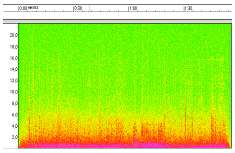

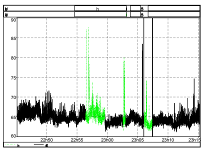

Acoustic Design #01

Dr. Nicolas REMY
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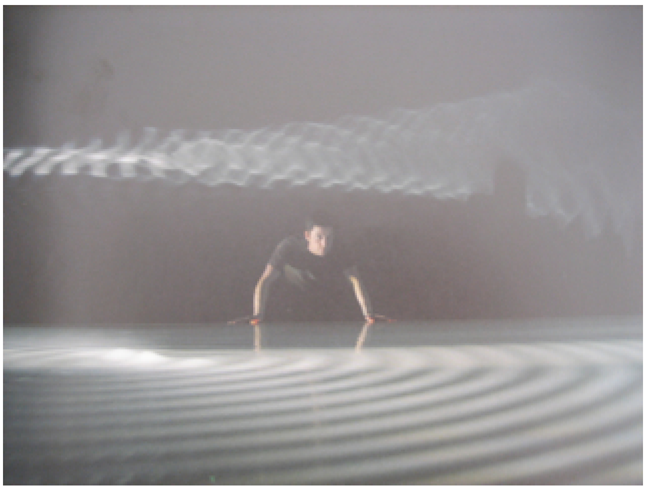
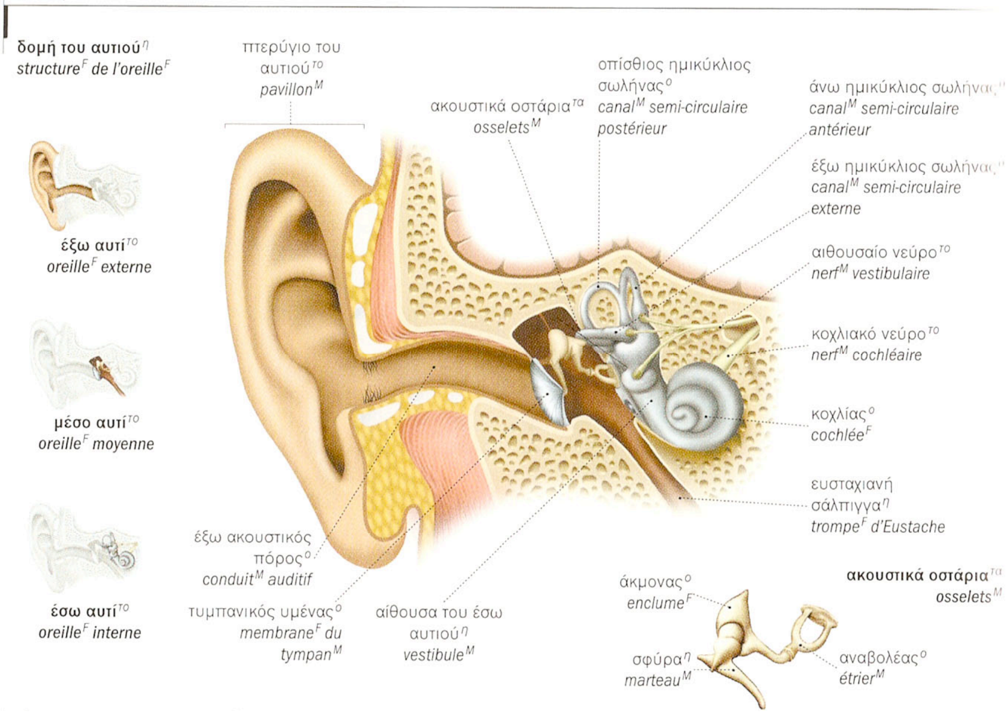
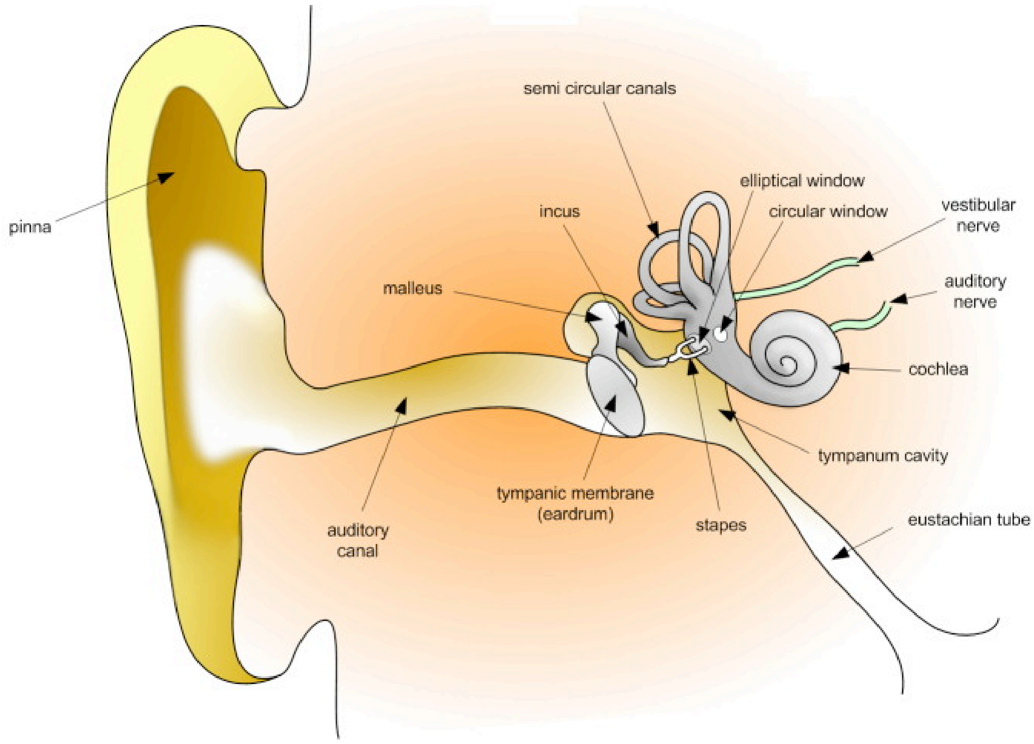
Definition

Sound : vibrations that travel through the air or another medium and can be heard when they reach a person's or animal's ear.



Physiology of the ear





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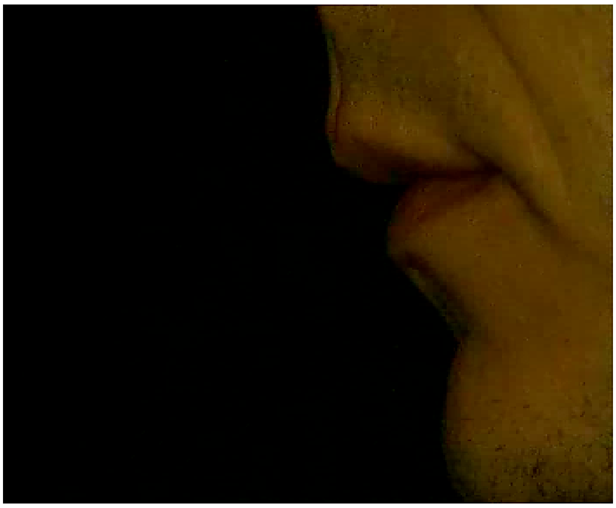
Physical parameters
medium of propagation

Sounds : feelings caused by the disturbances of an elastic material physical environment (air, water...) and generated by the stimulation of the sensory elements of the inner ear, generally by the acoustic waves.



Antonio Fischetti
Initiation à l'acoustique

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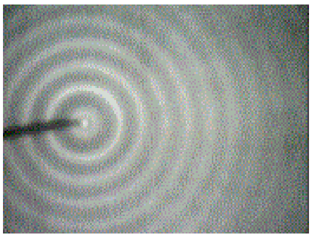
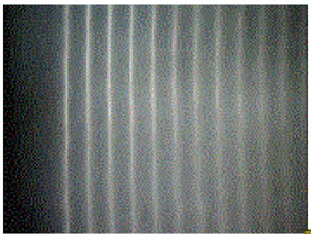
Physical parameters
medium of propagation

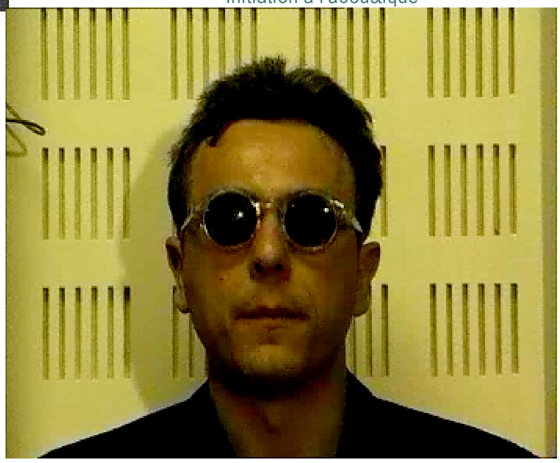


Spherical waves



flat waves

Antonio Fischetti
Initiation à l'acoustique



Qualities of the medium change properties of sounds

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Physical parameters
speed of sound

The speed of sound depends on the medium through which the waves are passing, and is often quoted as a fundamental property of the material. In general, the speed of sound is proportional to the square root of the ratio of the elastic modulus (stiffness) of the medium to its density. Those physical properties and the speed of sound change with ambient conditions. For example, the speed of sound in gases depends on temperature.

In French, « Speed of sound » is also called celerity

$$C = 20\sqrt{T}$$

temperature in °Kelvin

exemples

T= 0°C ⇒ c= 330m/s

T= 20°C ⇒ c= 342m/s

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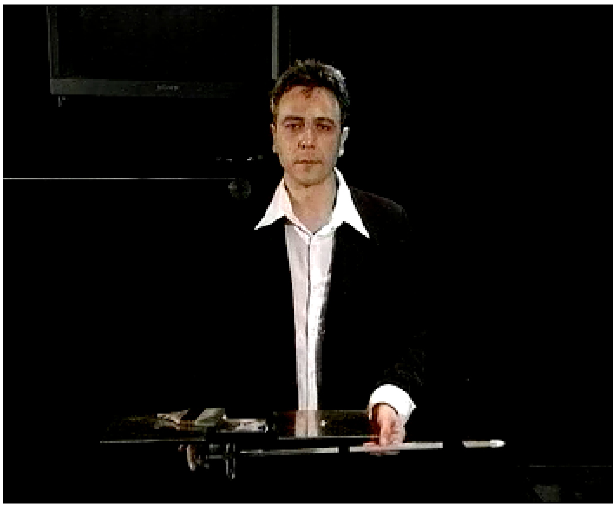
Physical parameters
medium of propagation and speed of sound

Sound is transmitted through gases, plasma, and liquids as longitudinal waves, also called compression waves. Through solids, however, it can be transmitted as both longitudinal and transverse waves

Speed of sound in …

- c_{water} = 1460 m/s
- c_{steel} = 5100 m/s
- $c_{concrete}$ = 4000 m/s
- c_{glass} = 5000 m/s



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Physical parameters
medium of propagation and speed of sound

Storm, thunder … sound and light phenomena in the same time but seen and listened separately…

Does the storm approach ?

Physical parameters
medium of propagation and speed of sound

Sound speed is the air is “slow” … difficulties to implement sound system in big stadium (for example, Stade de France 105m x 70m)

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Physical parameters
medium of propagation and speed of sound

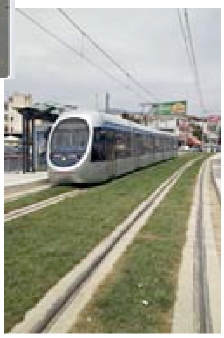
Sound cannot travel through vacuum….

From spaceship explosion …

…. To triple or double glass windows

Physical parameters
medium of propagation and speed of sound

Sound is transmitted through solids …



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Physical parameters

medium of propagation and speed of sound

Sound is transmitted through solids …

Laurie Anderson 1997

Why most of the people don't like to ear their own voice when the ear it recorded ?

3 parameters of sound

The ear is sensitive to 3 different parameters of sound :

- Sound level
- Frequencies
- Timbre

Sound level pressure

The ear is sensitive to variations of acoustic pressure (Pa or Pascals). It is very sensitive since the report/ratio of the acoustic pressure between the "first audible sound" and a painful sound is 1 million (10^6).

We define :

. auditory threshold P_O = 20mPa ou 2.10-5 Pa
. threshold of pain P = 20Pa

Sound Level pressure

Source of sound	RMS sound pressure	sound pressure level
	Pa	dB re 20 μPa
Theoretical limit for undistorted sound at 1 atmosphere environmental pressure	101,325	191
1883 Krakatoa eruption		approx 180 at 100 miles
Stun grenades		170-180
rocket launch equipment acoustic tests		approx. 165
threshold of pain	100	134
hearing damage during short-term effect	20	approx. 120
jet engine, 100 m distant	6–200	110–140
jackhammer, 1 m distant / discotheque	2	approx. 100
hearing damage from long-term exposure	0.6	approx. 85
traffic noise on major road, 10 m distant	0.2–0.6	80–90
moving automobile, 10 m distant	0.02–0.2	60–80
TV set – typical home level, 1 m distant	0.02	approx. 60
normal talking, 1 m distant	0.002–0.02	40–60
very calm room	0.0002–0.0006	20–30
quiet rustling leaves, calm human breathing	0.00006	10
auditory threshold at 2 kHz – undamaged human ears	0.00002	0

Sound pressure level

As the human ear can detect sounds with a very wide range of amplitudes, sound pressure is often measured as a level on a logarithmic decibel scale. The sound pressure level (SPL) or *L*p is defined as

$$L_\mathrm{p} = 10\,\log_{10}\left(\frac{p^2}{{p_\mathrm{ref}}^2}\right) = 20\,\log_{10}\left(\frac{p}{p_\mathrm{ref}}\right)\ \mathrm{dB}$$

where *p* is the root-mean-square sound pressure and pref is a reference sound pressure. Commonly used reference sound pressures, defined in the standard ANSI S1.1-1994, are 20 µPa in air and 1 µPa in water. Without a specified reference sound pressure, a value expressed in decibels cannot represent a sound pressure level.

Sound Level pressure

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Niveau sonore

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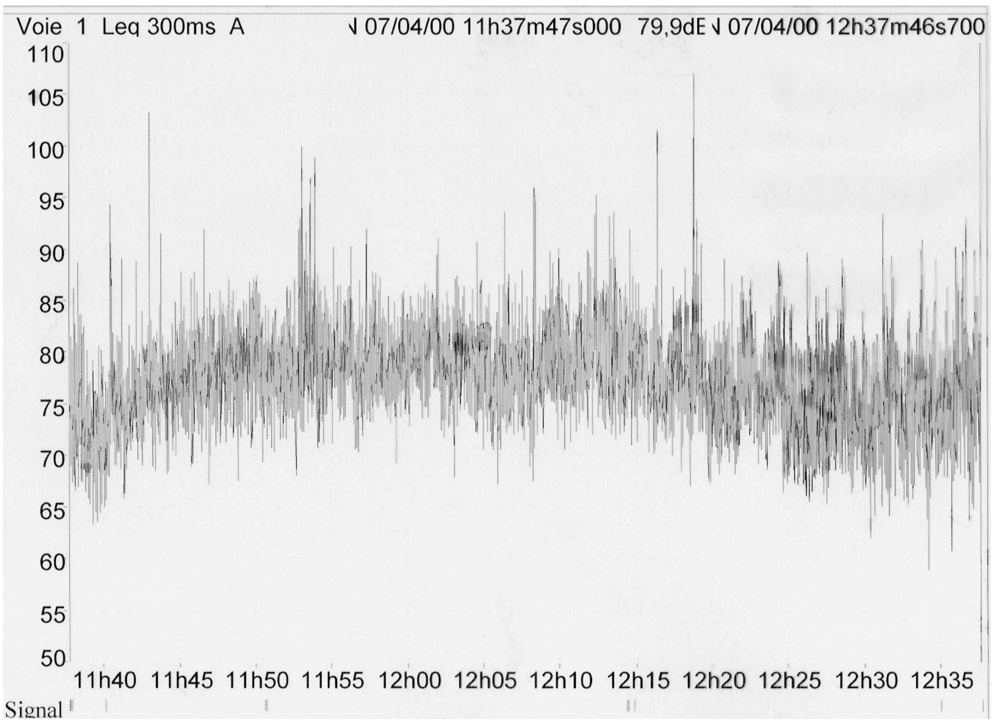
SLP measurements



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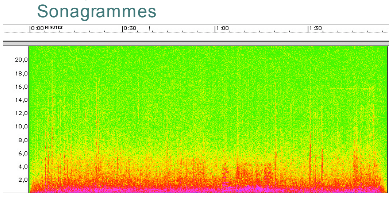
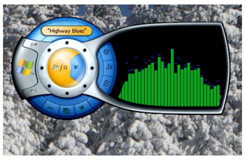
Fréquences

For humans, hearing is limited to frequencies between about 20 Hz and 20,000 Hz (20 kHz), with the upper limit generally decreasing with age.

This great field of sensitivity is divided into packages of frequencies which are ordered in a regular way for the ear. They are, for example, the octaves. When one passes from an octave to another, one has the auditive feeling that the frequenciesof sound has been doubled.

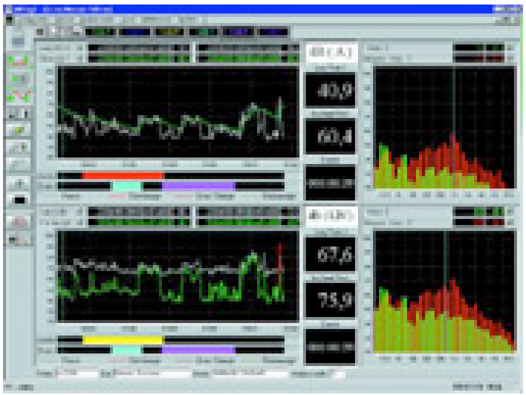
Exemples
Sonagrammes





fonction equaliser d'un lecteur audio sur PC

01dB - dBEnv32

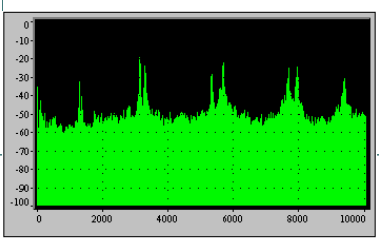


Fréquences

Ecoute de sons purs

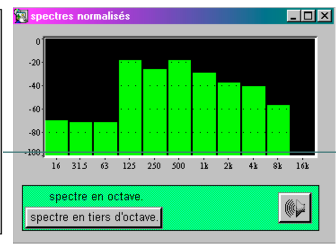
110 Hz 220 Hz 440 Hz 880 Hz 1760 Hz

Lp

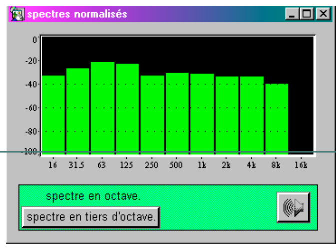


Téléphone

dans bruit de fond



saxophone



camion

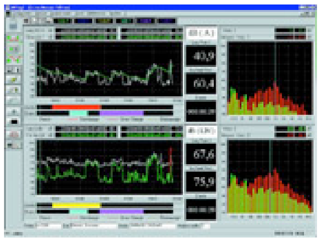
Hz

Octaves

Fmini	Octave	Fmax
44	**63**	88
89	**125**	176
177	**250**	353
353	**500**	707
708	**1k**	1414
1415	**2K**	2828
2829	**4K**	5656
5657	**8K**	11313
11314	**16K**	20 000

Ranges of octaves (Hz)

$fc / \sqrt{2} < fc < fc. \sqrt{2}$



Examples

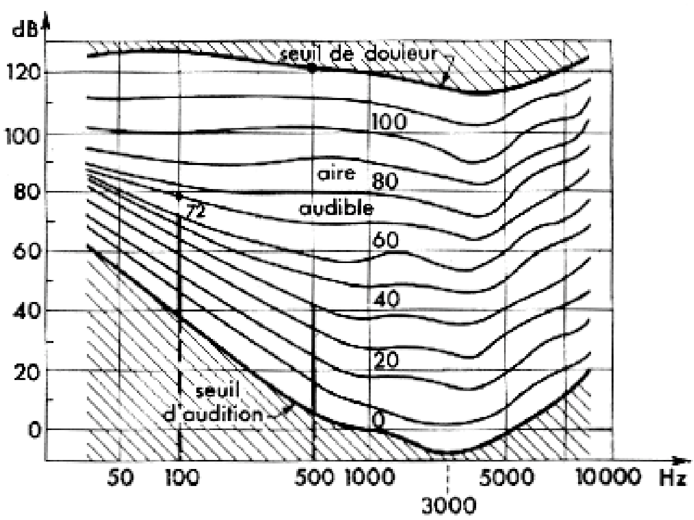
- electric generator 100-120hz
- LA from the phone 440 Hz
- human voice 300-4000 Hz
- Clavecin 63-18 000 Hz

Typology

- bass sounds 20-300 Hz
- medium sounds 300-1000 HZ
- treble sound 1000-16000 Hz

Fletcher et Munson, 1933

Le diagramme de Fletcher



dB(A)

A noise level expressed in decibel (dB) is not really representative of the human feeling because the ear is not very sensitive to the very low or very high frequencies (physiological reason).

The noise level must thus be weighted by a coefficient depend on the frequency of the emitted sound, in order to "penalize" the low registers and the treble ones compared to mediums.

It's A weighted sound level pressure

Pondération A							
Octave (Hz)	*125Hz*	*250Hz*	*500Hz*	*1kHz*	*2kHz*	*4kHz*	*8kHz*
Pondération A (dB)	*-15,5*	*-8,5*	*-3*	*0*	*+1*	*+1*	*-1*

Sound scale in dB(A)

Activities	dB(A)	Effects
Plane Takeoff	120	Shock, short-term deafness
Noise level limits for work	85	8H exposition*
From 30m to highway (4000 veh/h)	80	Vegetative disorders, disturb nervous
Busy street	70	Difficult comprehension of a conversation
Low trafin in town, noisy inside room, vaccum cleaner	60	Disorders of the drowsiness, insomnia
Residential area, calm restaurant or office	50	
Room class very calm appartement,	35	Zone of the sleep ; Time of recovery for the ear
Very calm appartement, rural area far away from noisy sources and without wind.	30	
Very isulated room	20	Oppression feelin
Absolute calm, level never found in « real situation « …	10	Deaf room

* Exposition time divided by 2 si +3dB(A)

timbre

The 3 parameters of sound are :
-sound level
- frequencies (bass, medium, treble)

The last parameter is te timbre :

In music, **timbre** is the quality of a musical note or sound that distinguishes different types of sound production, such as voices or musical instruments.

The physical characteristics of sound that mediate the perception of timbre include spectrum and envelope. Timbre is also known in psychoacoustics as *sound quality* or *sound color*.

For example, timbre is what, with a little practice, people use to distinguish the saxophone from the trumpet in a jazz group, even if both instruments are playing notes at the same pitch and amplitude.

Sound or Noise?

The noise (standardized definition)

1. erratic, intermittent or statistically random vibration

2. Any unpleasant or « unwanted » sound

sounds, noises... how can we make the difference ?

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Urban acoustic

Noises from means of transports
Protection of inhabitants
Urban engineering and town planning

Key words
Free field propagation
Meteorological effects
Noise treatments of road surfaces
Noises barriers
Insulation of building frontages

Revêtements acoustiques - www.boscoitalia.it

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Building acoustics

Noise problems inside a building, noisy activities near houses (industries, leisure, etc..)

Key words :
Sound insulation
Direct and lateral transmission of noises
Impact noises
Airborne noises
Floating floor
…

Isolant acoustique, laine minérale

Sous couche Velaphone, isolation bruit de choc

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Room acoustics

Deals with sound qualities inside a room. Largely developped for theaters, opera, etc… it also useful in large room with audience like restaurant, train stations, swimming pool, shopping mall, etc…

Mots-clés :
Direct and difuse field
Reverbération
Intelligibility of the speech
W.C. Sabine

la salle des Princes, Monaco - Système Carmen

Gymnase à Grenoble, Nicolas Michelin
www.cyberarchi.com

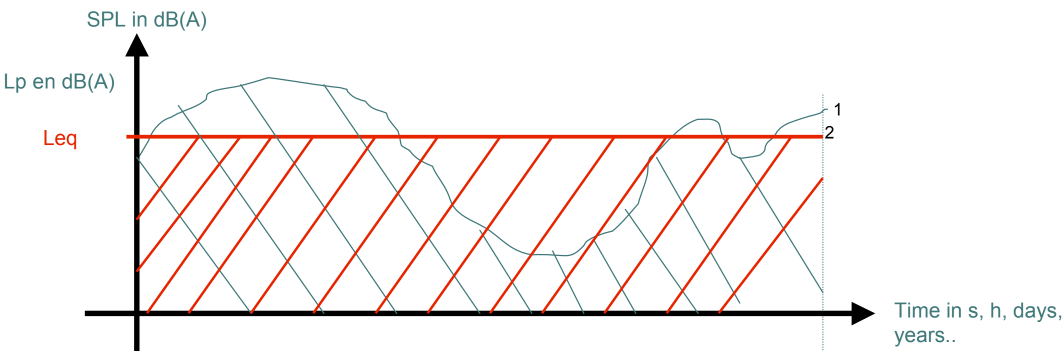
Hall de la Gare du Nord,SNCF- AREP - image N. Rémy

Technical tools 1

Acoustic criteria
. Leq or Equivalent Noise level

$$leq = 10\log\left[\frac{1}{T}\int_T 10^{\frac{Lp}{10}}dt\right]$$ in dB(A)

Sound energy is proportional to its level and to its duration. The equivalent noise level is taking account of the duration of the noise exposure. Ones can says it's a « clever average »
One loudly and short (in duration) noise will not affect very much the Leq
In this same sound (loudly) starts to stay, Leq will increase.



Surface under the blue-green curve (1) = surface under the red curve (2, the flat one)
ou

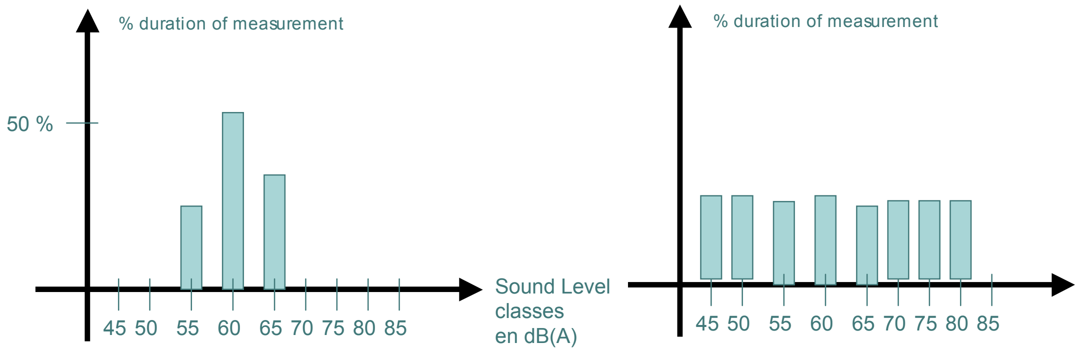
Intégrale de la courbe bleue = Intégrale de la courbe rouge

Outils techniques 2

. Statistical criteria
L5 : Sound pressure level expressed in dB(A) that has been gained during 5% of the measurement duration. (peak)
L95 : Sound pressure level expressed in dB(A) that has been gained during 95% of the measurement duration. (background noise)
L10, L20, L45 …

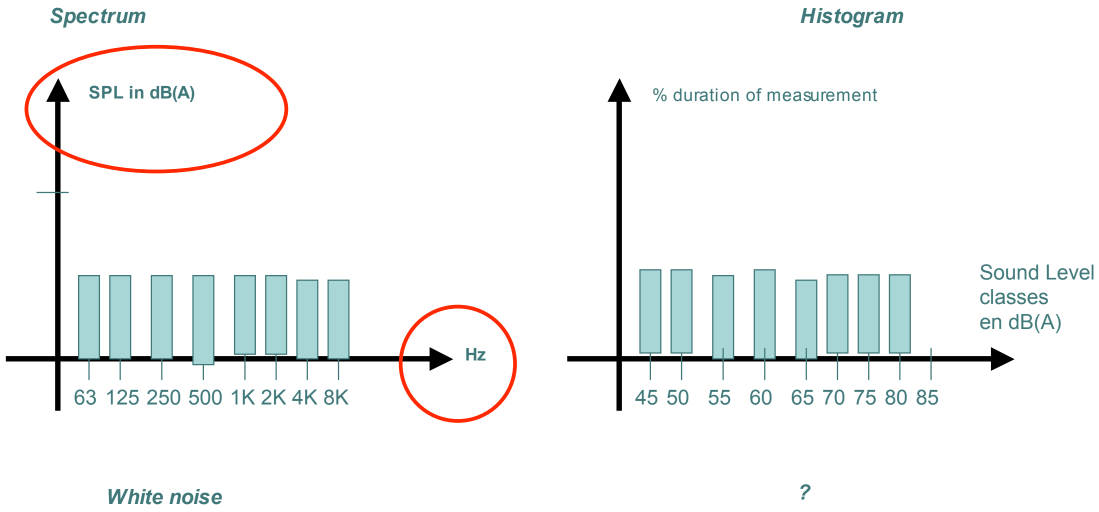
Lmax et Lmin : Sound pressure level maximum and minimum during the whole measurement.

Histogram …. Which histogram can represent a highway ?



Outils techniques 2

Confusions possible between ….



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SPL Addition

How can be add sound levels of pressure ? SPL addition is not arithmetic as we know for money, weight, dimensions, etc..

If we imagine to add ***n*** different sound level of pressure, we have to do the following sum :

$$L_{p_1} = 10\log_{10}\left(\frac{p_1^2}{p_{\mathrm{ref}}^2}\right) = 20\log_{10}\left(\frac{p_1}{p_{\mathrm{ref}}}\right)$$

$$+\ L_{p_2} = 10\log_{10}\left(\frac{p_2^2}{p_{\mathrm{ref}}^2}\right) = 20\log_{10}\left(\frac{p_2}{p_{\mathrm{ref}}}\right)$$

$$+\ \ldots\ldots\ldots$$

$$+\ L_{p_n} = 10\log_{10}\left(\frac{p_n^2}{p_{\mathrm{ref}}^2}\right) = 20\log_{10}\left(\frac{p_n}{p_{\mathrm{ref}}}\right)$$

n différents SPL

$$=$$

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Addition de niveaux sonores

If ***n*** Sound Level pressure named Lp_i
the sum is given by the formula :

$$Lp_{total} = 10 \times \log\left(\sum_{i=1}^{n} 10^{\frac{Lp_i}{10}}\right)$$

in dB(A)

For exemple : add 30dB(A) ⊕ 60dB(A) ⊕ 70dB(A) ⊕ 70dB(A)

$$Lp_{total} = 10 \times \log(10^{\frac{30}{10}} + 10^{\frac{60}{10}} + 10^{\frac{70}{10}} + 10^{\frac{70}{10}})$$

$$Lp_{total} = 10 \times \log(10^{3} + 10^{6} + 10^{7} + 10^{7})$$

$$Lp_{total} = 73{,}2dB(A)$$

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Addition de niveaux sonores

Graphical method

Example : add 30dB(A) ⊕ 60dB(A) ⊕ 70dB(A) ⊕ 70dB(A)

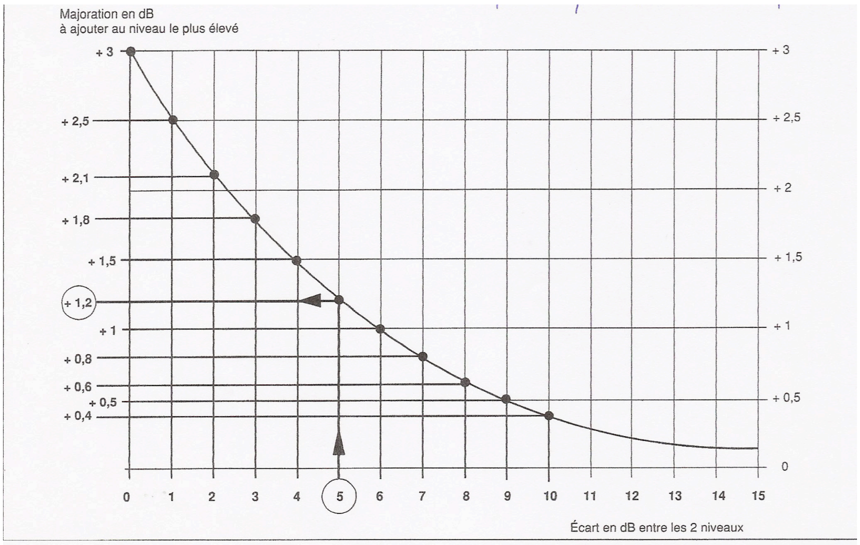

Fig. A.2 – « Addition » de deux niveaux sonores.

Addition de niveaux sonores

Graphical method

Example : add 30dB(A) ⊕ 60dB(A) ⊕ 70dB(A) ⊕ 70dB(A)

ΔdB(A) = 30 ⇒ + 0 ⊕ ΔdB(A) = 0 ⇒ + 3

60 dB(A) ⊕ 73 dB(A)

ΔdB(A) = 13 ⇒ +0,2

73,2 dB(A)

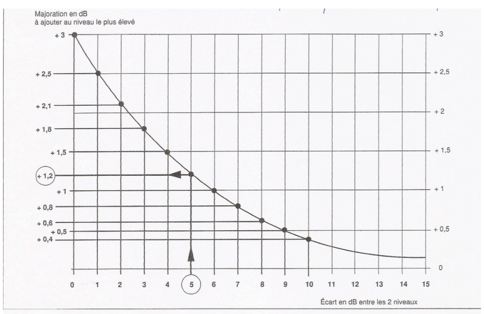

Fig. A.2 – « Addition » de deux niveaux sonores.

SPL Addition

To remind

Logarithm use has consequences on calculations and measurement analyses of sound or noise levels. We have to remind that :

. 1 (one) decibel weighted A or 1 dB(A) is the smallest unit that human ear can hear (it's theoretical and you can prove it inside a very silent place like a studio or under headphones)

. In ordinary life, we realise that sound level has changed if we're in front an increase or an decrease about 3dB(A)… that means is the sound level has been, physically, increased or decreased by 2.

. When you double the sound sources, the SPL increase about 3dB(A)

. In the other way, if you divide by 2 the number of sources, the SPL decrease about 3dB(A)

. BUT, in practice,, to have the « feeling » that sound level has been decrease about 10dB(A), you have to decrease, physically, the SPL about 10dB(A).