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TUNING YOUR STUDIO

Acoustic Analysis of Small Rooms for music

Ing. Lorenzo Rizzi

Saturday, April 26, 14:30 / 16:00

Intro (1)

- Music production business dynamics have moved most of the production phases to personal and project studios, these are built in flats and apartments
- This fact gives acoustically smaller and smaller rooms to study which are difficult to optimize (floor area ≤ 10 – 30 m^2)
- Small room acoustics is less studied

Intro (2)

- This lesson is about optimizing existing rooms and being aware of the room affecting our listening experience
- We'll look at the Physics & DSP tools we have
- Highlight the limits of each tool
- BUT we have to start with some theory from Physics

Intro (3)

REFERENCES

ITU-R BS.1116-1 Methods for the subjective assessment of small impairments in audio systems including multichannel sound systems

EBU Tech.3276 Listening conditions for the assessment of sound programme material: monophonic and two–channel stereophonic

Part 1

BACKGROUND THEORY

Sound in enclosed spaces (1)

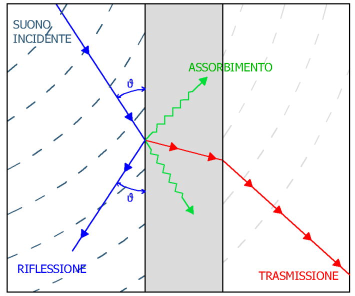
Energy conservation theorem, what happens to sound energy hitting an object:

- Sound wave **reflection**;
- **Absorption** inside medium;
- **Transmission** through medium

$$E_{inc} = E_r + E_a + E_t$$

Dividing by the incident energy, we have:

$$1 = r + a + t$$



Sound in enclosed spaces (2)

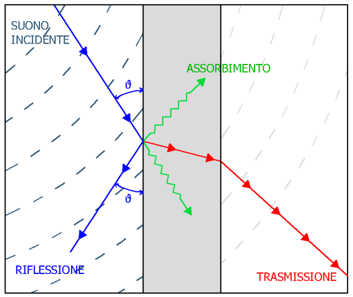
t < 0,001
a between 0,1 and 0,99

In lab, it is measured with **α – random incidence absorption coefficient**

Expressed in octave frequency band
(rarely in third-octave frequency band)

0 ≤ α ≤ 1

Values α > 1 are suspicious!



Reflections are specular or diffuse

$E_r = E_{spec} + E_{diff}$

Energetic scattering coefficient

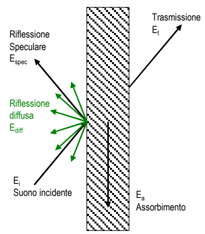
$s = \sigma = E_{diff} / E_i$

Measurement technique

Mommertz/Vorlander

UNI EN ISO 17497 part 1

Useful for computer modeling of big acoustic spaces



Scattering

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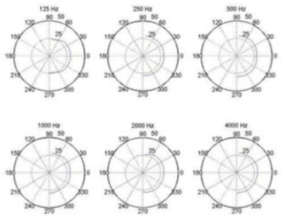
UNI EN ISO 17497 part 2: As it gets closer to perfectly omni diffusion from geometrical point of view d=1

Analysis of diffuse reflections geometry



Sound in enclosed spaces (3)

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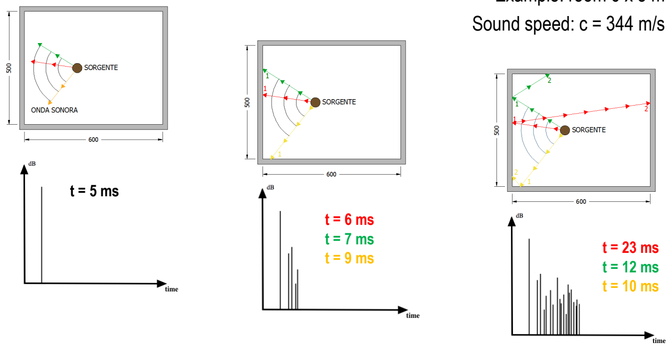
The number of reflections inside a room grows very quickly.

Example: room 6 x 5 m

Sound speed: c = 344 m/s



Sound in enclosed spaces (4)

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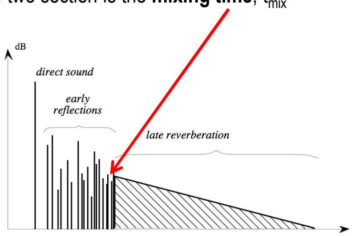
Early reflections are measurable, distinct and predictable with computer simulations.

After a few hundredths of a second they are completely mixed with each other, creating an unpredictable, **diffuse tail** (late reverberation)

The time instant which divides these two section is the **mixing time**, t_{mix}



Sound in enclosed spaces (5)

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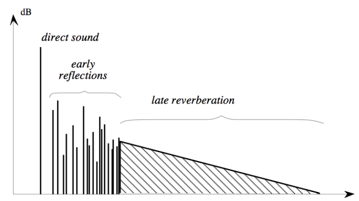
A sound field in which the flow of sound energy is equally probable in all directions, is called **diffuse**

DIFFUSE SOUND FIELD IS ALSO CALLED 'SABINIAN' BECAUSE IT IS THE BASE AT THE THEORY OF SABINE

NB We have diffuse sound field inside big spaces with not too much sound absorption



Actually in small rooms for music we have very short decays and very directive sound sources, **Sabine assumptions do not fully apply.**

Energetic analysis (1)

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Semi-reverberant field $L_p = L_w + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right)$

L_p = sound pressure level inside the room
L_W = sound source power level
r = source-receiver distance
R = room constant
Q = directivity of the source

R is the room constant $\boldsymbol{R = S\alpha/(1-\alpha)}$
Where S is the total surface of the room and α is the average absorption coefficient

Energetic analysis (2)

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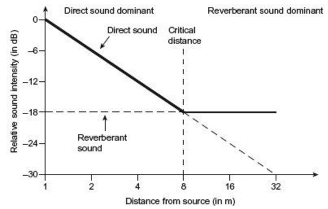
Semi-reverberant field $L_p = L_w + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4}{R}\right)$

In every real-life room we have the **spherical divergence decay** only very close to the source, after the critical distance dc we have **the diffuse field** that dominates

$d_c \approx 0{,}057\sqrt{\frac{V}{RT}}$ [m]

In small room for music we use a lot of absorption, so R is quite large and dc is longer: **the diffuse field influence is limited or almost absent**



Statistical analysis (1)

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Sabine formula

Time required for the level of sound source to decay by 60 dB (sound energy decades a million times from the moment the sound source is turned off)

$$T_{60} = 0.16\frac{V}{\sum_i \alpha_i S_i} = 0.16\frac{V}{A_m}$$

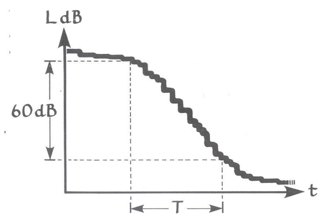
V = room volume [m^3]

S_i = i-th surface [m^2]

A_i = equivalent absorption area of i-th surface

A = $\Sigma_i\ \alpha_i\ S_i$ [metrical Sabin]

α_i = absorption coefficient of i-th surface



Statistical analysis (2)

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Norris-Eyring formula

Sabine formula is a good reference, but in small rooms for music it can be useful to use Norris-Eyring formula which is more accurate in very absorbed rooms

$$T_r = \frac{0{,}161 \cdot V}{S\left[-\ln\left(1-\alpha_m\right)\right]}$$

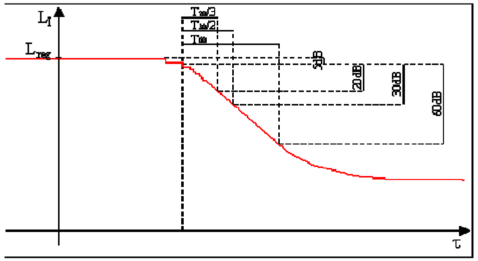
V = room volume [m^3]

S = room total surface [m^2]

α_m = average absorption coefficient of the room

Reverberation time (1)

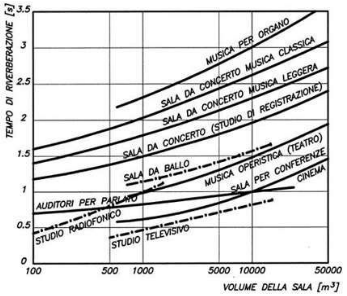
- Due to background noise, often it is impossible to measure directly the time for a full decay of 60 dB. Rarely in practice it is possible to have SNR ≥ 70 dB in all frequencies range.
- We measure the decay for 20 or 30 dB and simply multiply by 3 or 2: T_{20} **and** T_{30}



Reverberation time (2)

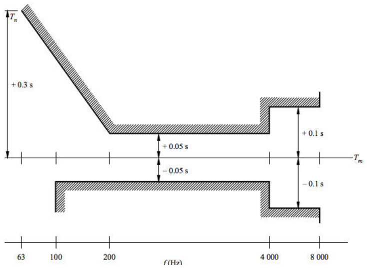
RT depends on room volume and on sound-absorbing material amount.
It is the first project-target in rooms for listening, speech and music.

Tables like this are useful.
They give target-value for T60
@ 500 Hz related to room volume.



Reverberation time (3)

ITU-R BS.1116-1 recommendation about reverberation time (equivalent to EBU 3276)



The average value of reverberation, T_m, measured over the frequency range 200 Hz to 4 kHz should be:

$$T_m = 0{,}25\,(V / V_0)^{1/3}$$

where:

V : volume of room
V_0 : reference volume of 100 m3.

The tolerances to be applied to T_m over the frequency range 63 Hz to 8 kHz are given in the figure.

Reverberation time (4)

ITU-R BS.1116-1 recommendation about reverberation time (equivalent to EBU 3276)

They set room dimension limits:

Monophonic and stereo – floor area 20 – 60 m2

Multichannel - floor area 30 – 70 m2

This translates into average reverberation times which are very short:

Monophonic and stereo – Tm 0,15 - 0,21 sec
Multichannel - Tm 0,17 – 0,22 sec

OSS short reverberation times are difficult to measure because of filter lengths, especially at low frequency

Statistical analysis (3)

$$f_c = 2000\sqrt{\left(\frac{T_R}{V}\right)}$$

f_c **Critical frequency (or Schroeder's frequency)** is the minimum frequency to start a statistical approach (apply Sabine's theory)

S = 20 m^2 – V = 60 m^3 – Tm = 0,15 sec – f_c = 98,7 Hz

S = 40 m^2 – V = 120 m^3 – Tm = 0,18 sec – f_c = 78,3 Hz

OSS This theoretical assumption is based on statistical calculations and it works only in large reverberant rooms

BUT it is useful to remember there is a lower frequency limit dividing the spectrum in a lower deterministic part and in an higher statistical (diffuse) one

Deterministic sound field

At low frequencies, Sabine's assumptions do not stand: sound field is not diffuse, there is not a random direction of sound waves but sound energy distributes in a clear, predictable order in space

Ordinary rooms have dimensions closely related to wavelengths that can be generated by most of the instruments

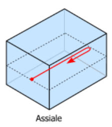
Shower (vocal booth): 1 x 1,5 x 2,5 m comparable to three sound at 344, 229, 137 Hz

NB these notes can be generated by male voice. Inside a concrete shower, this is particularly evident when you sing or speak!

Small control room: 3,8 x 4,5 x 2,7 m (S = 17 m^2, V = 46 m^3) → three sound at 90, 76, 127 Hz

Room modes – Standing waves

$$f_{n1,n2,n3} = \frac{c}{2}\sqrt{\left(\frac{n1}{l}\right)^2 + \left(\frac{n2}{w}\right)^2 + \left(\frac{n3}{h}\right)^2}$$



Where
l, w, h are room dimensions
c is sound speed in air
n1,n2, n3 are integer number refered to room mode number

Low frequency sounds generate standing waves.

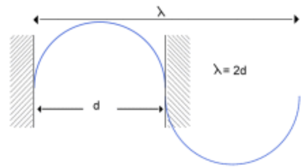
The strongest are axial modes that develop along a single dimension.

Axial modes (1)

The first axial mode is at a frequency with wavelength equal to twice the longest dimension of the room

Below this frequency the room does not support sound waves

We always have pressure maxima along the walls



$$f_{1,0,0} = \frac{c}{2}\sqrt{\left(\frac{1}{l}\right)^2} = \frac{c}{2l}$$

Axial modes (2)

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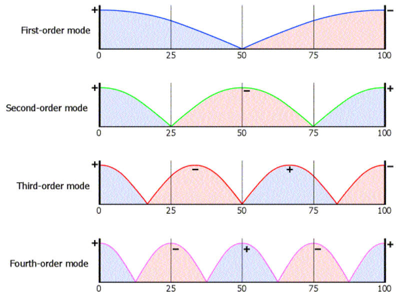
The second axial mode is at a frequency with wavelength equal to the longest dimension of the room. **Standing waves create regions of maximum and minimum energy**

$$f_{1,0,0} = \frac{c}{2}\sqrt{\left(\frac{1}{l}\right)^2} = \frac{c}{2l}$$

$$f_{2,0,0} = \frac{c}{2}\sqrt{\left(\frac{2}{l}\right)^2} = \frac{2c}{2l}$$

$$f_{3,0,0} = \frac{c}{2}\sqrt{\left(\frac{3}{l}\right)^2} = \frac{3c}{2l}$$

$$f_{4,0,0} = \frac{c}{2}\sqrt{\left(\frac{4}{l}\right)^2} = \frac{4c}{2l}$$



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Axial modes (3)

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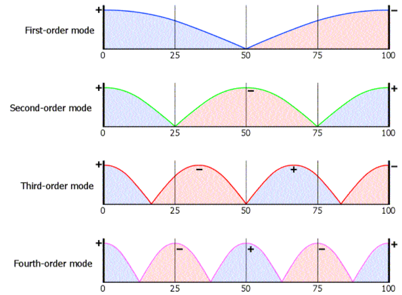
Try in your studio. Generate these pure tones remembering that *l* is room length and c is sound speed in air, then walk around and listen.
For example, for ***l* = 4.5 m** and *c* = 343 m/s, the pure tones will be:

38 Hz $f_{1,0,0} = \frac{c}{2}\sqrt{\left(\frac{1}{l}\right)^2} = \frac{c}{2l}$

76 Hz $f_{2,0,0} = \frac{c}{2}\sqrt{\left(\frac{2}{l}\right)^2} = \frac{2c}{2l}$

114 Hz $f_{3,0,0} = \frac{c}{2}\sqrt{\left(\frac{3}{l}\right)^2} = \frac{3c}{2l}$

152 Hz $f_{4,0,0} = \frac{c}{2}\sqrt{\left(\frac{4}{l}\right)^2} = \frac{4c}{2l}$



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Diffraction (1)

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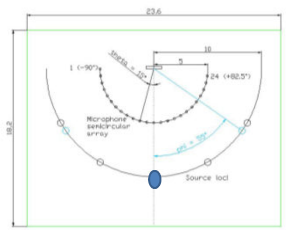
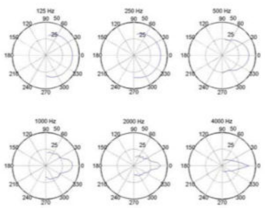
Measuring the reflection pattern of a flat panel 1,44 m x 0,72 m x 0,26 m





At 125 and 250 Hz it reflects as an omnidirectional ideal diffuser.
Actually sound is diffracting around the panel: **we measure energy 'bouncing back' as if the panel were a point source.**

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Wavelengths in air (1)

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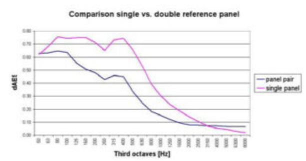
Sound interacts with objects with dimensions larger than a quarter wavelength

$d > \lambda / 4$ [m]

$f > c/(4d)$ [Hz]

Measuring the flat panels we observe diffraction at frequencies related to the depth and the width of the panels themselves.



Panel name	Width [mm]	f1 [Hz]	Depth [mm]	f2[Hz]
Single reference	720	119.4	260	330.8
Double reference	1440	59.7	260	330.8

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Wavelengths in air (2)

Freq. [Hz]	λ [m]	λ/4 [m]
20	17,15	*4,29*
25	13,72	*3,43*
31,5	10,89	2,72
40	8,58	2,15
50	6,86	1,72
63	5,44	1,36
80	4,29	1,07
100	3,43	0,86
125	2,74	0,69
160	2,14	0,54
200	1,72	0,43
315	1,09	0,27
400	0,86	0,22
500	0,69	0,17
600	0,57	0,14

Freq. [Hz]	λ [m]	λ/4 [m]
800	0,429	0,107
1000	0,343	0,086
1250	0,274	0,069
1600	0,214	0,054
2000	0,172	0,043
2500	0,137	0,034
3150	0,109	0,027
4000	0,086	0,022
5000	0,069	0,017
6300	0,054	0,014
8000	0,043	0,011
10000	0,034	0,009
12500	0,027	0,007
16000	0,021	0,005
20000	0,017	0,004

Diffraction (2)

NB: Sound interacts with objects larger than a quarter wavelength.

Library is 40 cm thick and 120 cm large. It interacts with sound from

f_1 > 343/1.6 > 214.4 Hz
f_2 > 343/4.8 > 71.5 Hz

Human body is 30 cm thick and 60 cm large. We interact from

f_1 > 343/1.2 > 285.8 Hz
f_2 > 343/2.4 > 142.9 Hz

Sound absorption (1)

Absorption coefficient $\alpha = (E_i - E_r) / E_i$

$0 \leq \alpha \leq 1$

The absorption coefficient of a porous material varies with frequency and with angle of incidence of the sound

It is function of fiber size and of porosity, thickness and density of the material

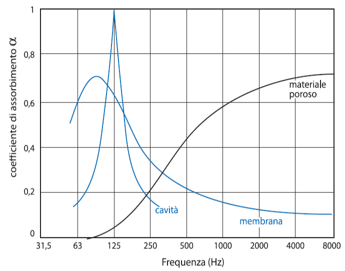
The mechanisms of absorption of a porous material, which produce a conversion of sound energy into heat, are called phono-resistive, and depend

- Viscous dissipation in the air cavity
- Friction between the fibers in vibration

Sound-absorbing material

Material used in acoustic treatment to control unwanted reflections, reverberation and noise

- Porous materials
(viscous dissipation)
- Helmholtz resonator
(cavity resonance)
- Vibrating panels (membranes)
(sfruttano la risonanza del pannello)

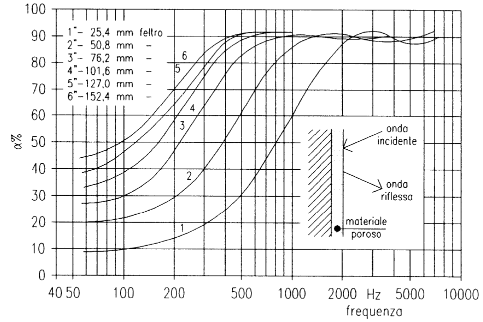


We always need composed systems,

It is better to use at least three different materials

Sound absorption (2)

Performance of the absorption coefficient α as a function of frequency and material **thickness**



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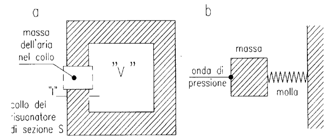
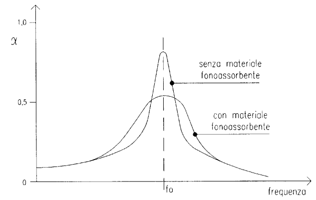
Helmholtz resonator

Energy dissipation for cavity resonance

$$f_{ris} = \frac{c}{2\pi}\sqrt{\frac{S}{l \cdot V}}$$

c speed of soound [m/s]
S neck section [m^2]
l neck length [m]
V cavity volume [m^3]





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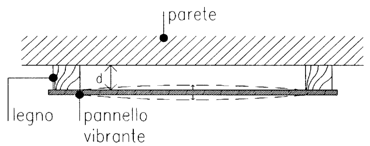
Vibrating panels (membranes)

Energy disspiation exploiting the resonance of the panel



$$f_{ris} = \frac{60}{\sqrt{(\sigma \cdot d)}}$$

σ panel surface density [kg/m^2]
d panel-wall distance [m]

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Scattering panels

Very useful to scatter specular reflections: there positioning is critical.

Again: **thickness regulates the minimum operational frequency!**

Panel with maximum depth of 5 cm works from 1720 Hz

Panel with maximum depth of 20 cm works from 415 Hz

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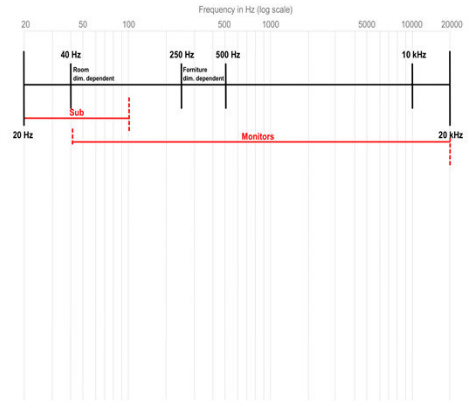
Summing up



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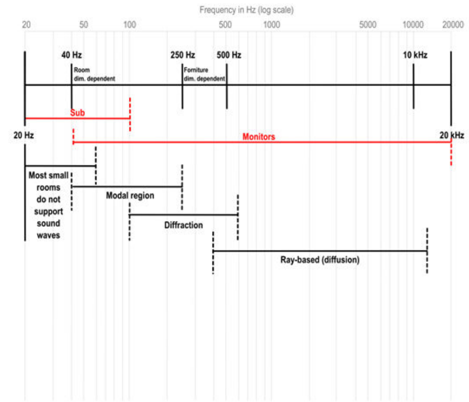

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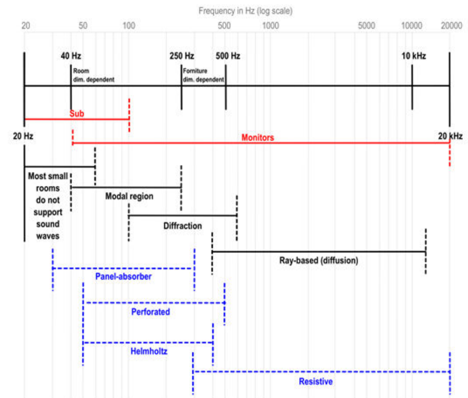
Summing up



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Part 2

PRACTICAL SECTION

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Protect your hearing (1)

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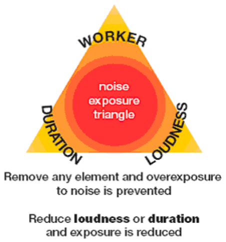
- First rule to protect our hears:
  IF YOU INCREASE SPL YOU MUST DECREASE EXPOSITION TIME



Protect your hearing (2)

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Continuous dB	Permissible Exposure Time
85 dB	8 Hours
88 dB	4 hours
91 dB	2 hours
94 dB	1 hour
97 dB	30 minutes
100 dB	15 minutes
103 dB	7.5 minutes
106 dB	3.75 minutes (< 4 min)
109 dB	1.875 minutes (< 2 min)
112 dB	.9375 min (~ 1 min)
115 dB	.46875 min (~ 30 sec)

www.dangerousdecibels.org/

Noise induced hearing loss (3)

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- It is very important to rest our ears in quiet places after a listening session with high level sound
- Bob Katz, in"Mastering Audio", proposes tio calibrate litening level at a maximum **SPL =83 dBC at the sweet spot**
- This is a safe level to protect your ears!
- **OSS It becomes very important to lower the noise floor within the room**

Noise floor (1)

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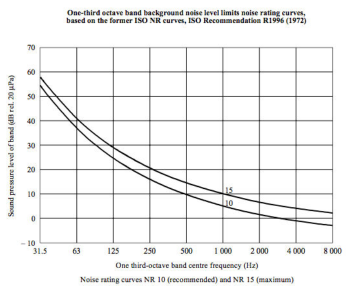
ITU-R BS.1116-1 recommendation about noise floor

The continuous background noise (produced by an air conditioning system, internal equipment or other external sources), measured in the listening area at a height of 1.2 m above the floor should preferably not exceed NR 10

Under no circumstances should the background noise exceed NR 15.

The background noise should never be perceptibly impulsive, cyclical or tonal in nature.



Noise floor (2)

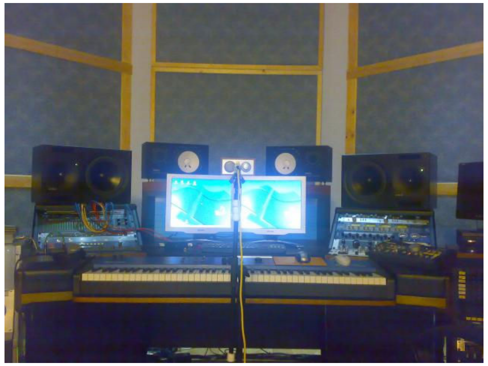
Low acoustical noise within the room means maximum SNR and maximum dynamics for your listening experience

To compare background noise to NR curves you must measure it in **linear dB.**

Sound Insulation is expensive, so:

- Select a **quiet location** for your room;
- Select **silent a/c and ventilation machines**;
- Move your noisy gear and hardware in an insulated cabinet or outside the room.

Sweet spot measurements (1)



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Sweet spot measurements (2)

Sweet spot correction is a crucial aspect in rooms dedicated to critical listening (mixing and mastering rooms, audiophile listening rooms...) where maximum quality is needed.

An untreated listening point removes value to expensive hardware

Small-rooms (surface < 40-60 m^2) act as acoustic filters that amplify and attenuate spectrum components and alter the temporal pattern of music content **even in near-field listening**.

We can never achieve a perfect sound field in very small-rooms so it becomes important to optimize it.
Sound engineer must be aware of the room effecting his listening.

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How to measure reverberation time (1)

ISO 3382:2 – 2008 *Measurement of room acoustic parameters -- Part 2: Reverberation time in ordinary rooms*

Hardware:

Omni-directional source able to generate a signal at least 45 dB higher than the background noise for T30 and 35 dB for T20 in the microphone position.

Omni-directional microphone, preferably less than 13 mm diameter

Class I precision measuring chain

NB at least 2 source positions and 3 microphone position for precision measurements
According to room volume, 12 combinations are recomended
This is important inside a reharsal room, but not inside a control room

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Reverberation in small-rooms for music

Reverberation in reharsal rooms:

- Different measurement positions allow you to make consistent spatial and temporal averages (find the best position for each instrument)
- Different measuring points can help you to avoid problems related to the specific characteristics of the measuring point (eg modal peaks in the position of sound source or microphone)

Reverberation in control rooms :

- Average of several measurement points around sound engineer head
- We use the monitors and the room's hardware in flat as the sound source
- We are interested to fully characterize the features of that particular area of the room

How to measure reverberation time (2)

ISO 3382:2 - 2008

Interrupted noise technique:
Turn off a pink noise source and record. If the SNR is good the processing is simple because it is enough to filter and analyze the decays.

Integration of room impulse responses:
- RIR can be obtained with direct methods (balloon pop, clapper, blank gun) or indirect ones (MLS, sine sweeps).
- Indirect methods use dsp (impulsive autocorrelation signals) to obtain almost perfect impulses.
- MLS is useful for places with high background noise
- Sine sweep is powerful because it excludes the non-linearity of measuring system (audio chain)

Freeware sw for RIR measurement

Prof. Farina **Aurora** project has been brought to Audacity platform and it is free of cost.

It can be used on Windows, OSX and Linux

You need to install Audacity 2.0.0 and copy on directory "modules" the file, available for free download, at

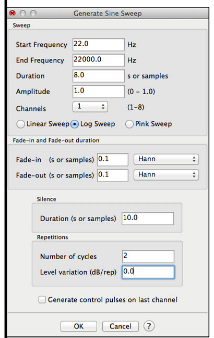
http://pcfarina.eng.unipr.it/Public/Aurora-for-Audacity/

Next some examples

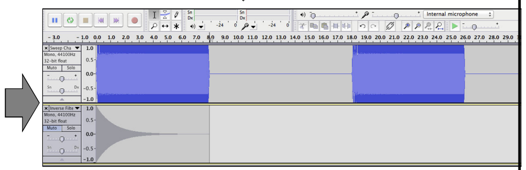
Sweep generation - convolution - analysis acoustical parameters

Step 1: sine-sweep generation

Generate→ Log sweep generator…



Log sine-sweep



Inverse sweep
NB: Mute this track, but do not delete it.

Sine-sweep is useful

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Note:

A long sine-sweep in the low frequency is very useful to spot object resonances.

Try to play a log sweep 20 sec long between 40 and 300 Hz and listen to object resonances

You should damp every spurious resonance before proceeding

Step 2: record sine-sweep

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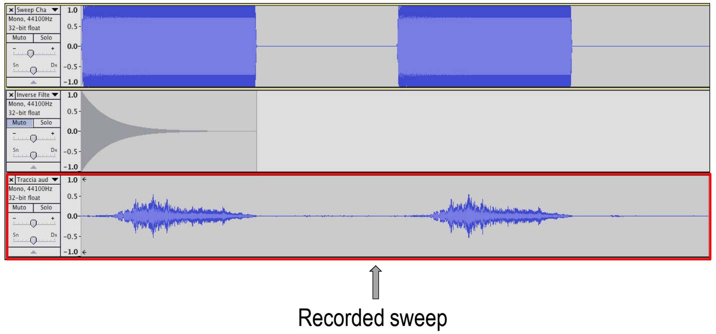

Step 3: perform convolution

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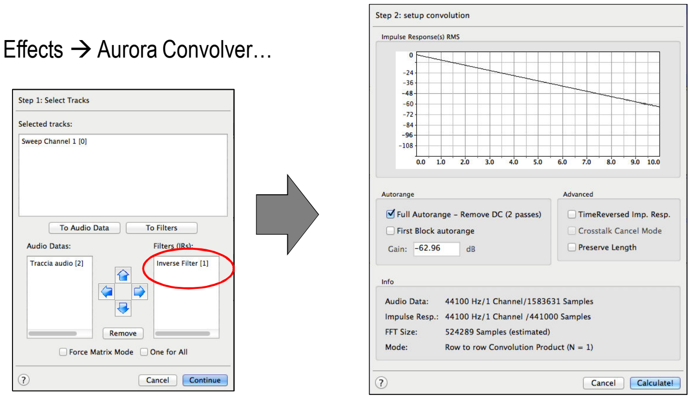
Effects → Aurora Convolver…



Convolution output

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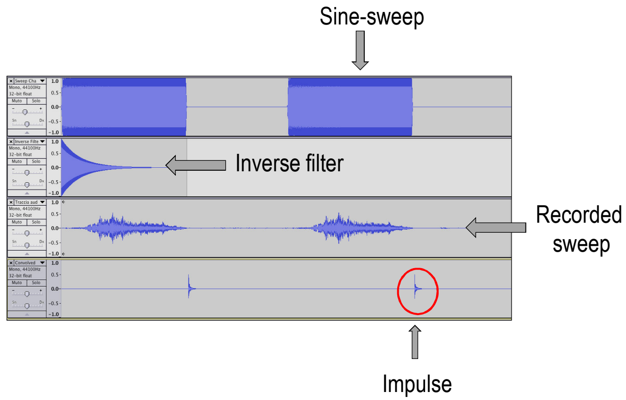
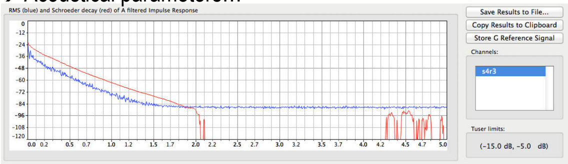


Step 5: calculate acoustical parameters

Analyze → Acoustical parameters…

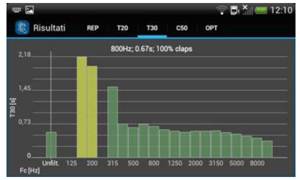


	31.5	63	125	250	500	1k	2k	4k	8k	16k	A	Lin
Signal [dB]	34.044	50.703	66.740	71.336	70.808	70.049	71.846	73.308	71.567	72.919	79.362	80.281
Noise [dB]	25.684	31.543	21.373	23.752	20.789	18.432	18.680	30.042	25.542	38.678	39.805	43.704
G [dB]	-34.956	-18.297	-2.260	2.336	1.808	1.049	2.846	4.308	2.567	3.919	0.362	3.281
C50 [dB]	0.022	5.805	3.832	1.431	1.296	4.852	4.807	4.976	7.996	10.911	4.928	4.171
C80 [dB]	0.680	11.452	6.007	4.733	3.400	6.307	6.922	7.648	11.269	15.104	7.233	6.641
D50 [%]	50.128	79.192	70.730	58.164	57.407	75.348	75.152	75.873	86.308	92.501	75.673	72.319
Ts [ms]	631.582	39.199	67.279	78.320	77.860	49.532	46.894	37.616	20.941	14.935	41.819	47.438
EDT [s]	25.271	0.520	0.754	1.392	1.661	1.125	1.041	0.794	0.569	0.377	0.937	1.042
Tuser [s]	23.999	-.-	1.101	1.582	1.567	1.390	1.525	0.906	0.607	0.359	1.230	1.344
T20 [s]	17.271	0.976	1.282	1.467	1.563	1.689	1.575	1.237	0.737	0.405	1.459	1.471
T30 [s]	17.005	0.918	1.350	1.438	1.675	1.839	1.624	1.335	0.889	0.417	1.550	1.538
Peakiness [dB]	19.785	24.632	25.389	25.861	29.850	33.150	35.863	36.772	41.507	43.390	40.641	40.533
Millisecs [dB]	19.694	24.489	24.922	24.541	26.733	29.856	30.407	29.379	33.327	32.782	31.467	30.671
Impulsivs [dB]	16.088	19.275	18.834	17.670	18.896	19.853	19.949	19.888	20.562	20.918	19.951	19.687

Quick estimation of Acoustical Parameters (1)

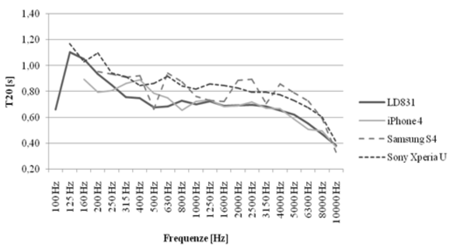
If you need a quick estimation of acoustical parameters on-site (room for performance, rehearsing) you can also use your smartphone

Using simple sound sources (handclaps or balloon pops), app like **APM Tool** Allows you to rapidly estimate the main Room Acoustic Parameters (T20, T50, EDT, C50, C80, D50, D80) with any Android or iPhone device.



Quick estimation of Acoustical Parameters (2)

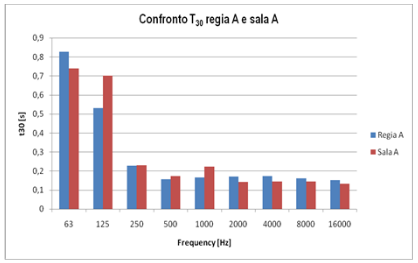
The results will give a good estimate **starting from 250 Hz**



The full version has a simple wizard to ameliorate room acoustics by selecting the best materials to be used on the ceiling. This is selected depending on the room volume and the room use

Reverberation time analysis

The traditional analysis of the reverberation time is very useful in order to make comparisons between different rooms



It is also useful to understand if you need sound absorption at mid-high frequencies

(> 1000 Hz)

It is risky to use it as a unique reference at low frequency (below 250 Hz)

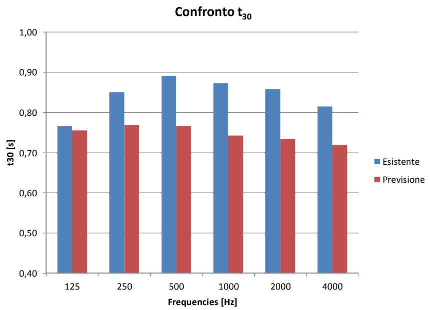
Handle it with care!

Practical example (1)

Starting from a reverberation time measurement, it is possible to **define the material needed for acoustic correction**

Starting from measured values (blue) it is possible to calculate existing "Am", reversing Sabine formula

$$A_m = 0.161\frac{V}{T_R}\ \mathrm{m}^2$$



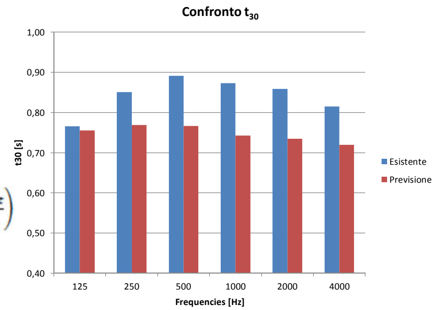
Practical example (2)

Knowing T_{target} (i.e. EBU-ITU) we can calculate A_{needed} to correct the room.

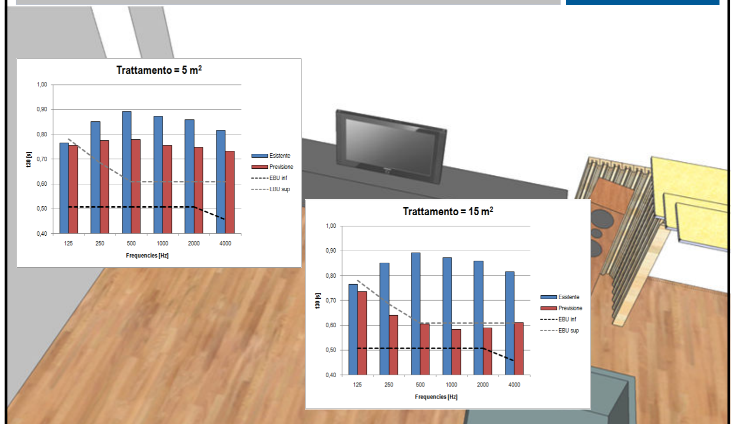
Than we study which material and in what quantity

$$A_{needed} = 0.161V\left(\frac{T_{meas}-T_{target}}{T_{meas}\cdot T_{target}}\right)$$

$$A_{needed} = \sum_i S_i\alpha_i$$



Practical example (3)



Frequency analysis (1)

RIR frequency analysis is the more traditional method of acoustic observation. However, it provides only partial information about the acoustic behavior of a room.

Let's see why.

An octave band analysis (useful, for example, for reverberation time) or a third-octave bands one (multi-band equalizers) appears to have too little resolution in order to provide useful information.

Frequency analysis (2)

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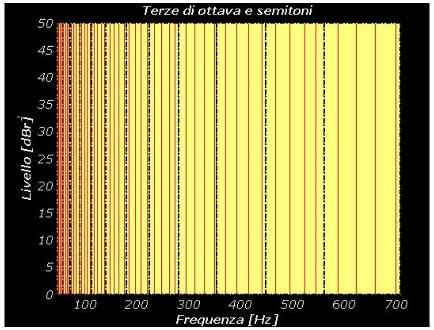

Looking at the picture we see that in each third octave band (black lines) there are 4 semitones (red lines).

Remember that people with absolute pitch clearly distinguish the quarter-tone.

It therefore appears as the third-octave analysis is a rough and outmoded tool..

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Fourier series

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Simplifying the theory behind Fourier transform, we can look at Fourier series:

- A periodic sound with period T, can be represented as an **infinite sum of sinusoidal components**.
- Each of these sinusoidal components is said spectrum

IMP **it applies only to steady state. It does not consider the transient nature of music**

$$S_N(x) := \frac{a_0}{2} + \sum_{n=1}^{N} (a_n \cos nx + b_n \sin nx)$$

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Fourier analysis

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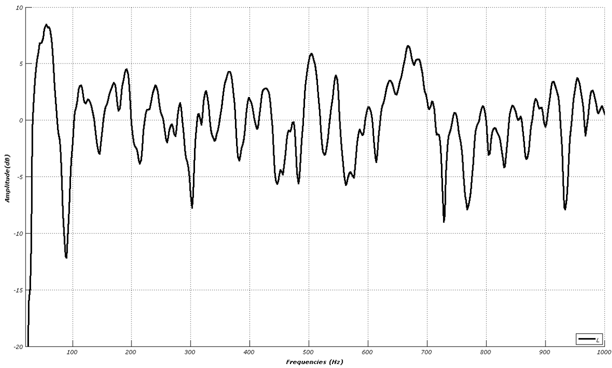

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Correct setting of dB axis(1)

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A misinterpreted graph can push you to try different solutions (expensive in terms of time and money) that will not bring the desired results

Typically on the internet, spectrum curves observed with dB dynamic badly set, are declared as outstanding!

If dB axis scale ranges from 0 to 120 dB, all rooms will seem flat!

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Correct setting of dB axis(2)

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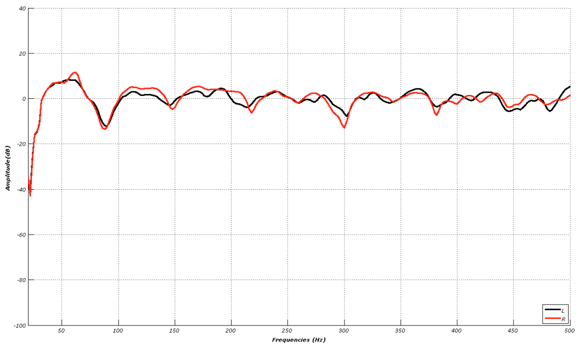
Spectrum observed between -100 dB e +40 dB



Correct setting of dB axis(3)

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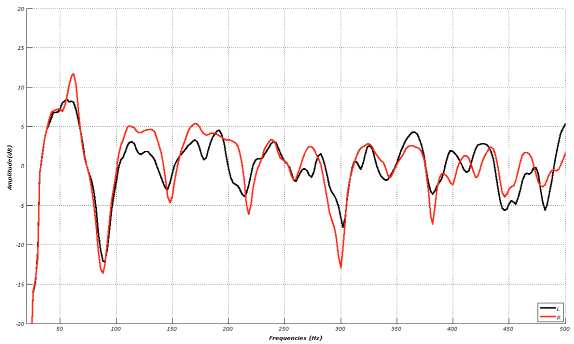
Same spectrum observed now between -20 dB e +20 dB



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Correct setting of frequency axis

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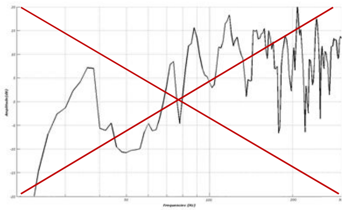
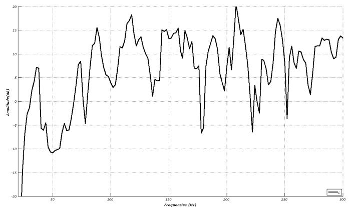
For a correct visualization of the spectrum at low frequencies, it is necessary to set the x-axis **in a linear scale** and not in a logarithmic one

NO



YES



The linear scale axis guarantees greater detail and clarity in the interpretation of the low frequency spectrum

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FFT analysis

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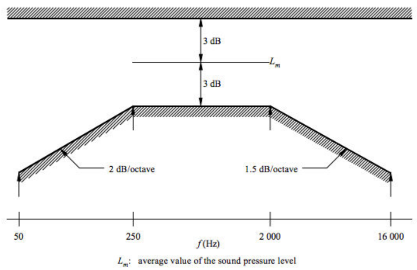
Steady state sound field: operational room respons curve (**ITU-R BS.1116-1**)



Better to make average of 3-4 measurements around sweet spot!

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Left – right balance

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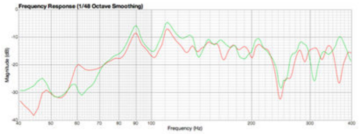
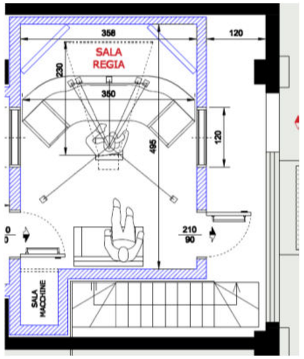
The FFT measurement is useful for checking left – right balance (one of the primary targets for a control room project)

One measuring point at the center of the listening area is enough





Optimal listening triangle (1)

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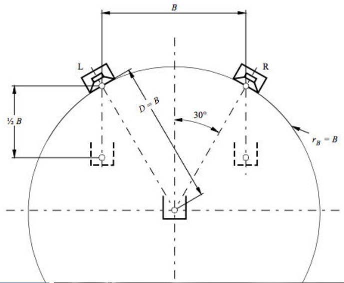
Finding the optimal listening triangle for the situation is one of the targets of sweet spot analysis.

The listening triangle is the triangle formed between the listener and left and right monitors

It is an equilateral triangle (or slightly isosceles) positioned at a distance from the front wall to avoid cancellation due to the first reflection coming from it



Optimal listening triangle (2)

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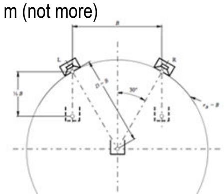
- The monitors should be placed at more than 1.5 m from each other
- The monitors should stay at least at 1 meter from the front wall
- The listening triangle has to be equilateral. If it necessary, the angle between head and monitor can be reduced from 60 degrees to (not less than) 40 degrees
- Both monitors must have equal height: from 1.20 m to 1.90 m (not more)



Optimal listening triangle (3)

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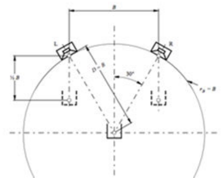
- Maintain **symmetry** in order to have balance during listening
- No object near the tweeter-ear line, raise the monitors
- Put monitors over anti-vibration systems
- Subwoofer positioning: never in the corner!
- Control first reflections and avoid comb-filter



Optimal listening triangle (4)

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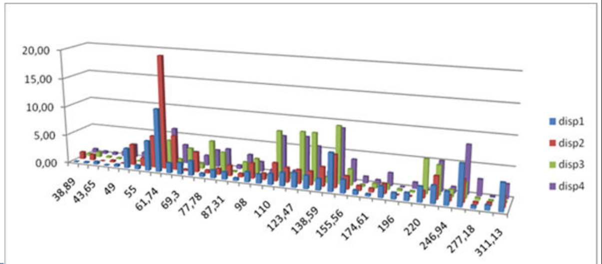
In the choice of listening triangle is necessary to mimize 'peaks and valleys' of resonance modes
The graph shows the variation between the Left/Right differences changing the position of the listening triangle



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Resonance modes analysis (1)

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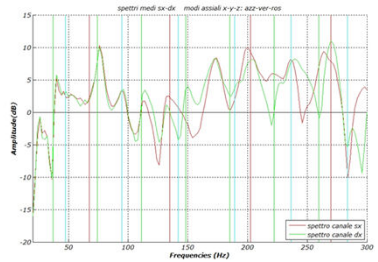
Overlapping spectra of left and right channels with frequency of the resonance modes of the room is useful to study their influence in detail. **This is one of the great advantages of building shoebox-shaped rooms!**



For accurate positioning of room modes, it is necessary to measure the internal dimension of the room.

The possible mismatch between the theoretical position of room modes and the peaks of the spectra has multiple motivations (eg, wall composition, presence of furniture)

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Resonance modes analysis (2)

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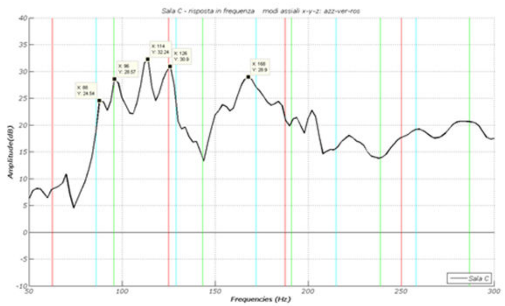
This type of analysis is useful for bass-trap design and to find the optimum listening triangle.



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Resonance modes analysis (3)

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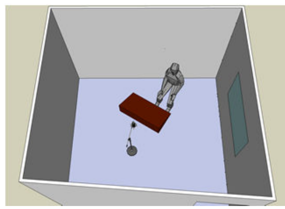
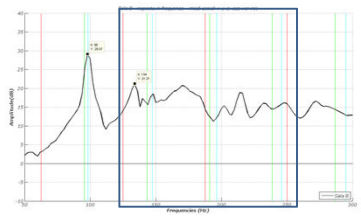
Look at the pictures:
- non-rectangular dubbing room (non-parallel walls)
- modal resonances do not coincide with calculated positions
- the myth of non-parallel walls do not solve the problems of the rooms: the effect of resonance modes is not deleted, but only "moved" on frequencies difficult to calculate





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Resonance modes analysis (4)

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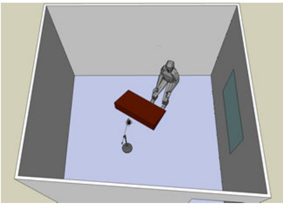
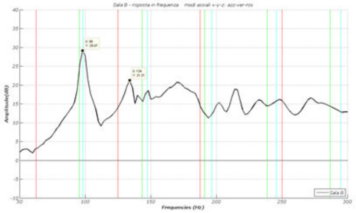
It is very useful to decide sound source positioning:

- Single subwoofer in the control room;
- Speaker in a vocal booth;
- Loudspeaker in a recording room.





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FFT analysis limitations

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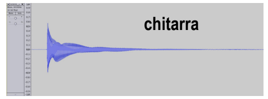
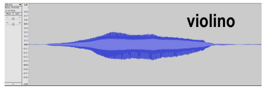
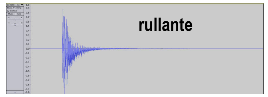
The FFT analysis would conclude the room acoustics investigation if the music were made up of sine waves of infinite length.

But the music is made of **transients**, i.e. those changes of temporal dynamic (transient) in attack and decay phases, which made a sound distinguishable from another.







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From FFT to EFT (1)

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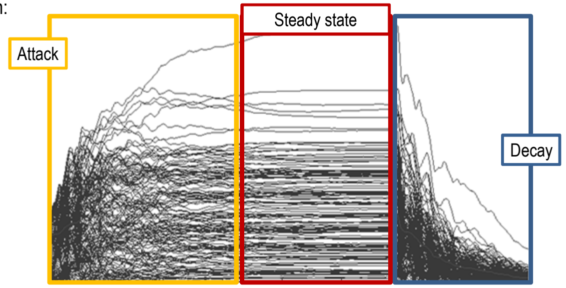
FFT expresses steady state behaviour of the room.

But sound evolution in an enclosed space is composed of several parts.

Let's imitate Mr. Sabine and give the room a series of pure tones; now superimpose them:



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From FFT to EFT (2)

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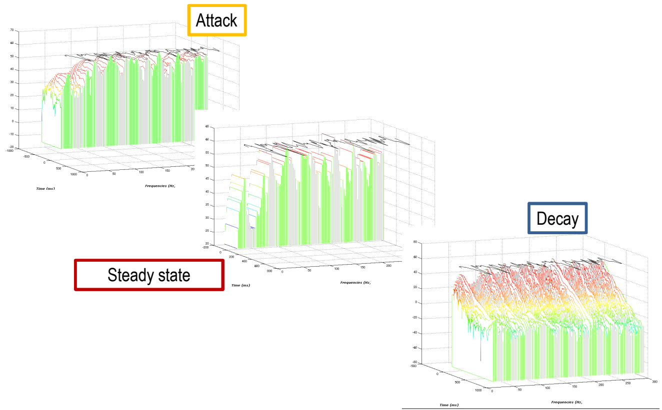

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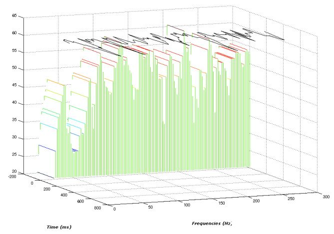
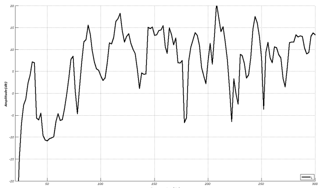
From FFT to EFT (3)

Note how **the steady state behavior corresponds to FFT as stated by Fourier**: decompose a signal into its equivalent part consists of the infinite sum of sine waves.



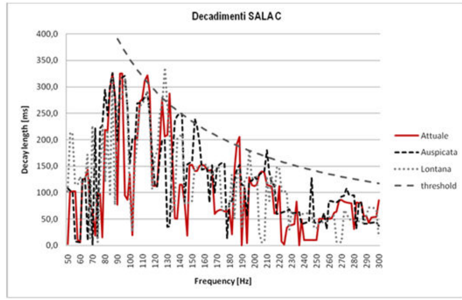


Modal decay analysis(1)

Modal decay analysis is very important:

- allows you to go beyond FFT and rev. time analysis
- provides information on the audibility of the resonance modes

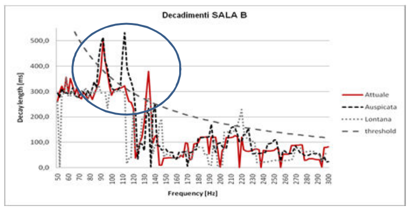
"Thresholds of detection for changes to the Q-factor of low frequency modes in listening environments" (M.R. Avis, B.M. Fazenda and W.J. Davies, JAES 2007)

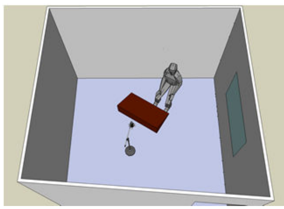


Modal decay analysis(2)

Let's observe again the previous example (dubbing room with non-parallel walls):

- Modal decay shows problems in low freq. region
- Non-parallel walls do not solve acoustic problems



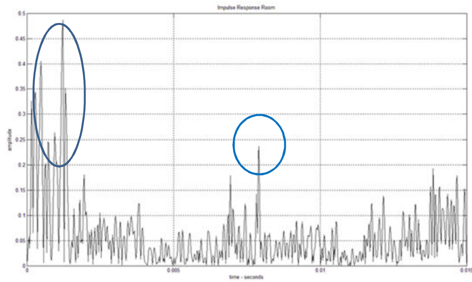


Temporal analysis of sound reflections

It is very important to look at the first part of the impulse response:
We **must control first reflections to avoid comb filtering** and direct sound corruption.

We should have reflections at least 10 dB lower than direct sound in the first 15 msec.

This translates into a 5,16 m delay from direct sound: it comprehends first and second order reflections.



Some new perspectives

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Suonoevita studies the transition from early reflections to the statistical, 'diffuse', soundfield in small rooms for music (white papers AES Budapest and AES Roma)

Using the kurtosis curve on segments of the impulse response we can spot significant correlated reflections.

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Analisi statistica del campo sonoro

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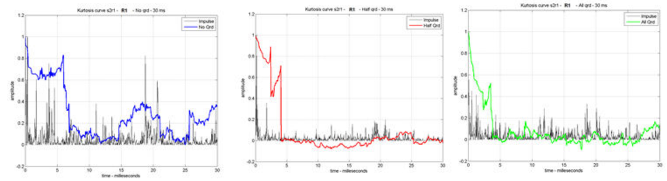
We demonstrated QRD scattering panels facilitate the transition to a diffuse soundfield, they are **very helpful in small recording rooms**.

We see that increasing the number of scattering panels the kurtosis curve stabilizes (0 values means a diffuse sound field)



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Advanced analysis– Eigenmike (1)

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The 'classic' RIR from an omnidirectional microphone does not help studying the direction of arrival and quality of single reflections.

Prof. Farina's team at University of Parma and Suonoevita use a spherical high resolution microphone (eigenMikeTM EM32 from mhAcoustics) to study in detail sound reflections.
This is an spherical array with 32 high quality mic capsules.

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Analisi avanzata – Eigenmike (2)

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Through matricial digital filtering we obtain the same result we had from an arbitrary set of microphones with an arbitrary directivity response: so we can post process the data and replay our measure focusing on any space detail we need.

This technique is called 'virtualization', it can break the classic omnidirectional response in small slices of the full solid angle.

These slices can be studied instant by instant, frequency by frequency, so we have a full dynamic panorama of the room-acoustic behaviour.

It is much easier to see it than to explain it in words!

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Analisi avanzata – Eigenmike (3)

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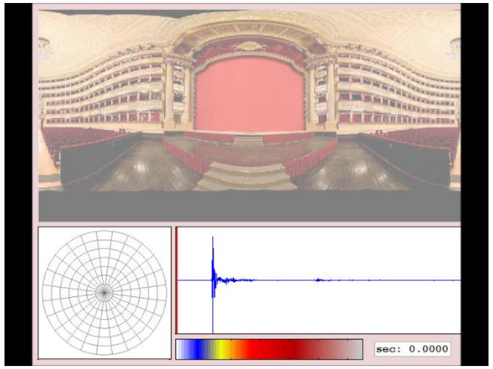

Analisi avanzata – Eigenmike (4)

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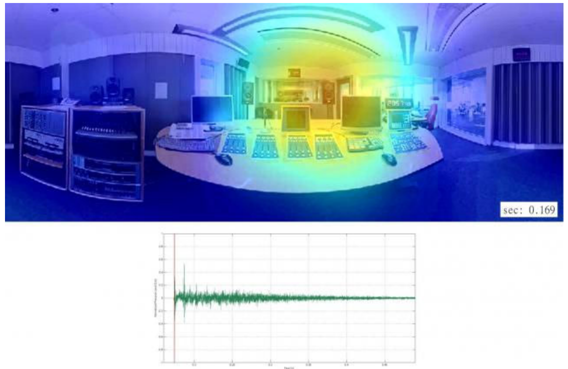

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Recap

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- **Small rooms can be optimised but often they will never be perfect: measuring is the only way to be aware of the situation and work at our best.**

- Use an SPL meter to protect your ears and to lower background noise;
- Reverberation times are very useful to set a correction project but lack of precision in mid and low freq;
- Symmetrize your listening system and forniture/hardware positioning based on your room shape;
- FFT is very useful for listening triangle/penthagon/subwoofer/sound source positioning;
- Use FFT modal analysis on measured RIR to project your bass traps;
- BUT remember EFT and modal decays durations to decide your first lf targets;
- Use RIR time analysis to control first reflections, scattering panels are useful;

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Thanks for your attention.

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