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Technical Information

Acoustic basics

Introduction

A sound is an auditory feeling generated by an acoustic wave. This wave is produced by a body's vibration (sound source) and reverberated in a material environment (example: air, water…).

BODY VIBRATION → **ACOUSTIC WAVE** → **SOUND**

The phenomenon of sound waves can be illustrated by dropping a stone into water's surface, which will spread outwards from the point of impact. These circles are considered 'waves'. The water is not moving, but the actual waves are running and propagating on its surface. The acoustic wave, or 'sound' wave, follows the same principle: it travels through the air, into our ears.

Three factors are essential to generate and receive sound:

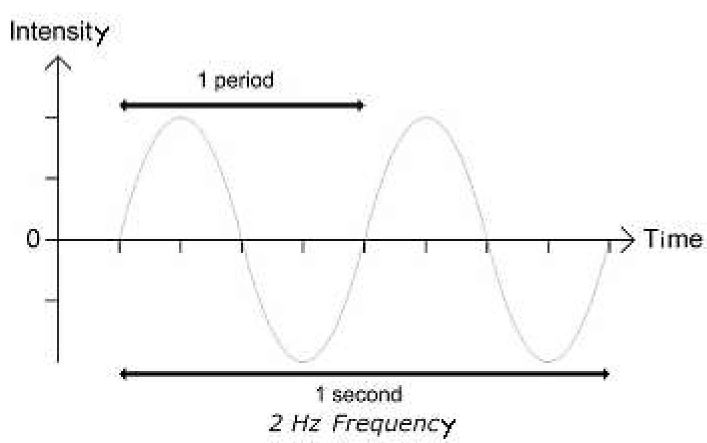
- a **sound source** to produce a mechanical vibration,
- an **expanding environment** (air) to reverberate and propagate this vibration as a wave (the speed of sound is around 340m/s at sea level),
- a **sound sensor** (eg. ear) to receive vibrations.

Generally, three parameters characterize a sound: frequency, intensity (sound level) and timbre (not explained in this newsletter).

Sound Frequency

Sound frequency – called a Hertz unit – refers to the number of oscillations or 'complete vibrations' produced in one second. For example: a 100Hz frequency corresponds to 100 oscillations per second.

Period is the inverse of frequency. One period corresponds to a full oscillation, in a time unit (example: second)



Sounds with a low frequency are perceived as ‘low sounds’ and sounds with a high frequency, ‘high sounds’.

The field or scale of audible frequencies for human ears extends from 20 to 20,000Hz, (20kHz). Within this scale, a human ear is especially sensitive to sounds registering frequencies between 1,000 and 4,000Hz.

Sound frequencies between 0 and 20Hz are called **infrasounds**. They are not directly perceived by the human ear, however, a human body can feel them as vibrations, for example when travelling in a car or during a concert.

Sound frequencies beyond 20kHz are called **ultrasounds**. Some animals can perceive them and some even produce them, such as dogs and dolphins.

20 Hz   200 Hz   4 000 Hz   20 000 Hz

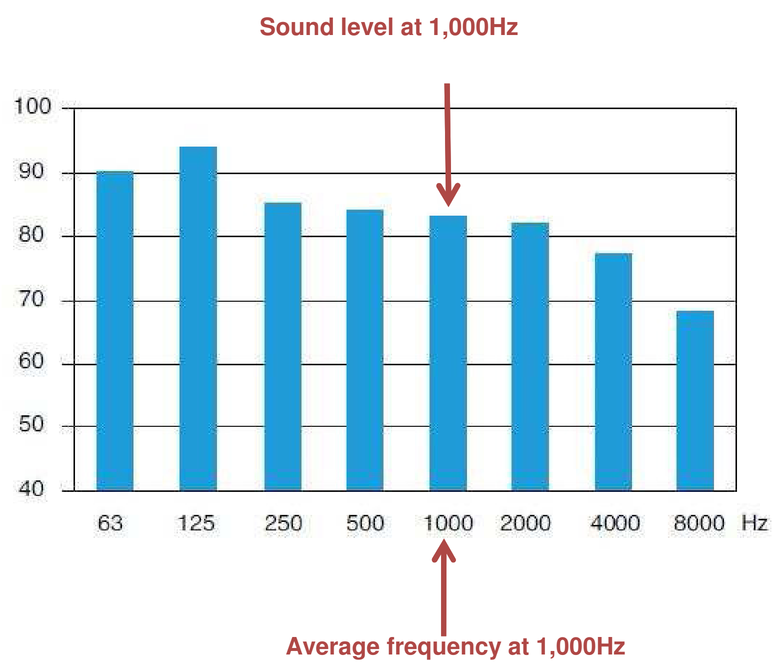
Infrasounds	Low	Medium	High	Ultrasounds
Perceived by human body	AUDIBLE FIELD			Perceived and produced by some animals

Acoustic spectrum and scale

Noise is a superposition of acoustic waves, with different frequencies and intensities. To build up a noise analysis, it is necessary to describe the **content** of a **specific sound signal**. In other words, all sounds have to be determined through a **spectrum analysis**, which aims to study the sound level for different frequencies.

In practice, some filters can isolate a cluster of sounds on a precise **frequency interval**. **Octave** is the most commonly used band of measurement. An octave represents an interval between two frequencies f1 and f2, such as f2 = 2xf1, and is represented by its average frequency, for example 125Hz correspond to the interval [88Hz; 176 Hz])

This analysis can be represented on a chart using an **acoustic spectrum** :



In a building, **frequencies between 63Hz and 4,000Hz octaves** are mainly experienced.

Octaves centered on 32Hz (or even 63Hz) and diffusing very low sounds are measured for acoustic analysis in night clubs.

Beyond 5,000Hz, high frequencies are easily stopped by walls and partitions.

Decibel

The ratio between the lowest sound that human ears can feel (threshold of hearing) and the highest (threshold of pain) is about one million, although using this kind of scale for reference is not particularly relevant in showing a sound level. A **specific scale** makes it easier using 'decibel' (dB) as a logarithmic unit.

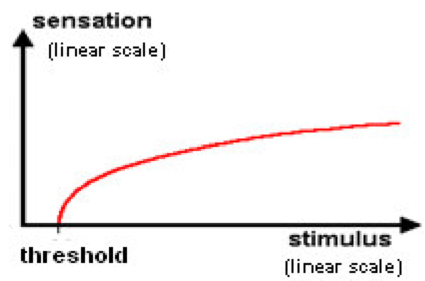
An **addition of several sounds is thus equal to a logarithmic sum**.

Example: the sum of two sounds - S1 and S2 (dB) : =>

Sum log (S1,S2) = 10.log (10[S1/10] + 10[S2/10])

It was scientifically proven that auditory sensation varies in correlation to the logarithm of the simulation. This scale is therefore more representative of the human ear's perception of sound.

In summary, the logarithmic '**decibel' allows us to fit an acoustic unit to human acoustic sensitivity**.



Sound pressure level / Sound power level

Sound pressure level is the air pressure variation created by a sound source and is equivalent to the perceived sound level. Its value depends on the **source environment** (for example, if there are some obstacles) and on the **distance from the source**. **The unit is Pascal (Pa) (= N/m²), or more generally decibel (dB),** and its relative value is $2x10^{-5}$ Pa (threshold of hearing), that is equivalent to 0dB.

Sound pressure levels can be measured with a sound level meter, or more precisely with a sound spectrum analyzer.

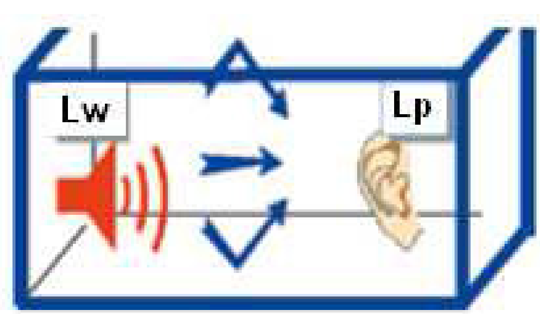
To create this sound pressure, the source must have its own power, which is necessary for the propagation of acoustic waves. This is the **sound power**.

Sound power is the total quantity of sound energy radiated by the source, per unit of time. This **intrinsic source parameter doesn't depend on other parameters** (particularly, the environment).
The unit is expressed in Watt (W), or more generally decibel (dB), and its relative value is 10^{-12}W.

These two notions are usually symbolized with the following letters: **Lp for sound pressure level (dB) and Lw for sound power level (dB).**

⇒ The sound pressure level Lp (dB) characterizes the acoustic phenomenon at one point. Its value depends on the position and the environment.

⇒ The sound power level Lw (dB) defines a sound source. Its value is distinct from its position and only depends on the source characteristics.



The A-weighted decibel

Acoustics is not only a « physical » measure for sounds.
Indeed, the **human ear doesn't perceive sound with different frequencies in the same way**. A 50dB sound with a 1,000Hz frequency produces a higher auditory sensation than a 50dB sound with 100Hz frequency.

Taking into account this phenomenon in order to replicate sound closest to the human ear's perception, **a filter (A) is used to balance sound levels according to frequencies**. **The measure is expressed in A decibel or dB(A).**

The noise measure in dB(A) is set up as a global measure for all frequencies. It is characterized by **only one value** that corresponds to the **logarithmic sum of weighted pressure or power levels**.

Other weightings exist (B, C, D) but those one are not used for common sound levels.

The significance of this weighting is to compare sound signals according to their intensity perceived by human ears.
As mentioned previously, two sounds with 50Hz and 1,000Hz, and a 50dB level for both of them, wouldn't be perceived with the same intensity. On the other hand, two sounds with a 50dB(A) level would be perceived with the same intensity.

The measurement tools (sound level meter) usually have a bank of filters (analogical or numerical) to calculate the sound levels for each frequency scale and the signal's weighted level.

Example of calculation for a global weighted sound level

Let's consider the example of a fan having the following acoustic spectrum for each octave:

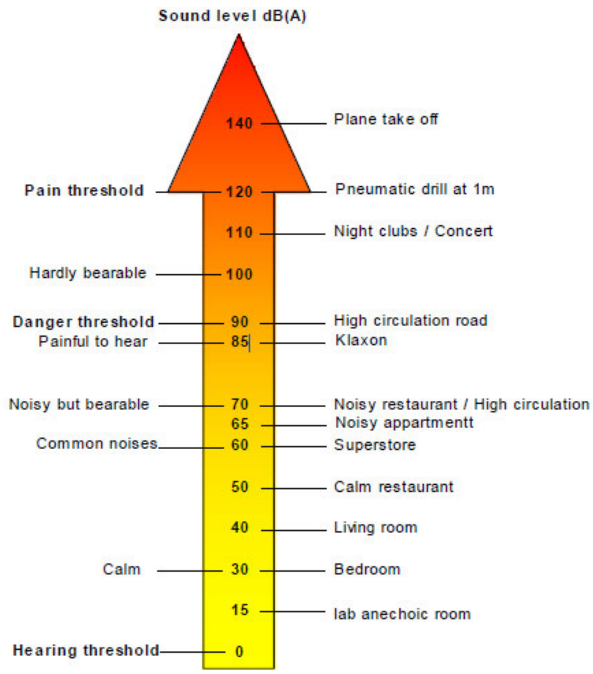
Octave scale (Hz)	63	125	250	500	1000	2000	4000	8000
Fan acoustic spectrum (dB)	78	77	75	66	67	65	61	55
A coefficient of balance (dB)	-26,2	-16,1	-8,6	-3,2	0	+1,2	+1	-1,1
Balanced acoustic pressure level (dB)	51,8	60,9	66,4	62,8	67	66,2	62	53,9

The global level in dB(A) is obtained firstly by adding the corresponding weighting coefficient to each octave level and secondly, by calculating the logarithmic sum of the weighted levels :

$$Lp_{total} = 10 \log [10^{5,18} + 10^{6,09} + 10^{6,64} + 10^{6,28} + 10^{6,7} + 10^{6,62} + 10^{6,2} + 10^{5,39}] = 72,7 \text{ dB(A)}$$

Sound level scale

The A-weighting coefficient is used to give a scale of noise levels perceived by human ears.



If the distance is doubled, the sound level is decreased by 6 dB(A).

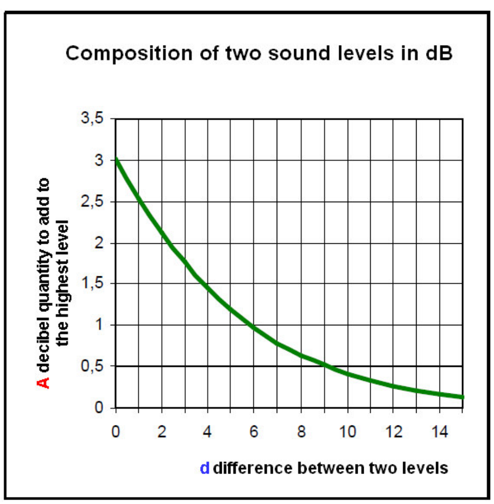
Addition of sound levels

As previously mentioned, the addition of sound levels is not arithmetic but according to a logarithmic progression. Consequently, two sources with both a 60dB sound level won't give a 120dB global sound level but a 63dB sound level.

Adding 2 sources with a same sound level means adding 3dB to this level.

60 dB + **60 dB** → **63 dB**

In order to avoid logarithmic calculations, charts or an abacus are commonly used to add two sound levels with an arithmetic difference (**d**) between the two levels (see below).



d in dB	0	1	2	3	4	5	6	7	8	9	10	11	12
A in dB	3	2.5	2.1	1.8	1.5	1.2	1	0.8	0.6	0.5	0.4	0.33	0.26

Addition of 2 sound levels:
A is the quantity added to the **highest level** if the arithmetic difference **d** between both levels is known.

Example :
64 dB + 60 dB => 65,5 dB (d=4 => A=1,5)

The previous graph and chart show that if **two sound sources have more than a 10dB gap**, the result of the two sources addition approximately corresponds to the highest source level sound (≤ 0,4dB to add).

In that case, the source with the highest sound level hides the source with the lowest one:

60 dB + **70 dB** → **~ 70 dB**

Decibel

The table below highlights the consequences of sound level increase on human ears :

Sound level increase (en dB)	*Auditory perception*
3	Slightly audible
5	Clearly audible
10	Sensation x2
15	Big difference
20	Sensation x4

For a sensation of doubled sound level, it is necessary to add 10dB, which is equivalent to **10 identical sound sources.**

Example : Addition of 10 identical sound sources of 60 dB
60 dB + 60 dB + 60 dB + 60 dB + 60 dB + 60 dB + 60 dB + 60 dB + 60 dB + 60 dB
= 63 dB + 63 dB + 63 dB + 63 dB + 63 dB = 66 dB + 66 dB + 63 dB = 69 dB + 63 dB
= 70 dB

Common misconceptions

⇒ **The sum of two sound sources is not arithmetic but logarithmic.**

⇒ **Two sound sources with the same sound level is equivalent to an increase of 3dB, which means a slightly audible increase for human ears.**

⇒ **According to its calculation mode, a global sound level is superior or equal to each value by frequency that constitutes it.**

⇒ **When a comparison is made between several sound levels, values have to observed under the same conditions for example: pressure/power, distance from the source, measurement conditions, environment etc. This ensures the relevancy of the information used in the final comparison.**