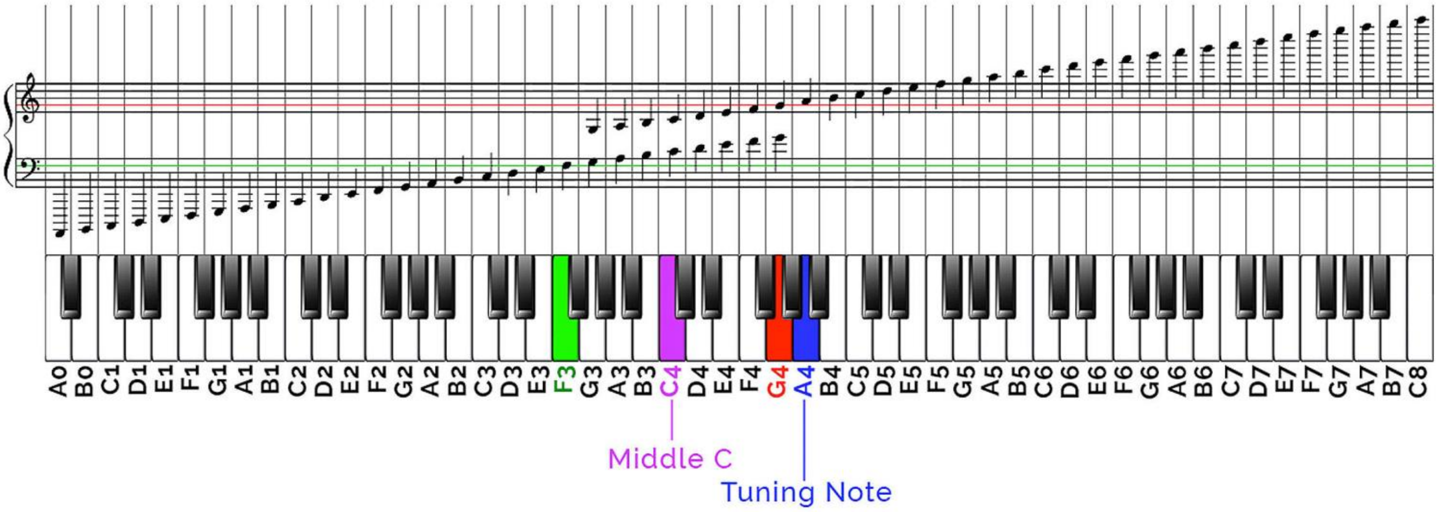
Sound frequency - Notes

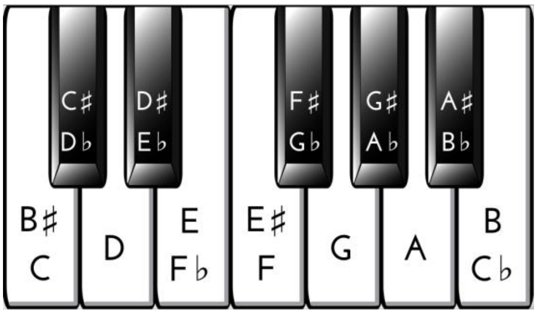
In music the frequency of a sound characterizes the musical notes. We might think that the note then corresponds to a pure tone, but as we know the same note can be produced by different musical instruments and thus be perceived differently. Actually, the note depends on the predominant frequency in the sound wave spectrum. All other frequencies characterize the instrument instead.

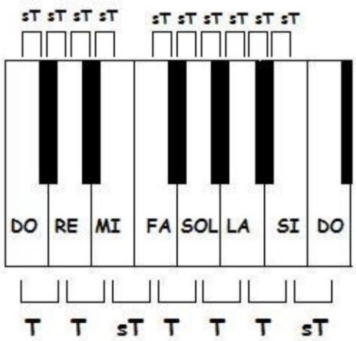
Each musical symbol used to describe a particular sound is defined as a musical note. The most known musical notes are those of the diatonic scale. They are 7 and are repeated at different frequencies.



However, there are other scales, such as the tempered scale and the chromatic scale.

For historical and psychoacoustic reasons, the notes are divided into intervals of the named octaves. The octave is the interval that elapses between equal notes, one of which has a frequency of twice the other. Each octave begins with same note of the previous octave (but of double frequency).



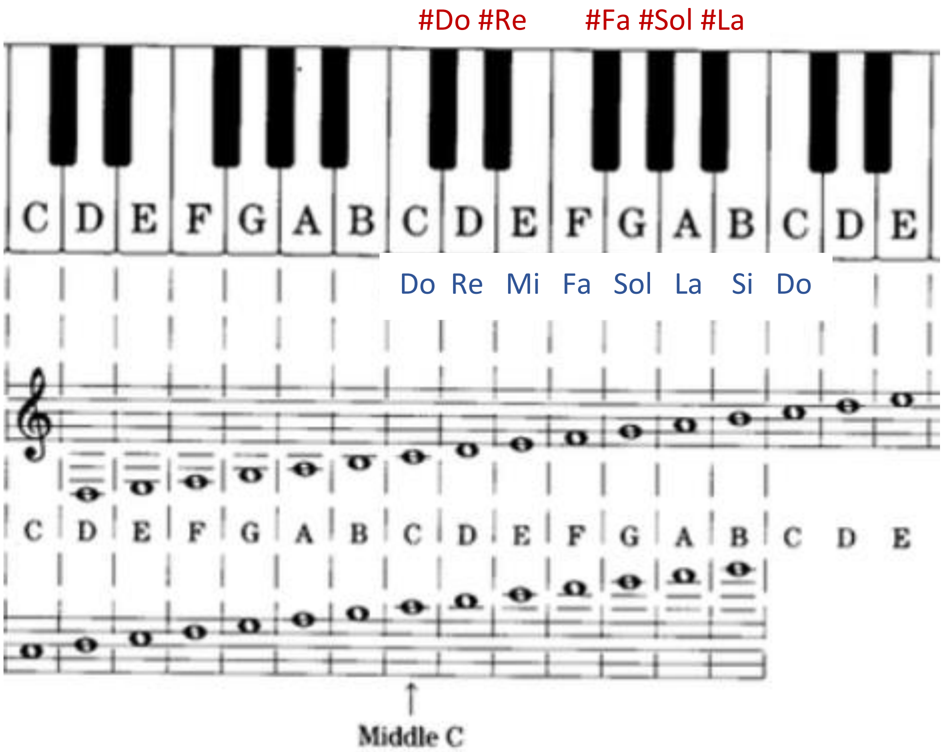


sT = semitone

T = whole tone (2 semitones)

In the temperate (western) scale, the octaves are devised in 12 semitones. A semitone consists of a frequency increase of a factor 2 ^ 1/12 between adjacent notes.

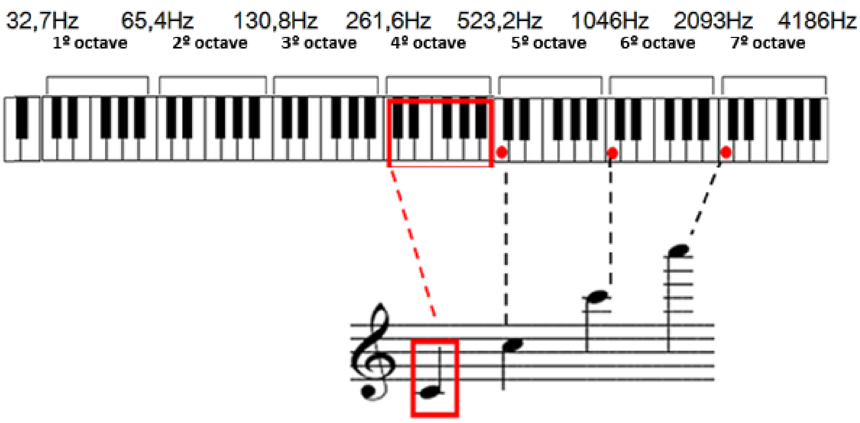
This means that the ratio between the frequency of a note and those preceding it will be equal to 2 ^ 1/12. Each octave contains 13 notes including those of the diatonic scale and 5 variations preceded by the symbol #(Es).



Octave

do$_4$	do#$_4$	re$_4$	re#$_4$	mi$_4$	fa$_4$	fa#$_4$	sol$_4$	sol#$_4$	la$_4$	la#$_4$	si$_4$
261,6Hz	277,2Hz	293,7Hz	311,1Hz	329,6Hz	349,2Hz	369,9Hz	392Hz	415,3Hz	440Hz	466,1Hz	493,9Hz

The octave is the interval that elapses between equal notes, one of which has a frequency of twice the other. Each octave starts with the note of the previous octave (but of double frequency).



Recently (1939) it was decided to use the La (A) as a reference note, fixed at a frequency of 440Hz. A properly constructed tuning fork can emit exactly one (almost) pure tone at this frequency.

The frequency of each note can therefore be defined based on the distance from the fundamental. A note distant n (relative integer) semitones from the reference note in the western scale will have frequency:

$$f_n = f_{ref} \times 2^{\frac{n}{12}} \qquad \text{con} \qquad f_{ref} = 440\ Hz$$

Note	Anglo-Saxon notation	Frequency (Hz)
la	A	$440.0 = 440 \times 2^{0/12}$
la#	A#	$466.2 = 440 \times 2^{1/12}$
si	B	$493.8 = 440 \times 2^{2/12}$
do	C	$523.2 = 440 \times 2^{3/12}$
do#	C#	$554.4 = 440 \times 2^{4/12}$
re	D	$587.3 = 440 \times 2^{5/12}$
re#	D#	$622.2 = 440 \times 2^{6/12}$
mi	E	$659.2 = 440 \times 2^{7/12}$
fa	F	$698.4 = 440 \times 2^{8/12}$
fa#	F#	$740.0 = 440 \times 2^{9/12}$
sol	G	$784.0 = 440 \times 2^{10/12}$
sol#	G#	$830.6 = 440 \times 2^{11/12}$
la	A	$880.0 = 440 \times 2^{12/12}$

Semitone

Octave

Table of notes

	C	C#	D	Eb	E	F	F#	G	G#	A	Bb	B
0	16.35	17.32	18.35	19.45	20.60	21.83	23.12	24.50	25.96	27.50	29.14	30.87
1	32.70	34.65	36.71	38.89	41.20	43.65	46.25	49.00	51.91	55.00	58.27	61.74
2	65.41	69.30	73.42	77.78	82.41	87.31	92.50	98.00	103.8	110.0	116.5	123.5
3	130.8	138.6	146.8	155.6	164.8	174.6	185.0	196.0	207.7	220.0	233.1	246.9
4	261.6	277.2	293.7	311.1	329.6	349.2	370.0	392.0	415.3	440.0	466.2	493.9
5	523.3	554.4	587.3	622.3	659.3	698.5	740.0	784.0	830.6	880.0	932.3	987.8
6	1047	1109	1175	1245	1319	1397	1480	1568	1661	1760	1865	1976
7	2093	2217	2349	2489	2637	2794	2960	3136	3322	3520	3729	3951
8	4186	4435	4699	4978	5274	5588	5920	6272	6645	7040	7459	7902

Some typical frequencies

Sound	Frequency (Hz)
The lowest note of a piano	27.5
The lowest note of a bass singer	100
The lowest note of a clarinet	104.8
The central C of the piano	261.6
The beyond the central do of the piano	440
The upper range of a soprano	1000
The highest note of a piano	4186
The upper harmonic of musical instruments	10,000
The limit of hearing in the elderly	12,000
The hearing limit	16.000-20.000

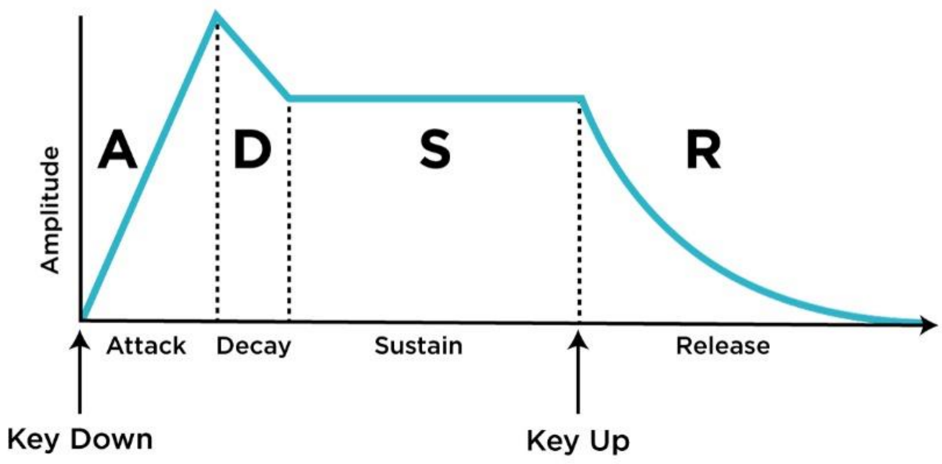
Amplitude - Envelope

Normally a sound starts in a certain instant of time and ends in another. Before and after we find silence.

How does the volume of a sound behave during its life time?

An envelope describes how a sound changes over time. In general, the amplitude variation follows a certain trend. The envelope is the trend of the amplitude or volume of a sound from the moment in which it is generated to the moment in which it is extinguished.

The envelope is divided into 4 transients or phases: attack, decay, sustain, release.



Attack:

This is the time it takes for the volume to go from zero to its maximum value. In an organ the attack is immediate because the note is played at maximum volume as soon as a key is pressed. Instead, other sounds can be characterized by a more gradual attack, such as a flute. In a piano it can last about 1/100 of a second. It is obvious that every sound has a phase of attack, in which every vibrating physical system responds with a characteristic time: the time necessary for the establishment of stationary waves, or the affirmation of a particular mode of vibration of the system.

Decay:

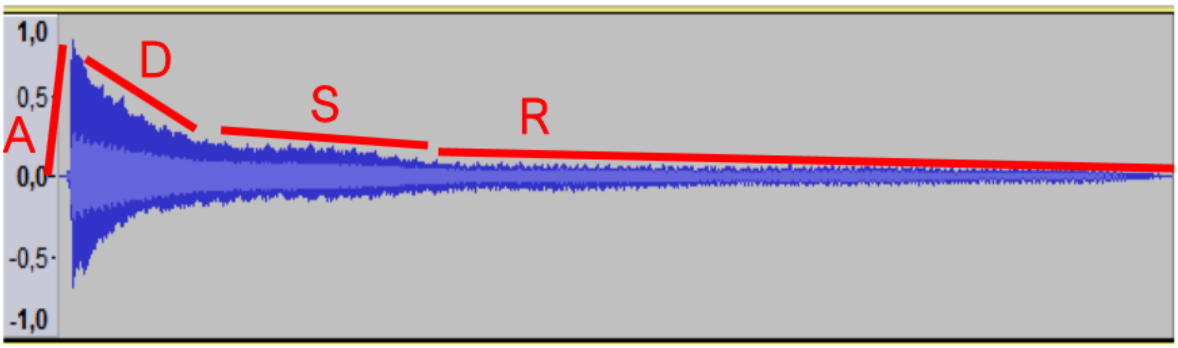
It represents the time that the sound takes to pass from the maximum volume reached during the attack phase to the sustain volume. That is the time it takes to reach a constant width. It is present in those instruments (e.g. trumpet) in which the sound is triggered only if a specific physical parameter (e.g. blowing pressure) exceeds a certain threshold.

Sustain:

Here the amplitude remains constant, while the performer continues to supply energy. This phase does not exist for percussion instruments.

Release:

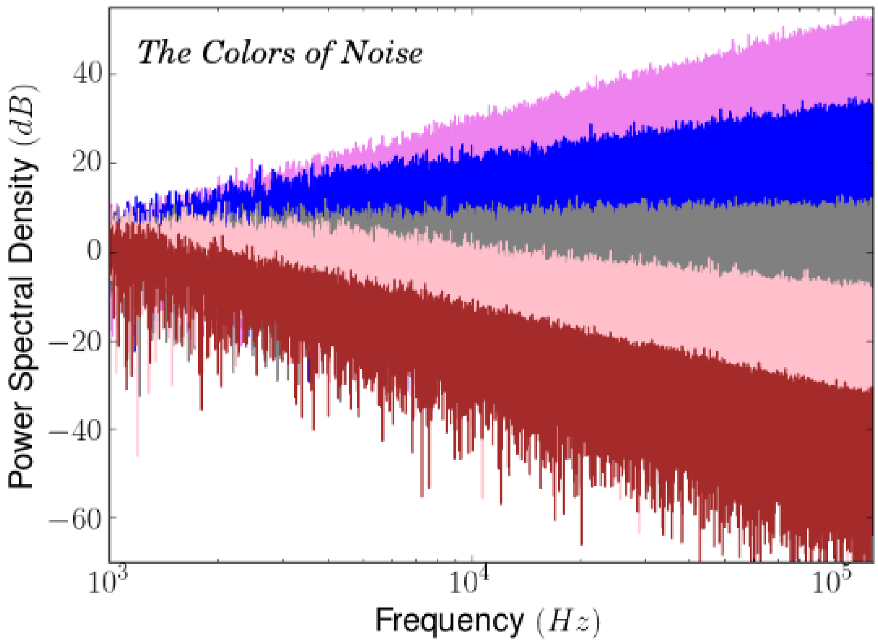
In this phase the volume decreases up to the value 0. Setting the release defines the speed with which this decrease occurs. It is the phase that begins when the performer stops supplying energy to the instrument and the sound decays more or less rapidly. This phase can also be very long in percussion instruments (think of the sound of a gong), while it is usually short in strings and winds. Obviously, all the sounds have a release. In an organ the release phase is instantaneous: as soon as the organ key is released, the note ceases; instead in the emulation of the sound of a guitar this phase is slow.



Example Guitar

Colours of noise

In our daily life sounds, noises and colours are essential components of our life. Between them, between sound and noise, there is a profound difference: in the first one there are regular and rapid oscillations, while in the noise such oscillations are irregular and unpredictable. It is perceived as a signal of disturbance with respect to the information transmitted in a system. In most cases being classified as "disturbances" one tries to mitigate them as much as possible. But there are some that, characterized by a random component, are studied. The main noises are named after the colours of the visible spectrum.

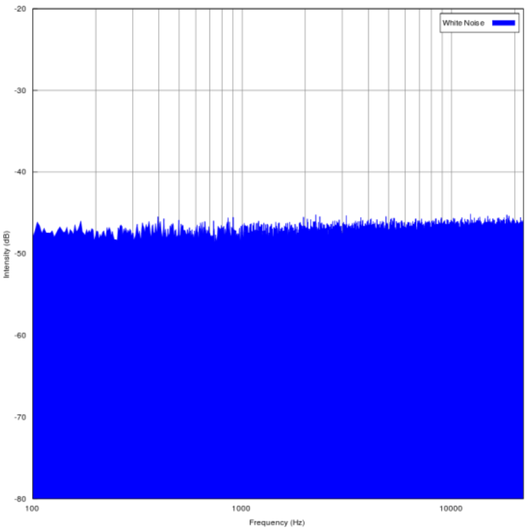


All in acoustics, there are particular sound waves, with a well-known spectrum that are called noises, but only because they are characterized by a random component. In reality these noises are studied and used advantageously.

Frequency spectra

The frequency spectra of the noises are very similar to the electromagnetic radiations absorbed by the human eye to see the colours. To understand it even better: as white is the sum of all colours, white noise is the sum of all the frequencies audible to the human ear. They can be classified as noise: white, pink, brown, blue, purple, grey, red.

White noise



White noise is a signal (or process), named by analogy to white light, with a flat frequency spectrum when plotted as a linear function of frequency (e.g., in Hz). In other words, the signal has equal power in any band of a given bandwidth (power spectral density) when the bandwidth is measured in Hz.

Its amplitude is constant and is not periodic over time. It is a noise that does not exist in nature but is artificially created by some equipment. It is called white by analogy with the fact that an electromagnetic radiation of similar spectrum within the visible light band would appear to the human eye as white light. Its use is very varied as it is perceived by the ear as something pleasant and relaxing.

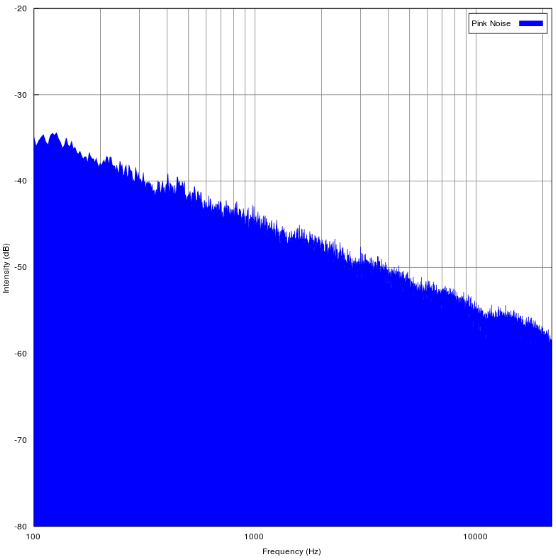
Mathematically speaking we can speak of a random vector w and it is white noise if and only if its mean vector and its autocorrelation matrix are respectively:

$$\mu_w = \mathbb{E}\{\mathbf{w}\} = 0$$
$$R_{ww} = \mathbb{E}\{\mathbf{w}\mathbf{w}^T\} = \sigma^2\mathbf{I}$$

That is, there is a zero mean vector and an autocorrelation matrix which is a multiple of the identity matrix. When the autocorrelation matrix is a multiple of the identity matrix the correlation is said to be spherical.

In psychoacoustics, white noise is used to combat noise and in the field of tinnitus retraining therapy as a masker. Noise and other sounds are subjectively perceived as less noisy and annoying when superimposed with white noise.

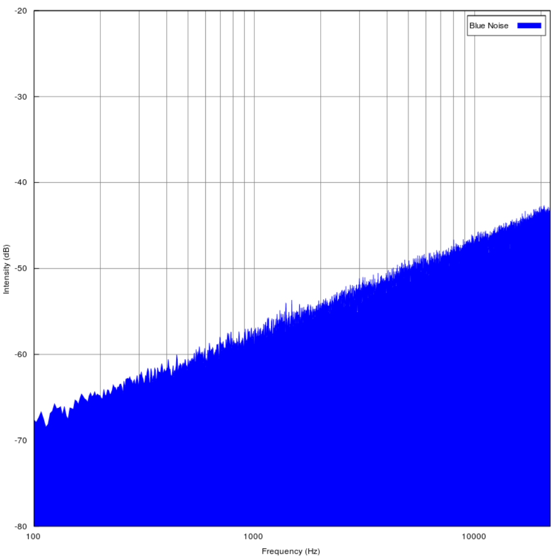
Pink noise



The frequency spectrum of pink noise is linear in logarithmic scale; it has equal power in bands that are proportionally wide. This means that pink noise would have equal power in the frequency range from 40 to 60 Hz as in the band from 4000 to 6000 Hz. Since humans hear in such a proportional space, where a doubling of frequency (an octave) is perceived the same regardless of actual frequency (40–60 Hz is heard as the same interval and distance as 4000–6000 Hz), every octave contains the same amount of energy and thus pink noise is often used as a reference signal in audio engineering. The spectral power density, compared with white noise, decreases by 3 dB per octave (density proportional to $1/f$). For this reason, pink noise is often called "$1/f$ noise".

It is used in large offices or waiting rooms to promote concentration and relaxation. This type of noise is structured in such a way as to compensate for the sensitivity of the human ear to the various frequencies and is used for the equalization of sound in a professional environment.

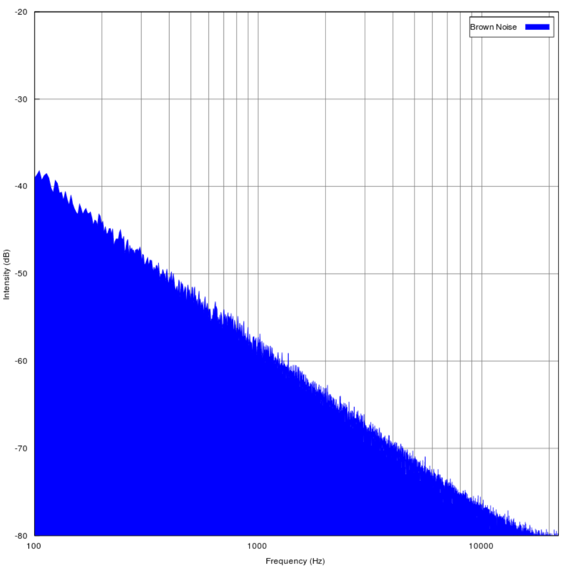
Brown noise



Brownian noise can be generated with temporal integration of White noise. "Brown" noise is not named for a power spectrum that suggests the colour brown; rather, the name derives from Brownian motion. Also known as "random walk" or "drunkard's walk". "Red noise" describes the shape of the power spectrum, with pink being between red and white. The energy of this noise resides in the low frequencies, very abundant compared to the white and pink noise. The sound appears similar to that of thunder. Or the roar of waterfalls.

Like pink noise, the spectrum has an inversely proportional relationship. The intensity is reduced - 6dB per octave. The power spectrum of brown noise is given by $S(\omega) = \frac{S_0}{\omega^2}$.

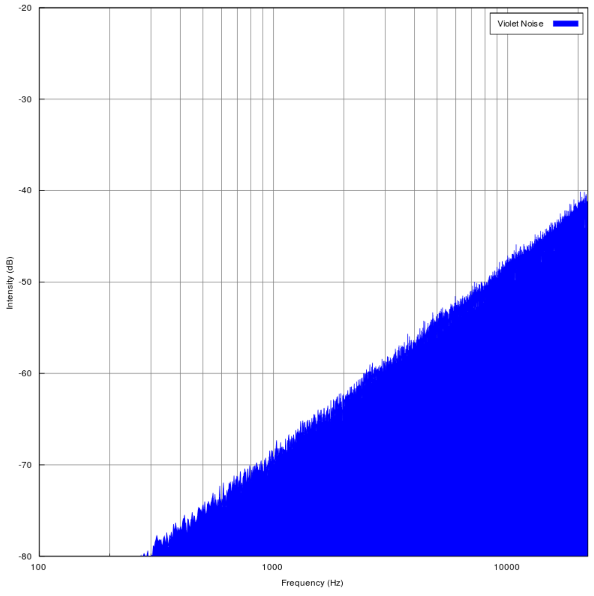
Blue noise



Its amplitude is not constant and presents a prevalence of high frequencies. It has a directly proportional dependence with an increase of 3 dB per octave. It has a shrill and artificial noise.

This can be good noise for dithering. Retinal cells are arranged in a blue-noise-like pattern which yields good visual resolution.

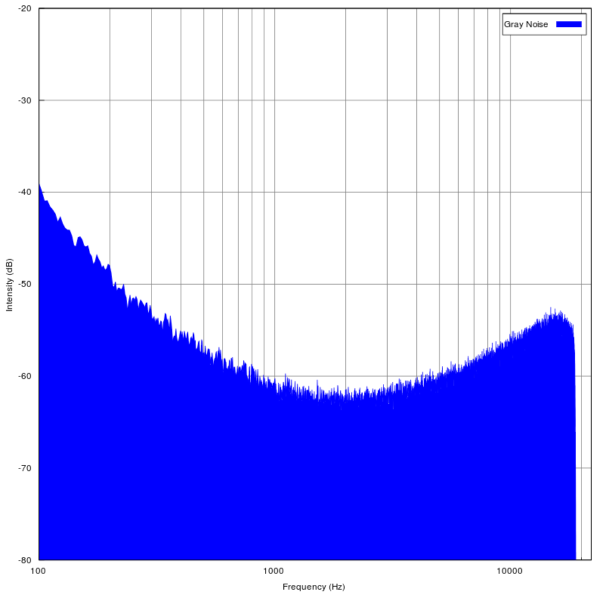
Violet noise



It has a proportional growth as the frequency increases with an increase of 6 dB per octave. It is considered the most annoying and produces a very strident hiss.

Also, the violet noise is a signal suitable for treating tinnitus (hearing disorders). The sound produced is reminiscent of a steam jet.

Grey noise



Grey noise is random noise subjected to a filter curve equal to psychoacoustic sensitivity (isophonic curves) in a given range of frequencies, giving the listener the perception that it is equally strong at all frequencies.

This is in contrast to standard white noise which has equal strength over a linear scale of frequencies but is not perceived as being equally loud due to biases in the human equal-loudness contour.

It is used to equalize audio signals so that all frequencies are perceived by a human listener at the same volume.