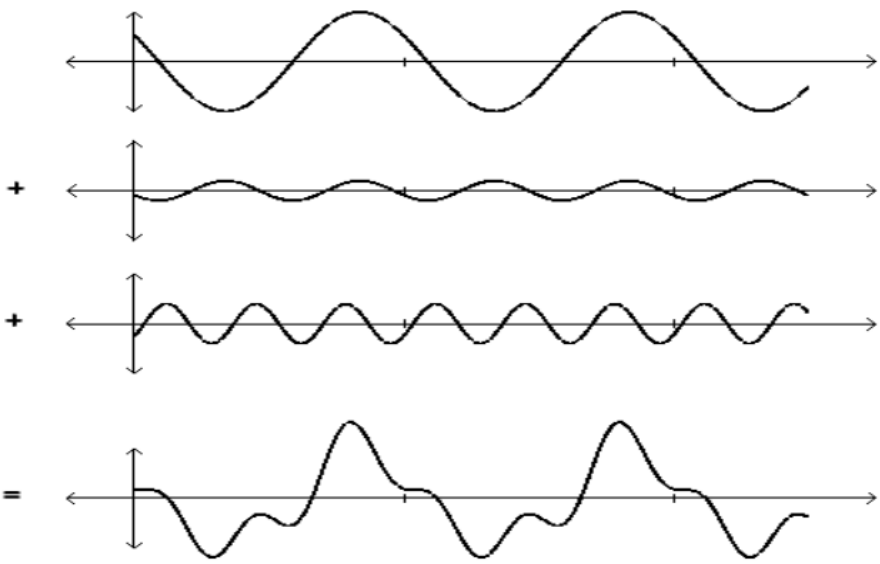


A representation in the time domain describes the evolution of a quantity, in our case the sound intensity. Considering a point on the curve, it will represent the intensity of the sound at a precise instant of corresponding time on the abscissa. Similarly, therefore, if a representation is in the frequency domain, the curve that describes a signal associates the intensity with the specific frequencies.

Fourier-Transformation

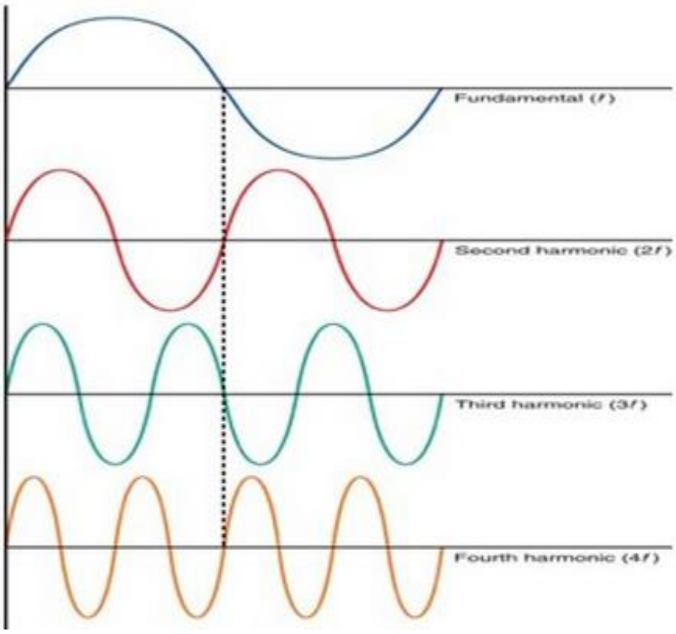
The French mathematician Fourier demonstrated that any complex signal could be described as a sum of simple sinusoidal signals. He is the author of the mathematical method known as the Fourier Transform that allows us to identify the frequency components of a signal.

The main idea is that a complex signal consists of several simple signals. The frequencies of a complex signal refer to the frequencies of these simple signals.



The requirement of the complex signal is the periodicity, that is a trend, even if partial and limited, which is repeated at regular time intervals. The overlap of the waves implies that at a time instant, simple waves are added together to obtain the total amplitude of the signal.

The component frequencies are harmonics of the fundamental frequency means that these frequencies are integer multiples of the fundamental frequency. That is, if the fundamental frequency is f, the harmonics of f are 2f, 3f, and so on. Not all harmonics are present, but all the frequencies present are multiples of the fundamental frequency.



Fourier Series and Fourier Transform (ab S.23, Transformation ab 34)

The difference between them is Fourier series is applied on periodic signals and Fourier transform is applied for non-periodic signals.

The mathematical tool for finding the elementary terms that make up a periodic wave is the Fourier series. In most cases the waves are not periodic, but they can still be run using the Fourier Transform. In this case the frequencies of the elementary waves will not belong to the discrete set of multiples of the fundamental frequency but will vary in a continuous whole.

Fourier transform

$$y(t) = \int_{-\infty}^{+\infty} C(n) e^{i\omega n t} dn \qquad C(n) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} y(t) e^{-i\omega n t} dt$$

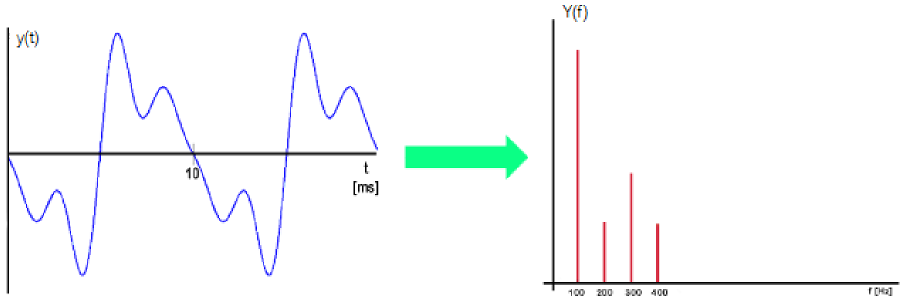
Fourier series

$$y(t) = \sum_{n=-\infty}^{\infty} c_n \, e^{i\omega n t} \qquad c_n = \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} y(t) e^{-i\omega n t} dt$$

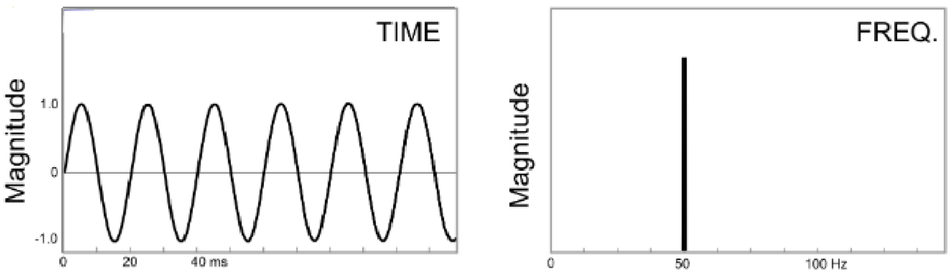
As can be noted, the Fourier Series is a special case of the Transform. In practice, for digital signals, the Discrete Series and the discrete Fourier Transform are used.

Fourier series - Spectrum

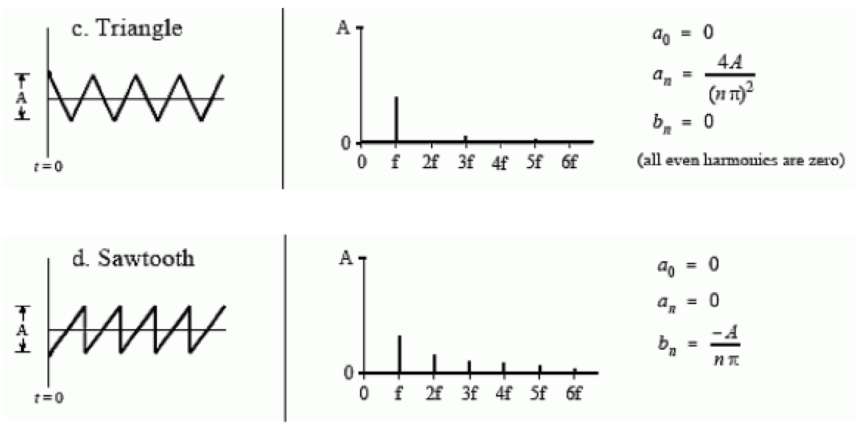
The set of elementary wave frequencies, with relative contributions, which constitutes a complex wave is called spectrum. The spectrum can be represented in a frequency-amplitude graph. It then passes from the domains or time to that of frequencies



Examples - Sine wave spectrum

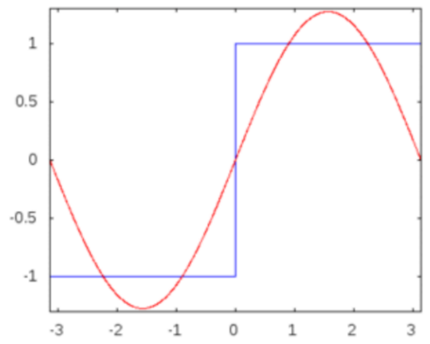


Examples - Triangular and Sawtooth

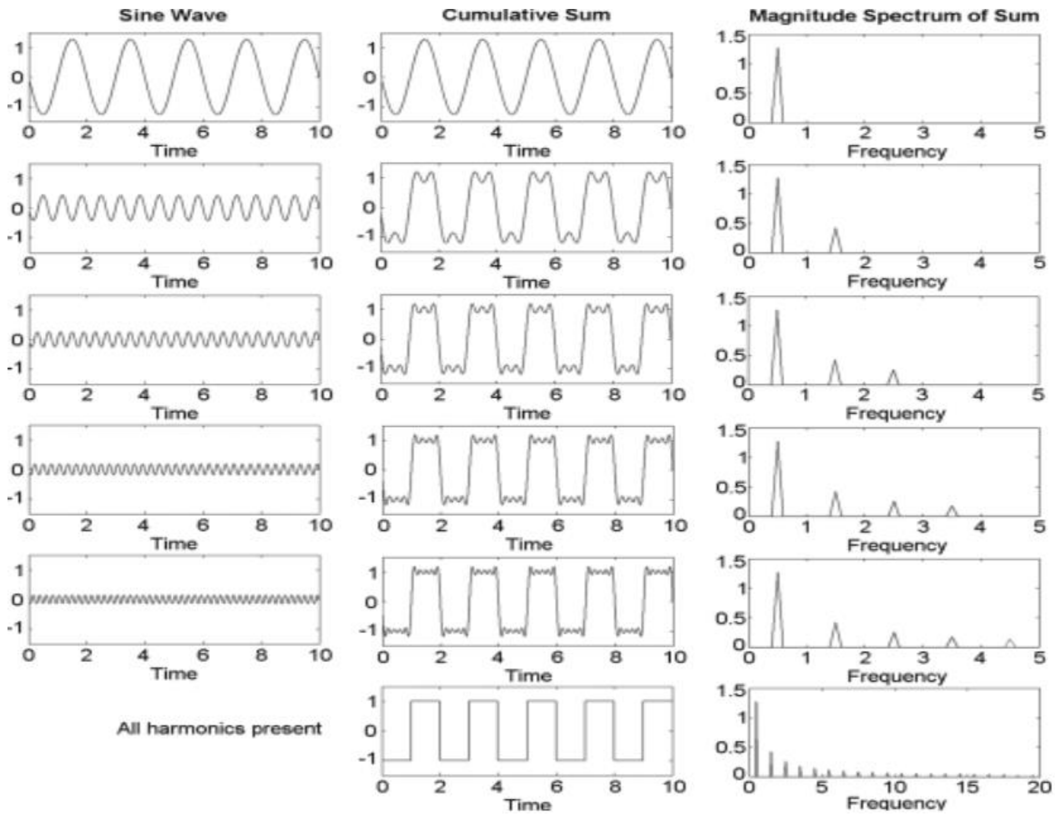


The triangular and sawtooth wave requires infinite terms to be synthesized. At the digital level this is clearly impossible, so normally only the first terms are used to approximate the original wave.

Examples - Square wave spectrum



An ideal square wave has instantaneous transitions between the high and low levels. In practice, this is never achieved because of physical limitations of the system that generates the waveform.



images sequence of the additive synthesis of a square wave with an increasing number of harmonics

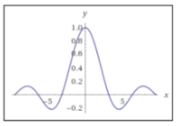
In musical terms, they are often described as sounding hollow, and are therefore used as the basis for wind instrument sounds created using subtractive synthesis. Additionally, the distortion effect used on electric guitars clips the outermost regions of the waveform, causing it to increasingly resemble a square wave as more distortion is applied.

Dirichlet conditions

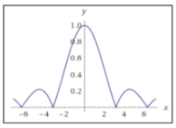
Not all periodic functions can be written using development in the series of Fourier. For this to be possible a function *f* must satisfy the Dirichlet conditions.

1. *f* must be absolutely integrable over a period.

$f(x) = \frac{\sin(x)}{x}$

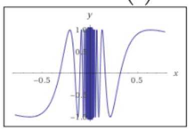


$|f(x)| = \left|\frac{\sin(x)}{x}\right|$

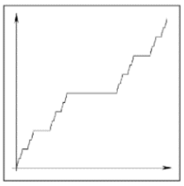


2. *f* must be of bounded variation in any given bounded interval.

$f(x) = \sin\left(\frac{1}{x}\right)$



3. *f* must have a finite number of discontinuities in any given bounded interval, and the discontinuities cannot be infinite.



Summary of definitions given (from the text)

- Fourier Harmonic Analysis: The identification of simple signals that make up a complex signal
- Fourier transform: It allows to identify the frequency components of a signal
- Fourier series: Special case of the Fourier Transform, applicable in the case of complex periodic signals
- Fourier spectrum: The set of components of a signal, with its own amplitude and phase
- Fourier synthesis: The synthesis of a sound from simple sinusoids

Spectrogram

A spectrogram usually represents the composition of a signal (for example, a sound or spoken language) from individual frequencies over time. It is the graphic representation of the intensity of a sound as a function of time and frequency. In this case, a spectrogram, more precisely expressed, is a time-variant representation of the frequency distribution using the short-term Fourier transform.

It is possible to represent the function i (t, f) as a surface (on a Cartesian diagram with axes t, f and i), usually for spectrograms another graphic representation is used, in which:

• the time in linear scale is shown on the abscissa axis:

• on the ordinate axis the frequency is shown on a linear or logarithmic scale;

• each point of abscissa and ordered date is assigned a shade of colour, representing the intensity of the sound at a given instant of time and at a given frequency; the relationship between the intensity of the sound and the scale of colours can be linear or logarithmic