23rd International Congress on Sound & Vibration
Athens, Greece 10-14 July 2016
ICSV23

IMPROVED ROOM ACOUSTICS CALCULATIONS USING COMPLEX IMPEDANCE AND SPHERICAL WAVE REFLECTION & DIFFRACTION COEFFICIENTS

Panos Economou, Panagiotis Charalampous

P.E. Mediterranean Acoustics Research & Development Ltd, Cyprus
email: panos@pemard.com

Until recently geometrical acoustics has been considered an approximate method of calculating the sound field within a 3D environment because of certain limitations in existing methods. Geometrical acoustics mostly refers to the use of ray tracing and image sources. Ray tracing is a pure energetic method, while the image source method, despite calculating complex sound pressures and theoretically representing a solution to the wave equation, has certain limitations. One of the limitations found in most of the image source implementations is the use of plane wave reflection coefficient and absorption coefficients, a fact that prohibited image sources to be an exact solution of the wave equation. In this paper we extend the image source method, using spherical wave reflection and diffraction coefficients as well as complex surface impedance. We compare the results of the calculations with published data and we conclude that the use of spherical wave coefficients and complex impedance can improve room acoustics predictions.

1. Introduction

There has always been a difference in approach in solving problems between the academia and the industry. The fact is that problem solving of physical phenomena starts with analysis which can be infinitely deep and endless depending on the perspective given to a problem. It is therefore inevitable that, those equipped better to attack a physical phenomenon are in the case of acoustics, physicists. However, when it comes to designing, manufacturing and building, when one has to bring phenomena from their abstract world and apply them in practice, an engineer is better equipped. Until the computer revolution, engineers had to strip from their calculations the complexity of the phenomena to be able to cope with the pressures of life and profitability. However, nowadays due to the advent of technology, there is no justification for doing so. Complex analysis is incorporated in user friendly software applications in which the user only needs to grasp the essence of understanding the mechanisms involved in acoustical phenomena, without the need of knowing the details. Such approaches bridge the two worlds, the academia and the industry, theory and practice.

In this paper we will demonstrate the use of physical acoustics in analysing real life projects. We use the Wave Based Geometrical Acoustics method [1] to analyse small room acoustics, and more specifically, the effect of mixing consoles in audio control rooms. An audio control room is an acoustical environment free from acoustical defects, which enables the mix and processing of sound to be played by consumers in other spaces. The need for neutral acoustics is to be able to detect and correct room acoustical defects during the recording process. It seems that the use of mixing consoles in control rooms, an object affecting drastically sound perception, is controversial. In this paper we show using Olive Tree Lab-Suite [2] a Wave Based Geometrical Acoustics software application, how console sound reflections and edge diffractions colour sound reaching the sound engineer. We also demonstrate that there is no such thing as a “sweet spot” in a control room, demystifying old myths.

This paper is divided into the following parts. The second part which follows, introduces the concept of Wave Based Geometrical Acoustics while the third part provides evidence for the validation of OTL-Suite. In the fourth part we demonstrate with the use of OTL-Suite that there is no big divide between theory and practice in analysing a real control room project. Finally we draw some conclusions.

2. Wave Based Geometrical Acoustics (WBGA)

Geometrical Acoustics (GA) is based on the concept derived from Optics that wave fronts travel in straight lines until they encounter a discontinuity, an impedance change [3]. The use of GA in room acoustics has been proven to be a very useful tool. However, the lack of phase information in sound rays due to sound propagation discontinuities, limits the range of applications which GA has applicability. In contrast, WBGA [1] extends GA to accommodate for impedance surfaces, complex pressure summation, spherical wave propagation, and with the use of the image source method, can account for the phenomena of reflection, diffraction, refraction, transmission and others. It has been shown [1] that in rectangular rooms the WBGA is as accurate as the BEM. This paper presents calculations showing the influence of mixing consoles on the sound field in Control Rooms using Olive Tree Lab-Suite, a sound propagation software application which employs WBGA in a 3D simulation environment.

3. Validating Olive Tree Lab-Suite a WBGA software application

We have prepared for this conference a trilogy of papers dealing with WBGA. One of our paper [4] validates Olive Tree Lab-Suite in terms of sound reflection in calculating room resonances, based on the work of R.H.Bolt [5]. The second [6] validates Olive Tree Lab-Suite in terms of sound diffraction in calculating the seat dip effect based on the work of Ando [7]. The current paper, based on the validated results of the other two papers, shows that the sound field a sound engineer is exposed to in front of a mixing console is far from ideal. Furthermore, that the “sweet spot” is a myth.

3.1 Room Resonances - Calculation vs experimental results

For validation purposes, Figures 17 and 18 of Bolt’s paper [5] were used. In that paper, Bolt experimented with a small scale model room 1/10th of real size. The room was essentially two-dimensional, with non-parallel walls. The height of the model was small compared to the sound wavelength used therefore no normal modes with vertical components could develop. The figures below show in colour the results calculated based on WBGA using OTL-Suite. Superimposed are the experimental results at frequencies higher by a scale factor of 10, courtesy of the Journal of The Acoustical Society of America.

From the figure below, one may conclude that there is adequate correspondence between measurements and calculations especially if one takes into consideration the following: (a) During the experiments only a single frequency was used while for the simulation, 4 frequencies within the 1/3rd octave band (mapping in 1/12th octave). (b) The 1/3rd octave bands centre frequencies values do not correspond to the frequency values reported by Bolt. (c) As reported by Bolt in the same paper, microphone positioning was very sensitive to sound level changes. This means that frequency deviations (wavelength) cause equally abrupt changes in level.

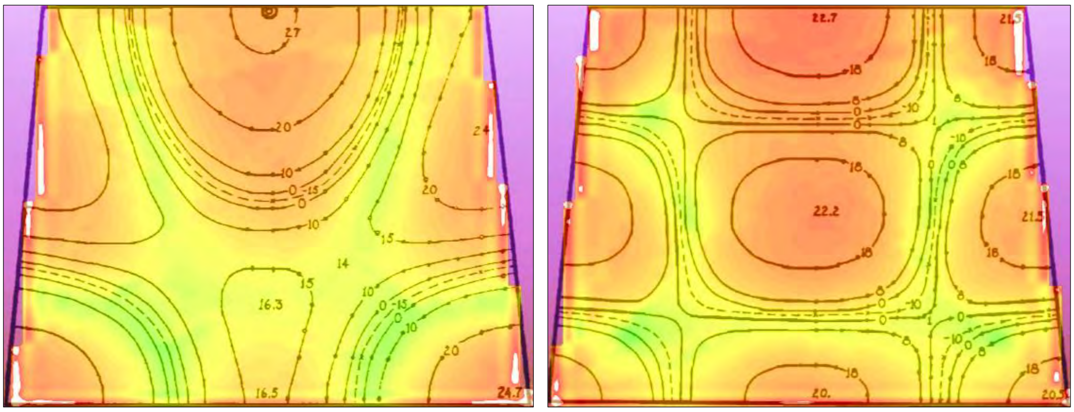

Figure 1: Mapping on the left is at 1721 Hz (higher by a scale factor of 10, experimental data, courtesy of the JASA) while the coloured mapping in the 1/3rd octave band of 200 Hz. The mapping on the right is at 2302 Hz (higher by a scale factor of 10, experimental data) while the coloured mapping in the 1/3rd octave band of 250 Hz**.** In red high sound levels and in green low [5].

3.2 Validation of the WBGA in simulating Seat Dip Effect

In another paper for this conference [6], we validate the use of WBGA to reproduce the Seat Dip Effect, a well-studied phenomenon of low frequency sound attenuation at grazing incidence over surfaces characterized by roughness, either of periodic or non-periodic structure [8]. This phenomenon is called the seat dip effect because it is mainly observed in theatres and halls. In effect, the total sound pressure is made up of the direct sound wave, scattered and reflected waves off seat rows and floor. For validation purposes, we present below the results from the 1982 paper by Ando [7].

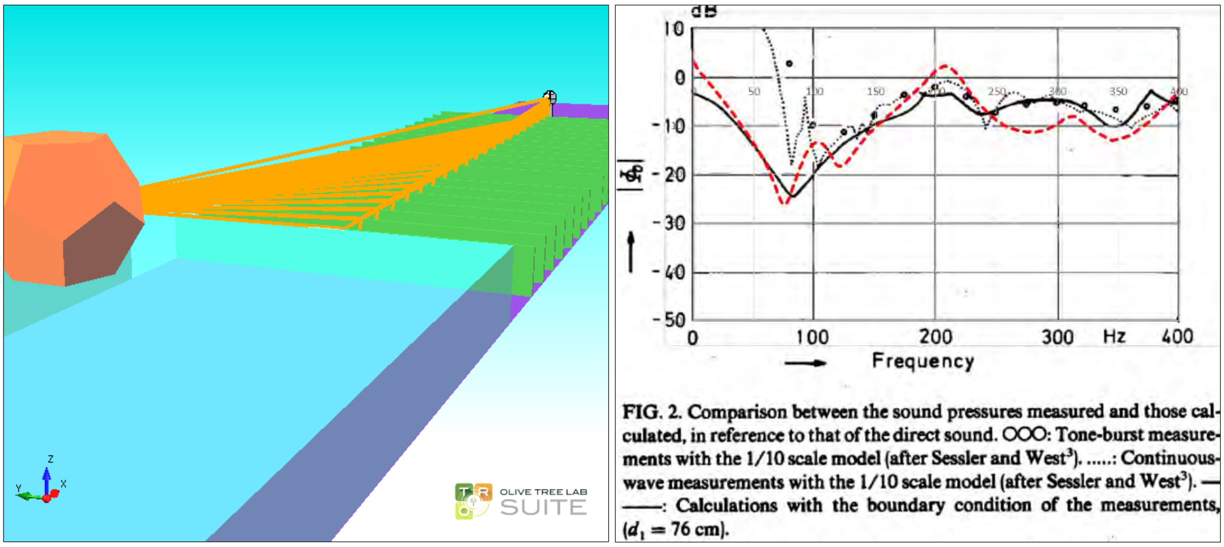

Figure 2: On the left, the 3D full scale model used for our calculations. On the right Ando's results compared to experimental data. Our calculations are superimposed as a red curve over the original graph by Ando (courtesy of the Journal of the Acoustical Society of America).

4. Using spherical wave reflection and diffraction coefficients, pressure summation and surface impedance

One of the drawbacks in conventional Geometrical Acoustics, in contrast to Wave based Geometrical Acoustics, is the use of the sound absorption coefficient instead of surface impedance. In their seminal publication Reviews of Modern Physics in 1944 [9], P.M. Morse and R.H Bolt have expressed the concerns of the acoustical community at the time, about the use of sound absorption. What follows is an extract from that publication. *"It has been demonstrated in a number of ways that the absorption coefficient entering into the geometrical acoustical formulas is not a fundamental property of the wall surface. The measured value of the coefficient changes when the material is placed in different rooms…It is an average property… and has no meaning in cases where the sound distribution is not ergodic…It is true that the impedance is not a much more «fundamental» physical property than the absorption coefficient; its advantage lies in the fact that its measurement can be specified concisely and uniquely and that its value for a given material has a definite meaning no matter what the distribution of sound inside a room"* page 87, section 16 of [9].

Another drawback in GA is the use of plane wave rather than spherical wave sound propagation. Spherical sound reflection coefficients, account for the "ground" wave (coined as such in electromagnetism) and surface wave components [8] while plane waves cannot. In essence, spherical waves allow for phase changes which take place when sound waves encounter materials or in general impedance discontinuities. Figure 3 shows the effect of summing the direct and reflected path to a receiver from a source over a soft surface and applying various methods described in the graph legend. The figure on the left shows the configuration while the figure on the right Excess Attenuation in dB (the ratio of total over direct sound field).

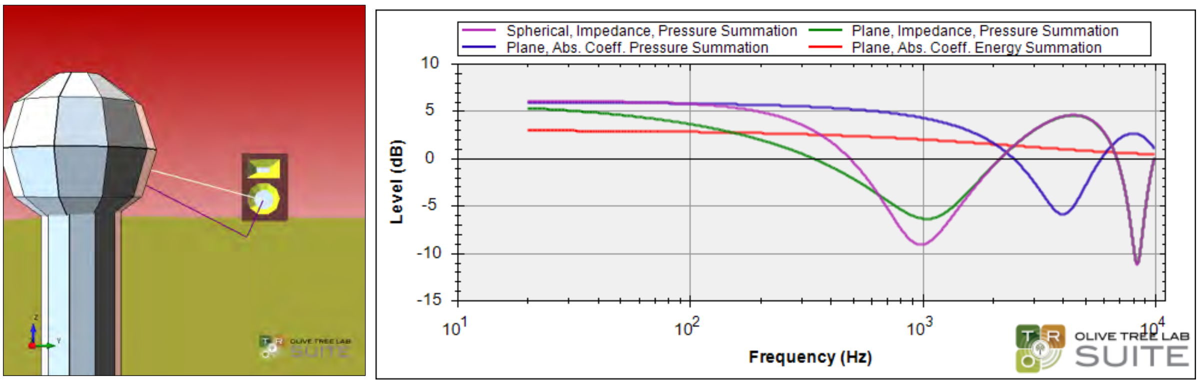

Figure 3: A source and receiver over a surface of finite impedance (corresponding to flow resistivity of 200kPas/m2). On the right, the effect of summing the direct and reflected path applying the different methods, shown as Excess Attenuation in dB (the ratio of total over direct sound field), from [4].

5. Audio Control Room and mixing desks

The calculation of the sound field in big spaces usually is more manageable since the field is more likely to be diffused even at low frequencies, whereas the sound field in small spaces, is dominated by zones controlled by the room normal modes of vibration. Typically, sound fields in small irregular in shape rooms with objects in them are calculated using numerical methods such as BEM and FEM which are heavy in calculation time. These tools are not user friendly nor are they the tools being used by acoustical engineers. Now with the use of WBGA, engineers are able to calculate all sorts of wave phenomena including sound diffraction.

The figure below shows the simulated distribution of sound and room resonances in a control room of a recording studio. The calculation time with a typical laptop took about 30 minutes when taking into account 5 orders of reflection, 1 order of diffraction and 1 reflection in between diffractions. The 3D model has 77 surfaces.

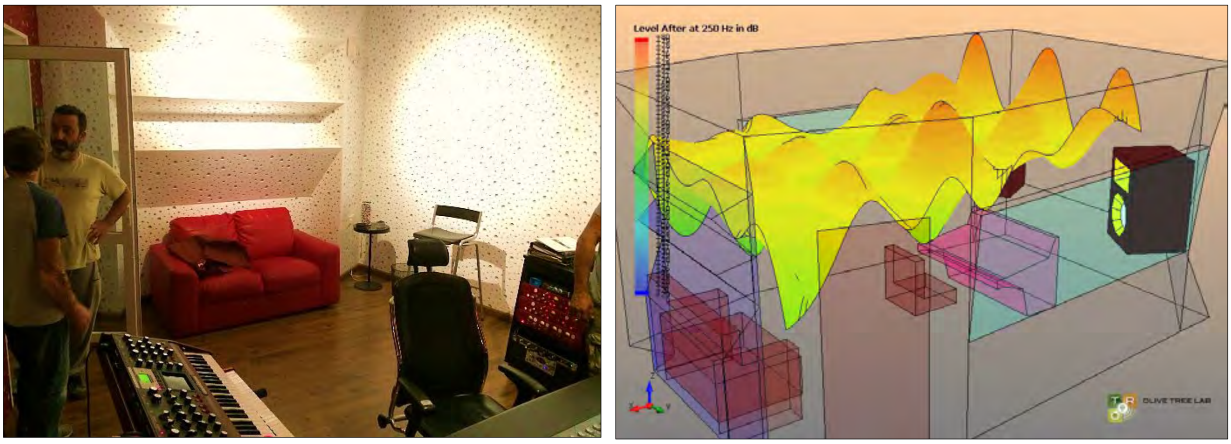

Figure 4: Picture of an audio control room and the simulated sound distribution in the 1/3rd octave band of 250 Hz. The room resonances are clearly evident.

To analyse the effect of the mixing desk and the "sweet spot" in a Control Room (CR), we have used in modelling, surface impedance calculated with the Multilayered Structure Builder (MLSB) of OTL-Suite based on the Transfer Matrix Method (TMM).

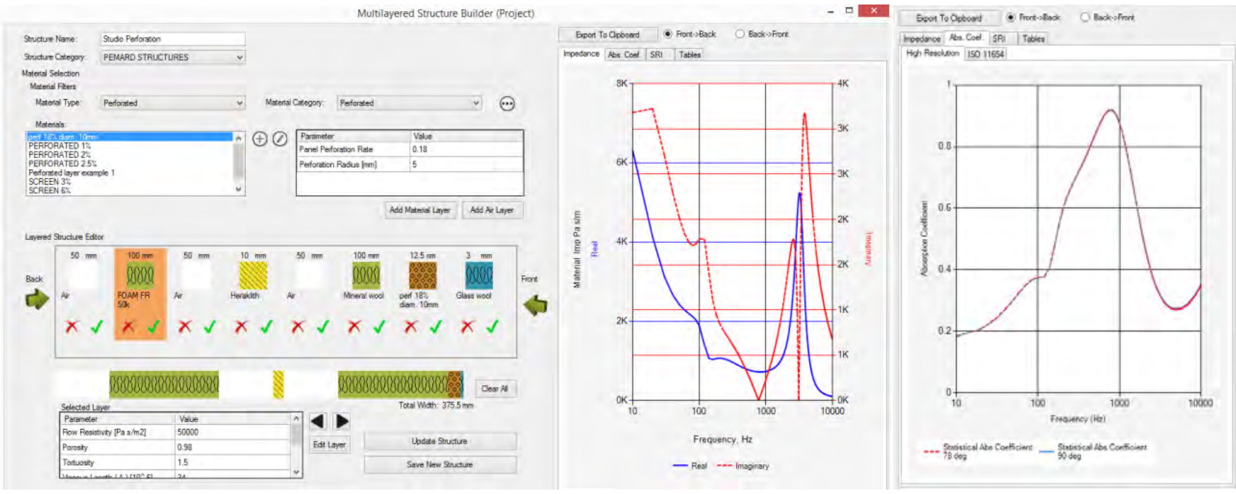

Figure 5: The Multilayered Structure Builder of OTL-Suite is used to calculate properties of the material layers used in the control room walls. The graphs give the spectra of the surface impedance and the equivalent sound absorption coefficient.

The figure above, shows as an example the material layers used for the control room walls. The graphs give the spectra of the surface impedance and the equivalent sound absorption coefficient. The surface impedance values are used directly in the 3D model for calculation purposes.

5.1 Mixing consoles' detrimental effect on sound quality

First we examine the effect of the mixing console by analysing the components of the sound field the recording engineer receives. To do that only the speakers, the mixing desk and the microphone are participating in the calculation. All other surfaces and entities of the 3D model were made inactive. The following scenarios are examined:

- Direct sound and reflections from the mixing desk.
- Direct sound and edge diffracted paths (2nd order).
- Direct sound and edge diffracted paths (2nd order) and 1 reflection in between diffractions.
- All possible sound paths together. In the following figures, in green are diffractions and in blue are reflections.

The sound field the sound engineer is receiving, expressed in Excess Attenuation in dB (the ratio of total over direct sound field), is shown in the graphs below with a picture of the sound paths involved. Description of each case is given as inset in each graph.

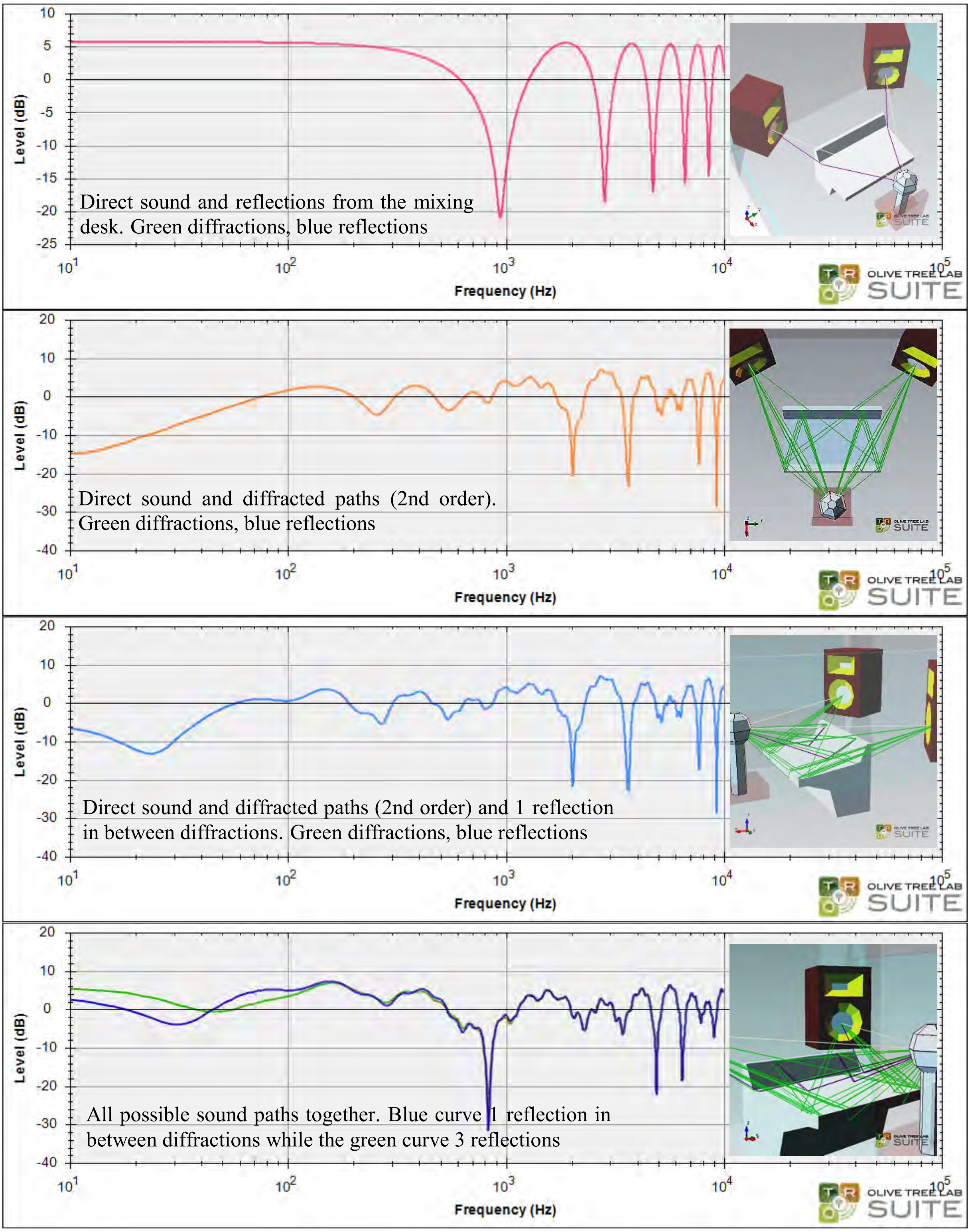

Figure 6: The graphs with a picture of the sound paths involved show the sound field a sound engineer is receiving behind a desk. Description of each case is given as inset in each graph. Results are expressed in Excess Attenuation in dB (the ratio of total over direct sound field).

For a neutral listening environment, one would expect a flat curve going through zero, i.e. just the direct sound. Anything above zero indicates that the room contributes to the direct sound and anything below, that the room removes from the direct sound. However what matters in terms of quality of sound is that the frequency response is as even as possible irrespective whether the curve is above or below zero. From the above curves, one may observe that both reflections and edge diffractions provide phase shifts which produce interference effects which are detrimental to sound quality. Sound reflections create the comb filtering effect (first graph in Figure 6). The last graph in Figure 6 shows a comparison between 1 and 3 reflections in between diffractions. The above indicate that mixing desks manufacturers ought to come up with a design with which to diminish these interference effects. Alternatively, the consoles ought to be as small as possible or preferably should be part of an augmented reality environment.

5.2 The myth of the "sweet spot"

In all audiophile and sound engineering magazines and books one encounters the term "sweet spot" of the control room where one gets the best sound due to the equal distance of the engineer from the speakers and any other room surface since control rooms ought to be symmetrical in order to be able to assess sound without any loudspeaker preferential positioning. The following examine sound from both speakers in free field, without the room. The graph below on the left, shows how a displacement of the listener's head by 10 and 50 cm brings about phase shifts, interference effects due to path difference.

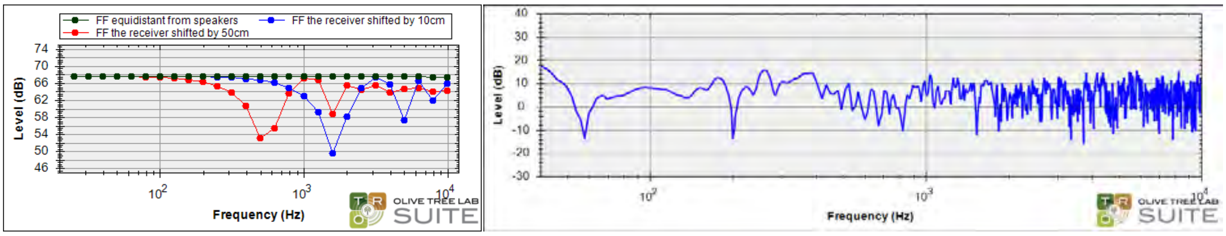

Figure 7: On the left, shows how a displacement of the listener's head by 10 and 50 cm brings about phase shifts, interference effects due to path difference. On the right, the frequency response the sound engineer behind the desk is receiving from all room surfaces and the mixing desk.

Sound mapping in free field is also done over an area of 50 x 50 cm (5 cm resolution) at a height of 1.2m with the listener's head in the centre of this area, located where usually the sound engineers sits behind the desk. From the mapping, it is evident that head shifts can bring about alterations to the sound field.

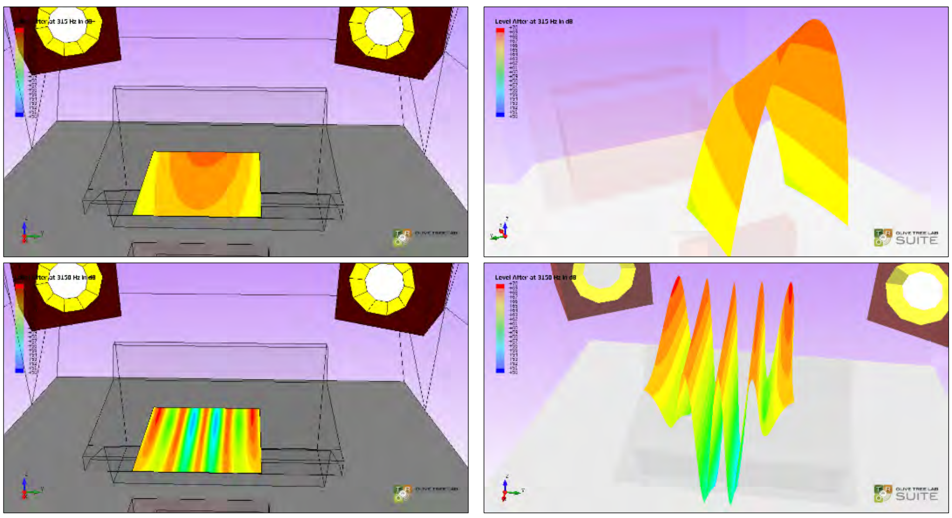

Figure 8: Free field mapping about the head of a sound engineer at a resolution of 5cm. On the left 2D mapping at 315Hz and 3150 Hz and on the right the same in 3D mapping.

The mapping below shows the same area but this time, the listener and speakers are inside the control room with a mixing desk and furniture. The mapping shows that there is no "sweet spot" since no matter where one is located behind the desk, there is always sound coming to the receiver with phase differences, creating unevenness in the sound field.

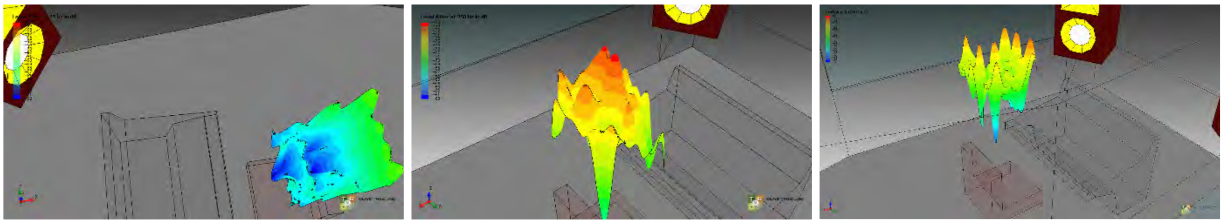

Figure 9: Mapping on the same area as Figure 8, but the listener and speakers are inside the control room with a mixing desk and furniture. The mapping at different 1/3rd octave bands shows that there is no "sweet spot" no matter where one is located behind the desk.

One may extend the findings to the two ears which complicate things even more. Whether the brain has the functionality to overcome subjectively the shortcomings of the control room acoustics, psychoacoustics, is beyond the scope of this paper.

6. Conclusions

The above results demonstrate that WBGA provides an accurate and fast alternative solution in comparison to numerical methods in Room Acoustics. We have also demonstrated that Wave Based Geometrical Acoustics with spherical wave propagation can accurately reproduce room modal and edge diffraction effects and provide the tools for the analysis and design of spaces used for music and speech. Using WBGA we show that mixing consoles in control rooms have a detrimental effect on sound. Furthermore, there is no such location in a CR which can be qualified as a 'sweet spot'.

REFERENCES

1 Lam, Y.W., Issues for computer modelling of room acoustics in non-concert hall settings, *Acoustical Science and Technology Journal,* **26** (2), 145-155, (2005).

2 Olive Tree Lab Suite software. [Online.] available: http://www.olivetreelab.com

3 Pierce, A.D., *Acoustics, An Introduction to Its Physical Principles and Applications*, The Acoustical Society of America, (1989).

4 Economou, P. and Charalampous, P., Room Resonances using Wave Based Geometrical Acoustics (WBGA), *23rd International Congress on Sound & Vibration*, Athens, 10-14 July, (2016).

5 Bolt, R.H., Normal Modes of Vibration in Room Acoustics: Experimental Investigations in Nonrectangular Enclosures, *Journal of the Acoustical Society of America*, **11,** 184-197, (1939).

6 Economou, P. and Charalampous, P., Seat Dip Effect using Wave Based Geometrical Acoustics (WBGA), *23rd International Congress on Sound & Vibration*, Athens, 10-14 July, (2016).

7 Ando, Y. Takaishi, M. and Tada, K., Calculations of the sound transmission over theatre seats and methods for its improvement in the low-frequency range, *Journal of the Acoustical Society of America*, **72** (2), 443-448, (1982).

8 Attenborough, K., Li, K.M. and Horoshenkov, K., *Predicting Outdoor Sound,* Taylor & Francis, (2007).

9 Morse, P.M. and Bolt, R.H., Reviews of Modern Physics: Sound Waves in Rooms, *Massachusetts Institute of Technology*, **16** (2), 69-150, (1944).