As presented by Eckhard Kahle at:

EUROREGIO BNAM2022
Joint Acoustics Conference
9th-11th of May, Aalborg, Denmark

Not included in official proceedings

Acoustical aspects not covered by the common, standardised room acoustic parameters

Tor Halmrast[1,2]

[1]Cowi, Oslo, Norway

[2]University of Oslo, Dept. of Musicology

torhalm@online.no.

Abstract

The standardised Room Acoustic Parameters (RAP) are of great help in the design and evaluation of concert halls. However, there might be excellent halls that do not fulfil the criteria, and, on the other side; halls that fulfil most of these criteria that still are not of high quality. This paper will present some acoustical aspects not covered by the common, standardised parameters. As an introduction, we might remember the words by Albert Einstein: *"Not everything that counts can be counted, and not everything that can be counted counts".*

The paper will give examples of some aspects not covered by the standardised parameters, such as: Directivity of the source, Level of the Reverberation, Investigations of the very early part of the Impulse Responses, Room Acoustic Attack, Time limits for room acoustic parameters, Direction of perceived reverberation, What is an echo?, Frequency Response/Resonances, What is Bass Response?, Critical Distance in detail, Focusing effects from corners and curved surfaces, Early reflections/Comb filter coloration, Direction of early reflections to the audience, Envelopment from the rear of the hall, Empty/Occupied stage, Response back to the musician, Flutter Echoes, Seating arrangements for the orchestra, etc. Some of these aspects can be counted and measured, but by non-standardised measurements. We need to learn which of these aspects that counts the most! Acoustic design is like cooking a good meal or composing music: We know how each ingredient tastes and how each note sounds, but the problem is to choose the right amount of each of them.

Keywords: room acoustics, parameters, non-standard measurements

1 Introduction

A working group has been convened by the European Acoustics Association to develop optimum Room Acoustic Parameter (RAP) ranges for large musical performance and rehearsal spaces. A Technical Memorandum, outlining the proposals of the working group is in production [1]. While the possibility to develop novel parameters was at first discussed, is has been agreed that the RAPs already defined in ISO 3382 Part 1 will be used. The parameters discussed in this Memorandum are highly needed and important for the design and evaluation of concert halls. However, there might be halls that fulfil most of these criteria that still are not of high quality, and on the other hand; excellent halls that do not fulfil the criteria. One of the chapters in the Memorandum points out some acoustical aspects not covered by the common, standardised parameters. This paper gives some more elaboration on these aspects.

A detailed discussion with examples for each aspect would exceed the length of a conference paper, so this paper is more like an overall list than a deep discussion on each aspect.

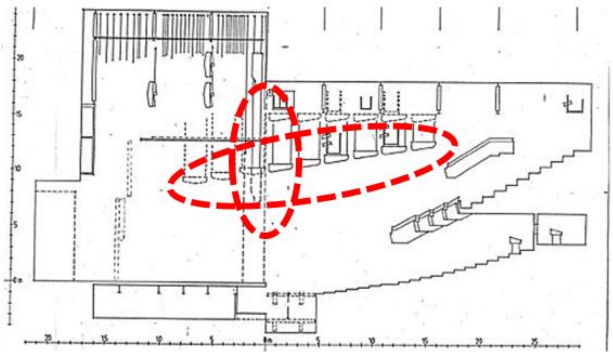
2 Aspects not covered by the standardised Room Acoustic Parameters (RAP)

2.1 SOURCE

Directivity of the source.
No musical instruments are omni-directional. (See Jürgen Meyer [2]). This aspect is especially important when receivers are positioned behind musicians in vineyard halls etc. The following pictures shows the orchestra, seen from behind, in Phil. de Paris and Danish Radio Concert Hall. Measured RAP´s with omni sources do not give any necessary info about such matters.

2.2 COUPLING BETWEEN STAGE AND AUDITORIUM

Olavshallen Concert Hall in Trondheim, Norway has recently been refurbished (COWI in collaboration with Kahle Acoustics). One of the most important improvements was that the fire curtain and surrounding structure could be removed, giving a much better coupling between the stage and the (upper part of) the auditorium, as shown in the following picture (before renovation).



Additional improvements were the new design of the orchestra shell, which improved not only the coupling to the auditorium, but also the stage acoustics.

2019

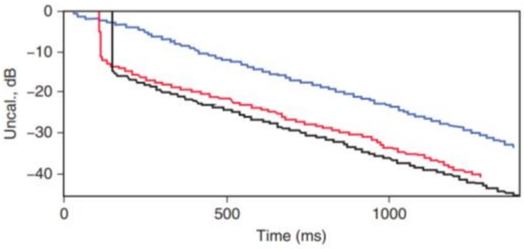
2022

We will not go into details about this refurbishment, but both audience and musicians are very pleased with the result. We achieved a broader, "airier" sound field, which was perceived as more "sonorous", even if the preliminary measurements shows that standardised reverberation time parameters actually gave lower values! Some additional aspects from this renovation are given in part 2.3.12

2.3 GENERAL ROOM ACOUSTICS

2.3.1 Level of the Reverberation (compared to the direct sound)

The room acoustic parameters include several reverberation time parameters but do not give any indication about the level [dB] of the reverb compared to the direct/early sound. The following figure does not show exactly this situation, but something similar; the sound decay for a common measurement with a loudspeaker source at a distance (upper curve/blue), and two measurements of a musician´s own clap and tongue-drop, back to himself (measured within-ear microphones) [3]. We see that the Schroeder curves for the main decay are parallel (meaning the T30/T20 is the same), but the level of the reverberation, compared to the direct sound (0 dB) is different.

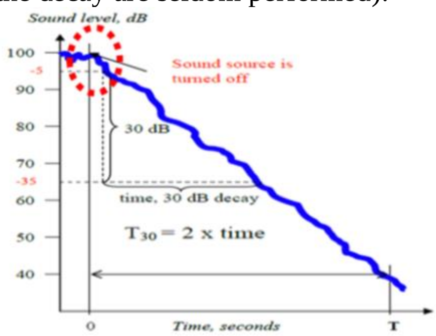


Schroeder-curves. Foyer. Comparison. Standardised Measurement and two In-Ear-Mic. Upper (blue): Standardised measurement Middle (red): Handclap, Lower (black): Tongue-drop.

The aspect of level of the reverberation is highly important because modern recordings often combine a strong direct sound and a very long reverberation time, but at a low level, thus securing both clarity and reverberation. The modern listener is used to getting both these aspects at the same time. In an acoustic concert hall, we might need close reflections to achieve such high level of "almost direct" sound.

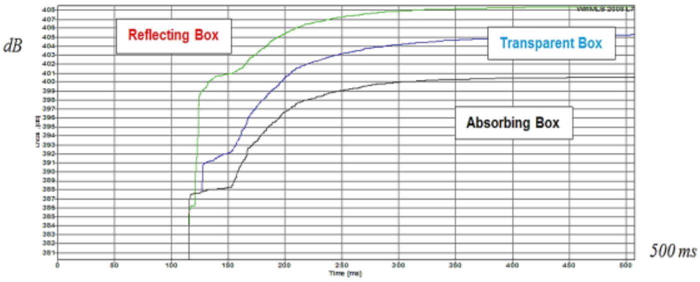
2.3.2 Investigations of the very early part of the Impulse Responses

In ISO 3382 most of the reverberation time parameters skip the first part of the decay, (to achieve reproducibility etc.) (Example: T30 is measured from -5 dB to -35 dB). This means that the important very early part of the decay is not included. (EDT might, however, include this first part, but close inspections of this very early part of the decay are seldom performed).



2.3.3 Room Acoustic Attack (Integrated Cumulative Imp. Resp.)

A hall with a long RT without close reflections often smoothens instruments attack so the hall sounds less "clear". Such "smoothening" is most clearly perceived for long signals, and less for sounds that are shorter than the "rise time" of the room. The following figure shows the simulated "build up" of the sound field in a typical hall, with 3 different surroundings around the source: 1) A Reflecting "box": open towards the hall, and all other surfaces reflective, 2) Transparent box: meaning no "box", no close reflecting surfaces, 3) Absorbent "box": meaning all surfaces around the source absorbent, except open towards the hall. (See [4]).



The figure above shows the build-up of a "continuous", long sound prolongs the attack, most clearly for the absorbent and transparent box (without close reflections). Close reflections (Reflecting box) shorten the "rise time" and gives less "smoothing" of the attack.

If the signal is much shorter than this "rise time", we do not get the whole build-up. Thus, in reverberant hall, a very short marimba sound will have a clearer attack than a viola phrase with longer notes. A singing voice is often a compromise between the understanding of the lyrics and the nice, enveloping long notes. Close reflections will reduce the build-up time of the short transients so that the text might be perceived more clearly. However, for such close reflections we might need to compromise between Room Acoustic Attack and Comb Filter Coloration, which can be done by including more close reflections with slightly different time delays. (See 2.4.1)

2.3.4 Time limits for room acoustic parameters

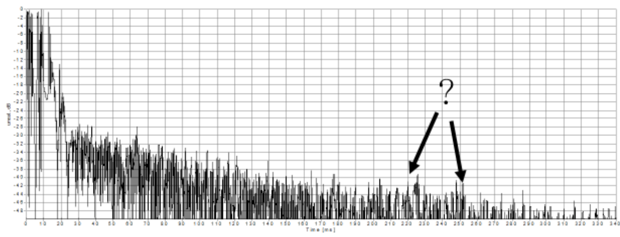
In ISO 3382 most room acoustic parameters have strict time limits (50 ms for C50 etc.). These time values might be reasonable but are too strict. (A reflection at 50.5ms will be perceived as "clear" as one of 49.5ms).

2.3.5 Direction of perceived reverberation

Parameters like LF_{late} might give some indication of the directivity of the reverb but does not show for instance if too much (or too little) reverberation arrives from the rear of the hall.

2.3.6 What is an echo?

Echo criteria like Dietsch and Kraak do not detect a cluster of rather weak reflections over a certain period of time, for instance from the rear part of a hall. Such late clusters of reflections can be perceived as “almost an echo” due to lack of reflections before these reflections arrive. How such an "echo" is perceived also depends on the type/length of the signal. The following figures shows the ETC curve of a measured decay in the old Oslo Opera. [5]. The area connecting the rear wall and the ceiling creates several reflections back to the stage/front of the hall (225-250 ms). Even if no single reflection is strong enough to give indication of echo using Dietsch and Kraak, the decay is perceived as a clear echo, especially for transient instruments. A marimba player on stage could have charged "double salary". PS! The orchestra musicians in the pit hated the echo, but some of the old singers on stage loved it, as they felt relieved by the response from the hall when they were "almost out of air”.



2.3.7 Frequency Response/Resonances

Simple measures like "Bass Strength", “Bass Ratio” or 1/1, 1/3 octave analysis are not accurate enough for judging the response for lower frequencies. Closer inspections of the Impulse Response in Waterfall/ Sonograms might be necessary to find more narrow bandwidth resonances etc. Such investigations are often used for sound systems in halls and should be done also for pure acoustic concert halls.

What is Bass Response?
In the literature it is often recommended that the reverberation time should have a rise in the bass for acoustic instruments, to give "warmth" and to support double basses. The necessary support for the double basses might, however, be achieved by designing a vibrating floor and/or placing the double basses close to a bass-reflecting wall. As this might give a more "punchy"/distinct bass-sound such a design might be more important than the bass rise of the reverberation time, which might sound more "boomy". Several nice halls have good response from the double basses (and lower regions of the celli) even if they do not have a bass rise in the reverberation time.

2.3.8 "Acoustic Glare

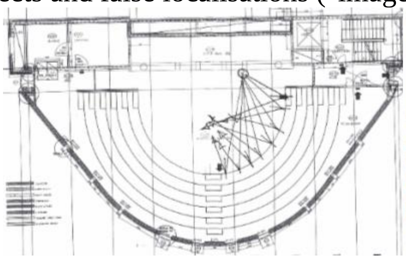
Beranek [6] mentions that *"If one listens to music in a rectangular hall with flat, smooth sidewalls, the sound takes on a brittle, hard or harsh sound, analogous to optical glare"*. This is of course highly important but is not covered by the common RAP´s and might need some more detailed studies regarding the pro et contras between brilliance and glare.

2.3.9 Critical Distance in detail

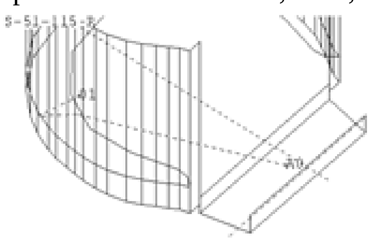
The literature distinguishes between near field and diffuse field. In order to understand more about which reflections gives coloration, we might need to go more into detail; How far away from the source is the sound field actually correlated/coherent? (and for which frequency bands?). (See also the comments on the build-up of comb filters in part 2.6).

2.3.10 Focusing effects from corners and curved surfaces. False localisations (image shift)

Focusing effects and false localisations ("image shift") are not indicated in the measured RAP´s.




False localisation from orchestra pit in National Theatre, Oslo, and in Munich Opera [7]:

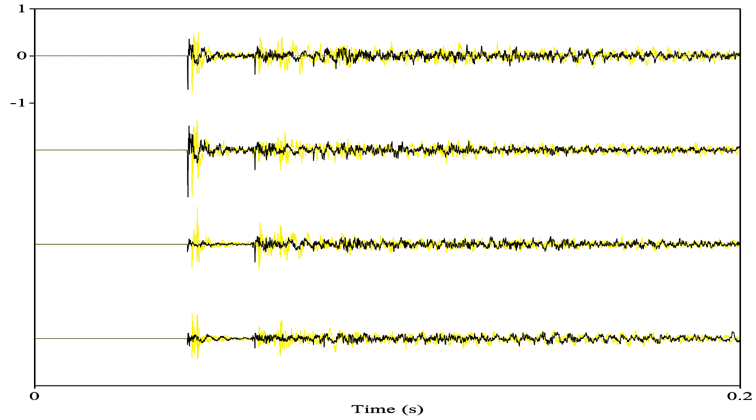



2.3.11 Steep audience areas

A steep seating area will of course give excellent view to the stage, and secure direct sound, but most of the important information from a (treble) source is projected only in a small "room angle" forwards from the instruments/singers. In order that a sufficient part of this room angle reaches walls etc., the audience area should not be very steep.

2.3.12 Time arrival of first reflections in different directions

In Olavshallen it was noticed as a problem that (especially on the lower, main part of the audience) the first reflections arrived from all directions at the same time. This is shown in the following analyses of the B-format wav-file (ch1=omni, ch2=x-axis/fig8, ch3=y-axis/fig8, ch4=z-axis/fig8). The black curve shows 2019, and the yellow shows 2022. We see that the first reflections in y-, and z- directions (ch3+4) appears exactly at the same time as for the direction of the direct sound (ch2). In the yellow curve (2022) the reflections in each direction are more distributed in time.

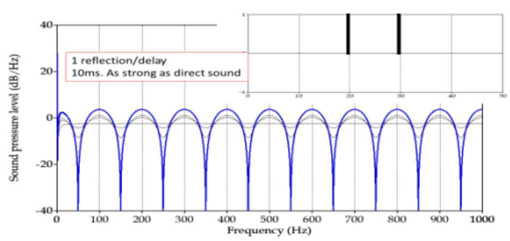


This shows the perceived effect that the refurbished orchestra shell/overhung reflectors etc. gives the more “airy”, less “punchy” sound to the audience. This perceived improvement is not shown in any RAP.

2.4 EARLY/VERY EARLY REFLECTIONS

2.4.1 Early reflections, Comb filter coloration

Early reflections are needed to increase the "almost direct" sound for acoustic instruments and singers. (see 2.3.3) Distinct reflections give comb filter effects. Short time delays give broad combs (almost like a bass-lift). Long time delays give narrow combs (and probably distinct echo in the time domain).
Medium time delays might give clear coloration (as the distance between the teeth in the comb filters are in the order of critical bandwidth in our cochlea). Such coloration might be beneficial to give the hall some "personality" but might also be dangerous. Introducing more close reflections with different time delays could reduce the danger of such coloration.



2.4.2 Direction of early reflections to the audience

Parameters like LF etc. do not clearly indicate if all lateral reflections arrive from just one side-(wall), giving no actual «envelopment»).

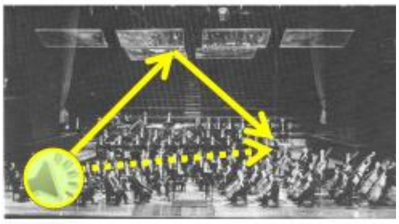
2.4.3 Envelopment

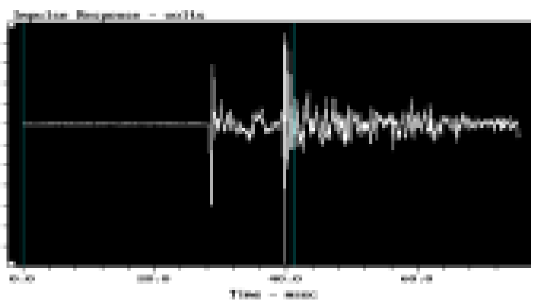
Envelopment from the rear of the hall (not just from the side/lateral) is, to a certain degree, beneficial, but is not covered by the common parameters.

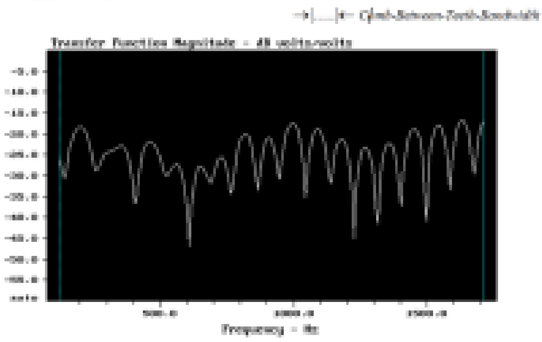
2.5 PODIUM ACOUSTICS

2.5.1 Empty/Occupied stage

Measurements (and loudspeaker orchestra tests) should not be done on empty stages (and in empty halls). There is a need for «dummy screens/absorbers» to simulate «none-empty» conditions, both for computer simulations and actual measurements. Investigations of podium acoustics can be done by Through Orchestra impulse Response (TOR), diagonally from rearmost violin 1 row to the wood wind on the other side of the podium. The following figures shows measurements with a test canopy in Oslo Concert Hall (Impulse Response and Spectrum) perceived as a clear comb filter coloration, see [8].







2.5.2 Response back to the musician

ST-parameters do not fully describe the listening situation for the musician him-/herself. This could be improved by analysing recordings non-standardised Impulse Responses of “musician´s” own clap with in-ear mic (or common omni-directional mic close to the musician's ear). (see [3], and 2.3.1 showing the result of such a measurement).

2.5.3 Flutter Echoes

Flutter Echoes between sidewalls on stage or ceiling/floor often gives a "tail" in the decay at some 1-2 kHz, often due to diffractions at the edges of these surfaces. Flutter echoes are not directly shown in the common parameters. (see [9]).

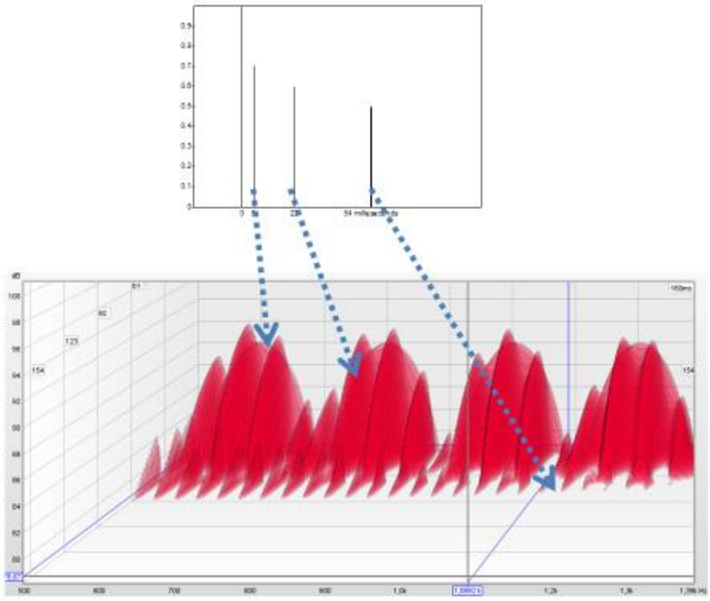
2.5.4 Other Podium acoustic aspects:

Reflecting floor in front of violin1
and violin/celli on the other side of the conductor to give reflections to the audience (and thus reduce the need of many extra reflections from walls etc. to reduce comb filter coloration)
Raked seatings
Raked seating/platforms for the musicians are often preferred. This gives clarity and projection from each instrument. Too steep ranking of the orchestra podiums (like a Hollywood orchestra), will, however, often give reduced "envelopment".
Musicians should be placed as close to each other as possible.
A "closer" orchestra on a smaller part of the podium makes it easier to play "together", rhythmically. (We must, however, secure that brass and percussion do not give excessive sound pressure levels to the musicians placed close to such strong instruments)
Absorbents behind strong instruments (perc.)
Directivity/reflections/Image shift
Some instruments, like horns, have a directivity pattern that often gives false localisation/image shift when reflections from the stage corner behind/to the side of these instruments are stronger than for the direct sound.
Reflections from the side give more "chorus" effect than reflections from above.
For the strings, with several musicians playing the same part, a reflection from above (from a ceiling or a canopy) will give more or less the same time delay for each row of musicians. Reflections from the side (wall/balcony etc.) will, on the other side, give reflections with larger differences in the time delays for each row of musicians, and the result will be a sort of "chorus" effect, and reduced comb filter coloration.

2.6 "COMB FILTER BUILD-UP" and SPECIAL ISSUES FOR SMALL ROOMS

The memorandum [1] and this paper deals mostly with medium sized and bigger halls. For smaller rooms, like music rehearsal rooms and sound control rooms we often have other kinds of room acoustic challenges. First of all, reverberation time is not a very useful parameter in small rooms, due to room resonances etc. and far from "diffuse" sound field. The comb filter coloration from early reflections goes for both large and small rooms, but might be even more important in small rooms, sound control rooms etc.

Coloration du to early reflections/"Build-Up" of comb filters
It is often stated by sound control room designer etc. that the timbre is decided early in the decay. This is not wrong, but the reason is not that it is early, but that the comb filters from "quite early "reflections have a CBTB (Comb Between Teeth Bandwidth) that is in the order of Critical Bandwidth. The following figure show the comb filters for a situation with 3 reflections at 5/22/54 ms with decreasing amplitudes (0.7/0.6/0.5). We see that the first reflection gives a broad comb filter that dominates the further comb filters from the later reflections. The very, very early reflections influence mostly the bass. Reflections arriving after some 5-25 ms gives comb filters that are perceived as clear coloration. Later reflections (as 54 ms in our example), gives "tighter" combs and probably no perceived coloration.



This situation also goes for the early reflections in a concert hall: The first reflections will give a coloration that influences the later ones. Also: the later comb filters will be narrower and narrower, with CBTB`s much smaller than Critical Bandwidth, so that they do not give perceived coloration in the same way as the earlier reflections, as a gradual evolution towards diffuse field.

3 Discussion and Conclusion

This paper has listed several acoustic aspects not covered by the standardised room acoustic parameters (RAP). Many of these aspects can be counted and measured, but by non-standardised measurements. We need to learn which of these aspects that counts the most! Acoustic design is like cooking a good meal or composing music: We know how each ingrediencies tastes and how each note sounds, but the problem is to choose the amount of each of them.

Acknowledgements

Thanks to Kahle Acoustics for the nice collaboration in the refurbishment of Olavshallen, Trondheim, Norway.

References

[1] Evan Green et al. Development of a Technical Memorandum Describing Optimal Room Acoustic Parameter Ranges for Large Musical Performance and Rehearsal Spaces. *Proc.Euroregio/BNAM* 2022

[2] Jürgen Meyer: *Acoustics and the Performance of Music,* Springer

[3] Tor Halmrast. When Source is also Receiver. *Building Acoustics*. Vol.20. No.4 2013. p. 403-422

[4] Tor Halmrast. Attack the Attack; Reverberation influences Attack and Timbre. *Proceedings of the Institute of Acoustics* (UK) Hamburg. 2018

[5] Tor Halmrast. The Influence of a large Reflector over the Orchestra Pit in an Opera House. *Proceedings of the Institute of Acoustics,* London, 2002

[6] Leo Beranek. Concert Halls and Opera Houses; Music, Acoustics and Architecture. 2nd ed. *Springer.* p.521

[7] Tor Halmrast. The delayed Phantom of the Opera. *Proceedings ICA,* Rome, 2001

[8] Tor Halmrast. Orchestral Timbre; Comb-Filter Coloration from Reflections. *Journ. Sound and Vibration* (2000) 232(1), 53-69

[9] Tor Halmrast. Why do Flutter Echoes "always" end up around 2 kHz. *Proceedings of the Institute of Acoustics*. Paris. 2015.