Audio Engineering Society

Convention Paper

Presented at the 137th Convention
2014 October 9–12 Los Angeles, USA

Visualization of early reflections in control rooms

Malcolm Dunn[1] and Daniel Protheroe[2],

[1] Marshall Day Acoustics, Auckland, 1141, New Zealand
malcolm.dunn@marshallday.co.nz

[2] Marshall Day Acoustics, Auckland, 1141, New Zealand
daniel.protheroe@marshallday.co.nz

ABSTRACT

Measurements were undertaken in a variety of control rooms with a system utilizing a compact microphone array and sound intensity technique to estimate the direction of early reflections. This paper presents the results of these measurements including 3D intensity plots which provide a visual representation of sound arrivals at the listener position. The effectiveness of this type of system for the detection of reflections and the evaluation of the listening environment is discussed.

1. BACKGROUND

The magnitude, quantity and arrival direction of early reflections play an important part in the acoustics of both large and small room environments. In larger performance spaces these reflections form part of the performance itself and are utilized to increase clarity and broaden source width. However in small rooms these effects are not always considered desirable.

Following listening tests with two loudspeakers in a small room Kishinaga et al. (1979) [1] concluded that whilst early reflections were desirable for 'fully enjoying the music' they were considered undesirable for 'monitoring and evaluating audio product.' This opinion, for the most part, has remained the dominant one in the design of critical listening environments.

A multitude of control room design philosophies, have developed with the goal of suppressing early reflections. The reduction of reflections in the listening position has been achieved by absorptive fronts to control rooms [2], using large reflective areas to deflect reflections to the side of the main listening areas [3][4] or diffusion to limit the strength of individual reflections [5]. Most modern designs incorporate elements of previous philosophies, utilizing a combination of absorption diffusion and deflection to control early reflections at the mix position.

2. DESIGN CRITERIA FOR REFLECTION CONTROL

The perceptual effects of reflections depend on the source signal as well as the presence of other reflections. The detection threshold for a single lateral reflection in an anechoic environment is illustrated in Fig. 1 below from Toole [6]. Even for one reflection the threshold of audibility changes depending on the type of signal. The situation is further complicated with multiple reflections. It is also noted that achieving appreciable image shift requires higher levels of reflected sound than what is just detected.

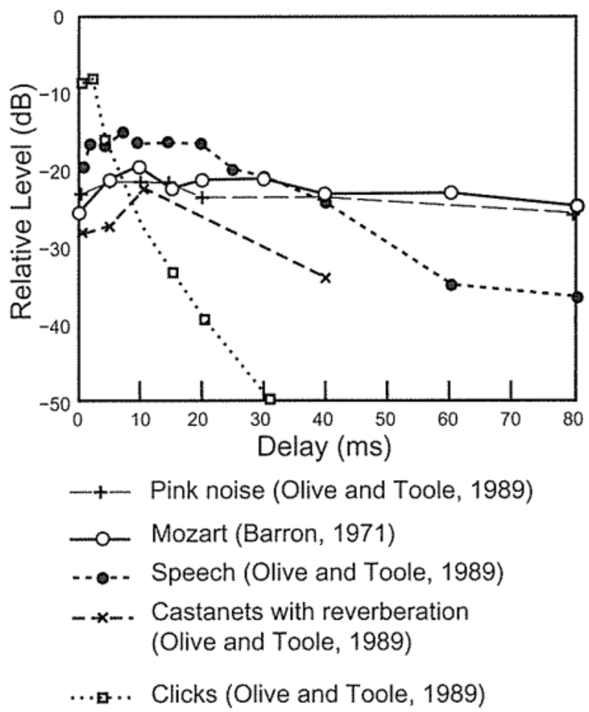

Figure 1 Reflection thresholds - Toole [6]

It is commonly considered that controlling reflections to 10 dB or more below the direct sound will prevent significant adverse effects. In a typical control room, the additional distance traveled by 2nd and 3rd order reflections often provides this degree of attenuation – even prior to the additional loss caused by surface treatment. The primary concern therefore has been first order reflections (within approximately 20 ms).

Common ‘reflection suppression criteria’ have been published by ITU [7], EBU [8] and AES [9] as part of guidance on the design of critical listening environments. EBU Tech 3276 [8] contains the following:

“Early reflections are defined as reflections from boundary surfaces or other surfaces in the room which reach the listening area within the first 15 ms after the arrival of the direct sound. The levels of these reflections should be at least 10 dB below the level of the direct sound for all frequencies in the range 1 kHz to 8 kHz.”

Following a study into the practical implication of reflection control environments for both stereo and multi-channel monitoring Walker [10] concluded that these represent “*a compromise, based on subsequent experience, between idealized requirements and what was reasonably achievable in practice.”*

A reflection control criteria however that does not consider the direction or number of reflections may be overly simplistic. As the most significant effects of early reflections relate to changes to the ‘imaging’ provided by the loudspeakers it is anticipated that a combination of quantity, direction and strength of reflections will influence the quality of the received sound.

The standard acoustic parameters Interaural Cross Correlation (IACC) and Early Lateral Energy Fraction (J_{LF}) [11] have been developed primarily in the context of large room acoustics but have also been shown to quantify to some extent the image change associated with side wall reflections in small rooms.

Listening tests and IACC measurements were undertaken by Kishinaga et al. [1] in a small listening room. IACC 0.26 was measured with reflecting side walls and IACC 0.44 with absorptive side walls. The reflective walls and lower IACC corresponded to a subjectively broad source width. With absorptive side walls and higher IACC the imaging was narrowed and this was preferred for critical listening. Similar results were noted in a recent study by Tervo et al. [12] looking at the preference of sound engineers with respect to standard acoustic parameters. This study showed that preference had a moderate negative correlation with J_{LF} at high frequencies (l kHz and 2 kHz octave bands) for mix engineers. Tervo et al. [12] also noted that in the future it would be desirable to visualize the sound field to identify the presence of strong early reflections and connect these more directly with the subjective comments from the engineers, particularly with respect to perceived stereo image.

3D IMPULSE RESPONSE MEASUREMENT SYSTEM

Control rooms are typically evaluated using omnidirectional impulse response measurements, providing information about reflections in terms of level and time, but not direction.

A 3-D impulse response measurement system was utilized in this study, which allows directional information to be included in the analysis. The measurements were undertaken using the 'IRIS' system developed by Marshall Day Acoustics [13]. This system utilizes a compact B-format microphone array (Fig. 2) which is capable of resolving the direction of incoming sound at the measurement position using a sound intensity technique.

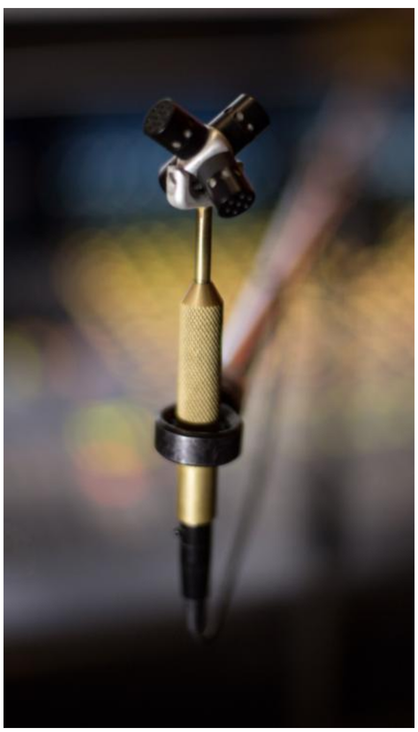

Fig. 2 B-format microphone

The IRIS system visualizes the resulting 3-D impulse response data as a 2-D or 3-D 'IRIS plot', in a similar style to Thiele's 'Igel' [14][15]. An example is shown in Fig. 3. First, the impulse response signals are divided into a series of short time windows, the intention being that each window encapsulates an important sound event, such as a reflection. The level and direction for each window is then calculated, resulting in a series of sound intensity vectors. Each vector is plotted as a line on a 3D Cartesian diagram, where the length of the line corresponds to level and its direction is the calculated direction of incoming sound. The vectors are colored according to when they arrive.

For the purposes of studio measurements, a time window of 1 ms was used, and the vectors were colored according to the following time intervals:

0 – 2 ms	Red
2 – 15 ms	Orange
15 – 50 ms	Green
>50 ms	Blue

The specific arrival time and data for a line may be determined from inspection of the pressure impulse response waveform. It is important to note that a single line represents the average sound intensity over the respective 1 ms time window. While it is tempting to view each line as an individual reflection, in many cases a time window will encapsulate more than one reflection, and the resulting line will indicate the average level and direction for all the included reflections.

The windowing process limits the lowest frequencies which may be included in the Iris plot, and a compromise must be found. A 1 ms period effectively constrains the directional analysis to 1 kHz and above. This is considered the best compromise for rooms of this size providing good time resolution for frequencies critical to spatial imaging.

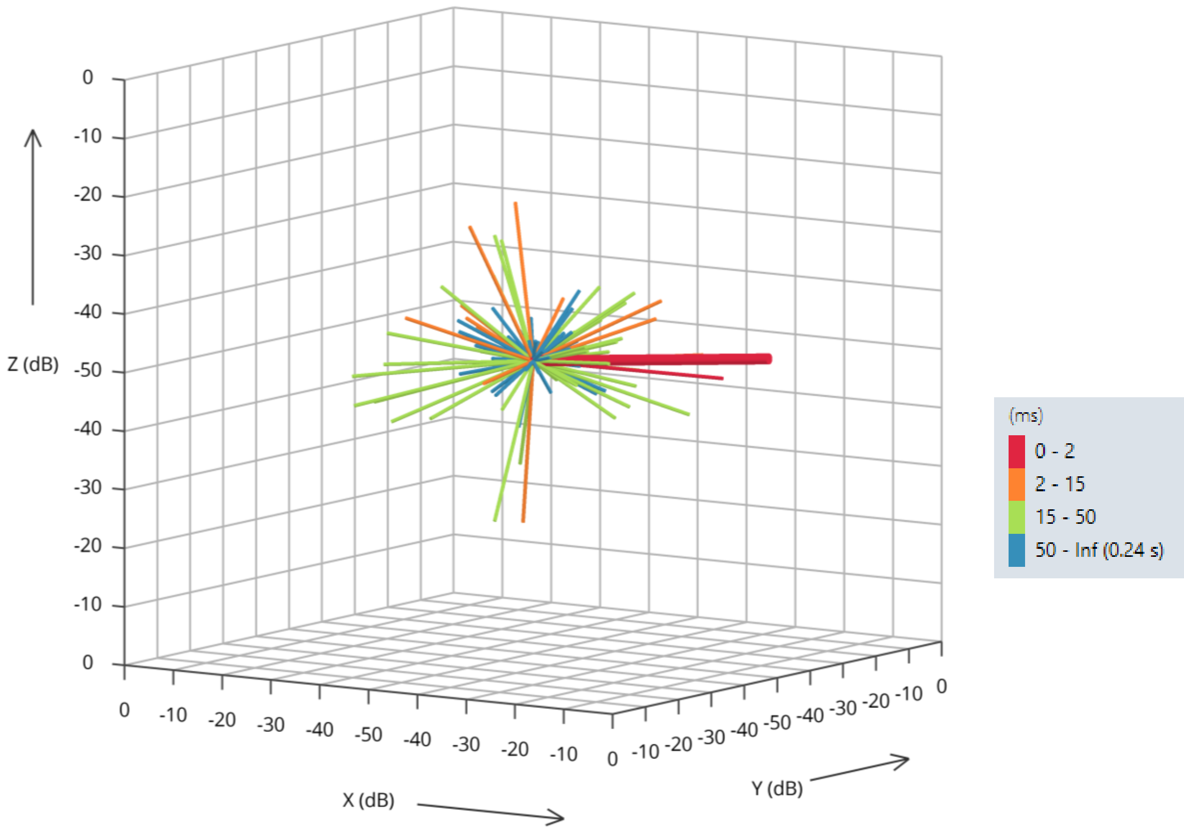

Fig. 3 Example Iris plot

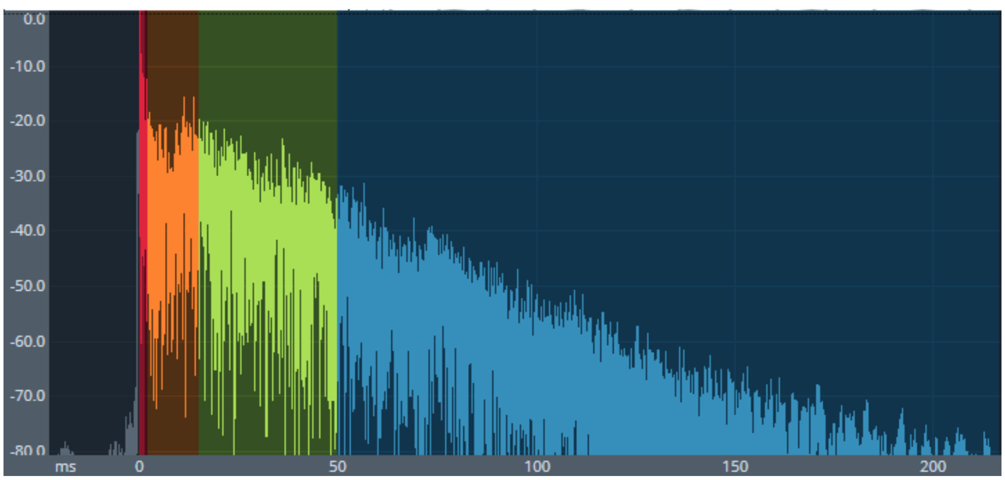

Fig. 4 Omnidirectional impulse response corresponding to Iris plot

There are two main functions that can be utilized with the Iris plot. Firstly, the system can assist with the identification and quantification of specific reflections. Significant reflections can be identified and the cause of the reflections related to features in the room. The magnitude of the most significant reflections can also be compared to recognised criteria to confirm whether or not a suitably 'reflection free' environment has been achieved. This is similar to what can be achieved with an omnidirectional impulse response but with direction information to assist any problem solving.

Second, the plots can provide an overall 'snapshot' of the sound field within the room. This can show, for example, where the early and late energy is coming from, and how this distribution changes over time.

With many modern control rooms adopting similar design philosophies and achieving similar objective criteria with regard to reflection control it may be expected that the effective sound field would be similar. However in recent 3D auralisations of control rooms by Tervo et al. [9] the most common attribute contributing to preference between rooms was the 'width, accuracy or stability of the stereo image' with 'localization' also being common preference.

It is often considered important that a mix is able to 'translate' between rooms and it is desirable for rooms that share material to also share common characteristics. It is anticipated that visual analysis of a number of rooms could be used to identify common patterns in the acoustics of rooms that share audible characteristics.

3. MEASURED ROOMS

Six control rooms were measured as part of this study. All rooms were working studios and are well liked by operators. The rooms range in size from a large film mixing studio to a small broadcast control room. In each case measurements were undertaken using one of the front (L-R) speakers as the source. The microphone was located in the mix position at a height of 1.2 m. The general acoustic parameters [11] for the rooms tested are tabled below. The results are from a single measurement position only and relate to the Iris plots shown in Fig. 5.

Line drawings of rooms are provided in Fig. 5 overleaf showing the main speaker locations and the measurement position. Overlaid over these drawings is the Iris plot in the X-Y plane. All rooms are shown to the same scale and the Iris plot has been scaled so the strength of the direct sound is the same in each case.

Even when restricted to two dimensions, the visual representation of the sound field can provide much more information about the room than can be gained by the traditional parameters.

Table 1 General acoustic parameters measured in the control rooms

		T_{30} (s)			C_{50} (dB)			Ts (ms)			J_{LF}		
Rm	Room Use	1kHz	2kHz	4kHz	1kHz	2kHz	4kHz	1kHz	2kHz	4kHz	1kHz	2kHz	4kHz
1	Film	0.15	0.16	0.17	20	20	20	5	6	6	0.12	0.14	0.13
2	Film/TV	0.36	0.32	0.34	15.1	15.1	12.8	6	6	9	0.06	0.08	0.1
3	Music - classical	0.21	0.22	0.22	16.9	20	20	9	5	5	0.14	0.09	0.09
4	Music - pop	0.16	0.17	0.18	16.9	16.9	16.9	11	11	9	0.21	0.22	0.17
5	Music - pop	0.22	0.24	0.24	16.9	13.8	12.8	9	11	14	0.09	0.13	0.19
6	Radio	0.1	0.1	0.1	31.9	31.5	29.6	6	5	7	0.07	0.11	0.18

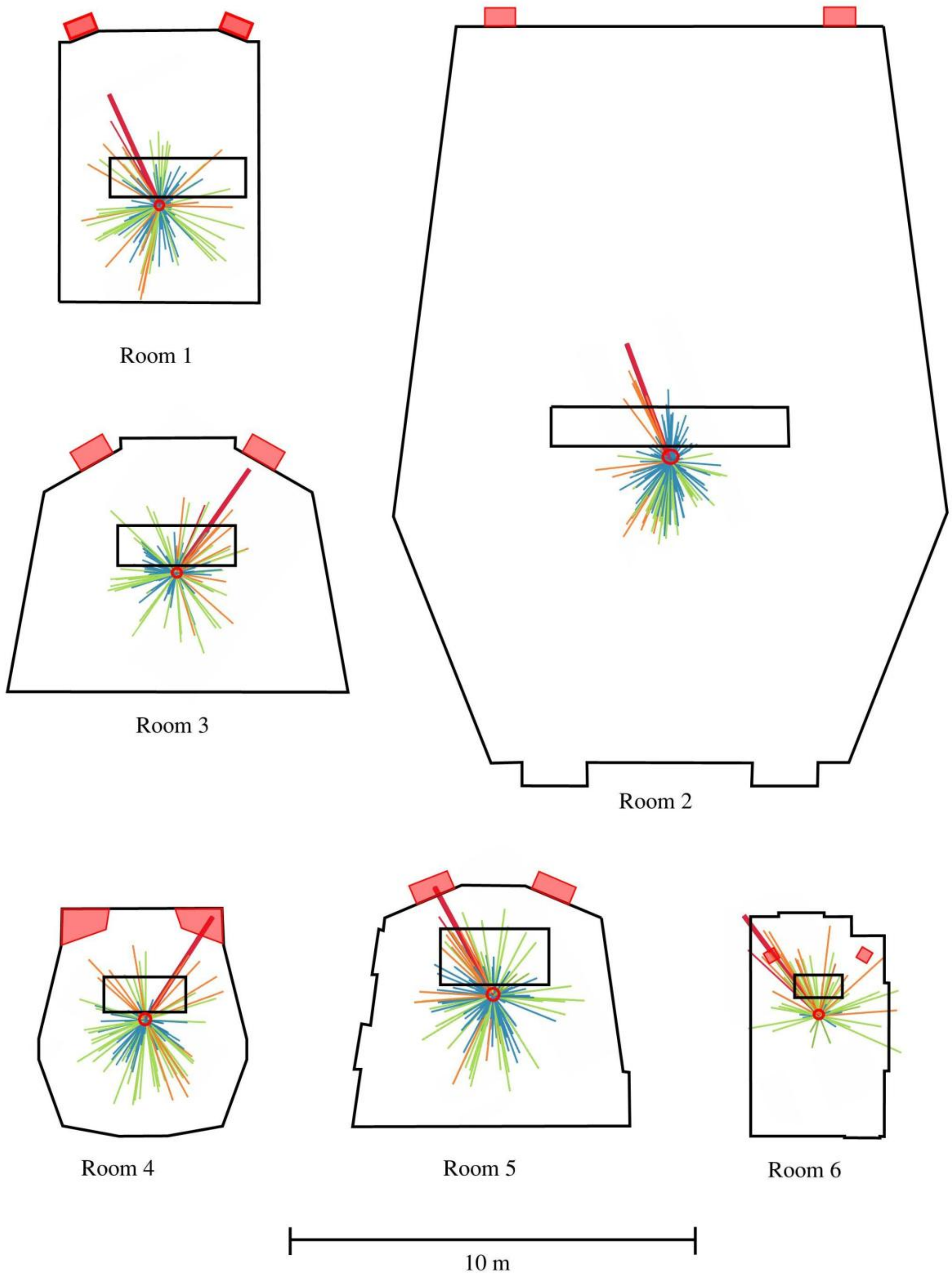

Fig. 5 Room layouts and Iris Plots

4. ANALYSIS

4.1. General distribution of rays

The average magnitude of lines or 'rays' in Room 2 are significantly lower than the other rooms. Room 2 is considerably larger than the other rooms and it can be assumed that the lower magnitude is due to additional distance attenuation. There is a more significant proportion of later energy (blue rays) as would be expected from the longer reverberation time in the larger room. It can also be seen that most of the reflected energy in Room 2 comes from the rear of the room. Although the rear wall surfaces in Room 2 are primarily absorptive there is a large amount of furniture in this part of the room including wooden desks and leather couches.

Room 6 shows a very different plot, with most of the rays from the front of the room. Absorptive surfaces at the rear of the room and a short reverberation time mean that there is very little energy from behind the mix position. Rooms 1, 3, 4 and 5 show a more even or 'diffuse' distribution of reflections although Room 1 and Room 4 appear to have a slightly higher proportion of rays arriving from the rear of the room.

4.2. Vertical distribution

All of the control rooms tested have absorptive ceiling treatment. Most have some reflective floor area around the mix position with the remainder of the room carpeted. This is reflected in the Iris plots with fewer rays from above and more energy from below. An example from Room 3 is shown in Fig. 6 below

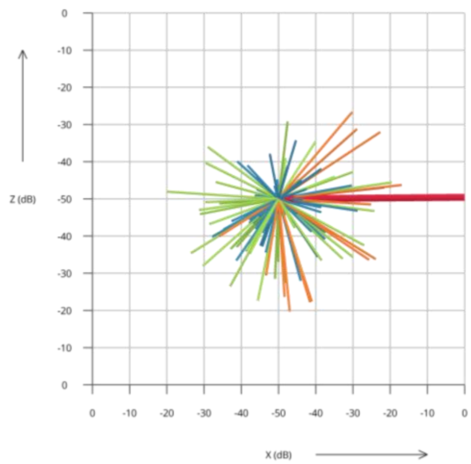

Fig. 6 Vertical Rays

4.3. More detailed analysis

4.3.1. Identification of large single reflections

All of the rooms tested have been acoustically designed to avoid large problematic reflections. To simulate the situation of an untreated wall or piece of furniture sending a strong reflection to the mix position a 1m x 1.5 m sheet of plywood was used. A measurement was undertaken in Room 2 with and without the plywood in place. As shown in Fig. 7 and 8 below, the reflection from the plywood appears on the Iris plot as a group of strong green rays pointing in the direction of the plywood.

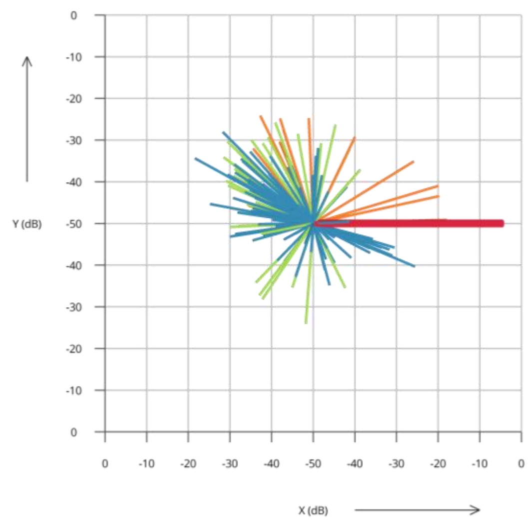

Fig. 7 Room 2 – no plywood

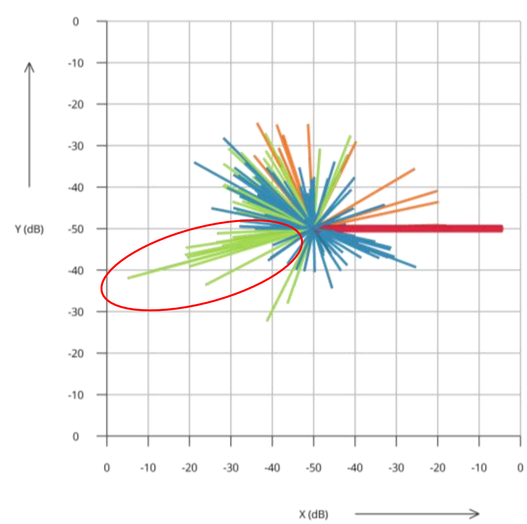

Fig. 8 Room 2 - with plywood reflector

4.3.2. Desk and Monitor reflections

Most of the plots in Figure 4 show a group of additional rays in a similar to the direction of the direct with a small time delay (red – orange). These are most marked in Room 6 where there are a number of rays within 5 – 10 dB of the direct. All of the rooms had a mixing desk in front of the measurement position. In Rooms 4, 5 and 6 near field monitors were positioned on the bridge of the desk. As would be expected, the most significant collections of rays are for rooms with the largest desks and the most equipment at the front of the room.

Room 3 has a relatively narrow modern mixing desk. The near field monitors in Room 3 are on motorized stands so they can be moved out of the way of the main monitors when not required.

The Iris plot of Room 3 with the near field speakers lowered is shown below in Fig. 9. The rays from the mix desk are approximately 20 dB below the direct.

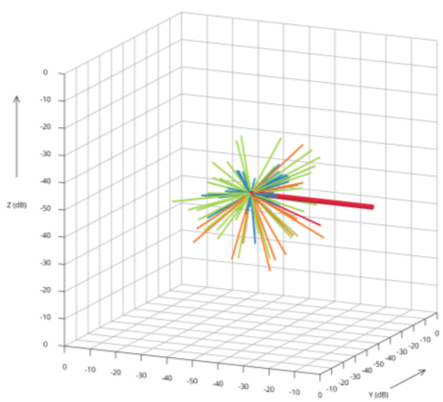

Fig. 9 Room 2 – near field monitors down

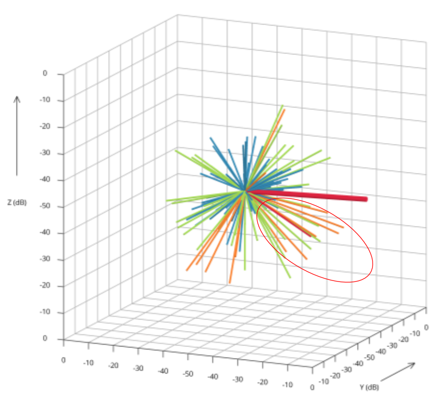

Fig. 10 Room 2 – near field monitors obscuring main monitors

With the near field speakers raised the direct path from main speakers is slightly obscured. This effectively increases the relative strength of reflections and increases the number of reflections from scattering of sound around the near field monitors. The reflections from near the desk are now in the order of 10 dB below the direct as shown in Figure 10.

A similar series of tests were undertaken in Room 5. A strong desk refection was identified when a set of near field monitors were used. An absorptive cushion was placed on the desk at the reflection point and this provided a 7 dB drop in level of the reflection (and a minor change in direction).

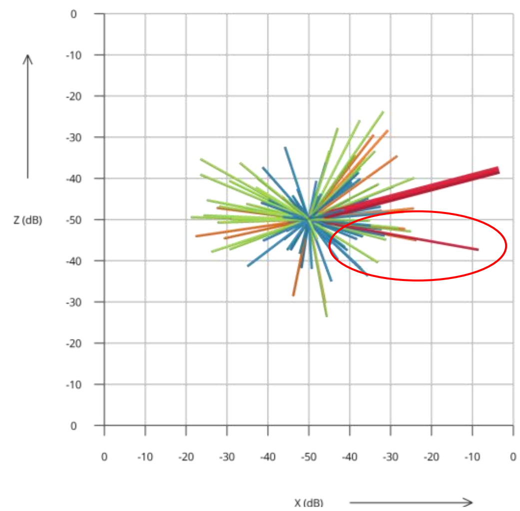

Fig. 11 Room 5 – near field monitors - strong desk reflection

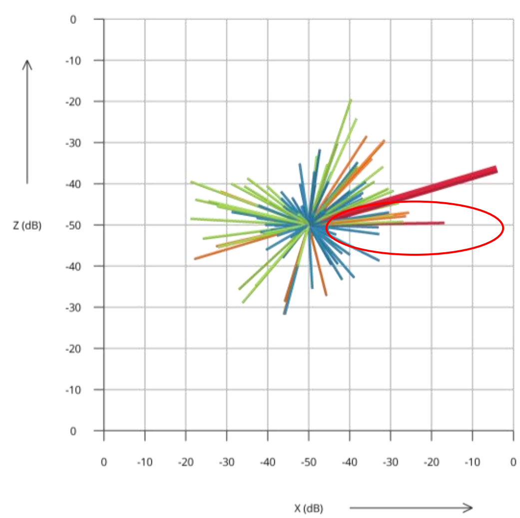

Fig. 12 Room 5 – near field monitors - desk reflection attenuated by absorption

4.4. Comparison with standard acoustic parameters

4.4.1. Reverberation Time

When comparing the Iris plots with reverberation time it is possible to see a correlation between the proportion of late energy (blue rays) and the reverberation time. Rooms 1, 3, 4 and 5 have similar reverberation times (0.15 – 0.25 s) and similar proportions of green and blue rays. Room 2 has a higher proportion of blue rays and correspondingly a longer reverberation time. Room 6 has minimal blue rays and a very short reverberation time.

However this is a relatively blunt tool for analyzing sound decay rates and it is not anticipated that such visualizations would replace standard reverberation time measures. The visualization of high frequency sound is seen as complementary to full frequency reverberation time measurement rather than a replacement.

4.4.2. Clarity Measures

Rooms 3 and 5 are a similar size with a similar reverberation time. A lower C_{50} is shown for Room 5 and this corresponds with the reflected rays in this room being larger relative to the direct with a greater number of blue rays. A very high C_{50} (approximately 30 dB) was measured in Room 6. This would be expected as there are very few late (blue) rays shown and therefore almost all of the energy arrives within the first 50 ms. Despite its larger size and longer reverberation time the C_{50} for Room 2 was comparable with the smaller rooms. Although there is a significant proportion of blue rays in this plot these are relatively small in comparison with the direct sound.

Generally the measured C_{50} values seem to correlate well with what is displayed on the Iris plots. However, how C_{50} relates to 'clarity' in a control room setting requires further investigation. The C_{50} is based primarily on the positive effects on the clarity of speech when early reflections are integrated with the direct sound. On the understanding that some early reflections are unwanted in a control room environment it may be appropriate to also look at alternative parameters with a very short initial time window such as 2 ms. For example, C_2.

Alternatively, centre time (T_s) may become a useful measure in control rooms. For rooms of similar reverberation time a shorter centre time would indicate fewer early reflections. In the measured rooms there is some variation in the centre time from 5 ms to 14 ms, with the larger values in the rooms with a greater number of early reflections.

4.4.3. Lateral Energy Fraction

The range of early lateral energy fraction (J_{LF}) values are comparable across the different sized rooms. The Iris plot for Room 2 shows very limited lateral energy and as would be expected this corresponds to a low lateral fraction of approximately 0.08.

Room 6 also has a low J_{LF} (0.1). In this case however a good proportion of the reflected energy is 'lateral' and the low fraction appears to be a result of sparse reflection density rather than the direction of the reflections. Whilst this may still provide some indication that the room has a general lack of interference from lateral reflections, using the J_{LF} to quantify this could be misleading.

Rooms 1, 3 and 5 show similar values overall but different variations with frequency. Room 4 has noticeably higher J_{LF} values than these rooms and this can be attributed to the larger number of significant side reflections shown in the Iris plot.

The value of using a lateral energy parameter in a control room environment requires further consideration. The figure-of-eight microphone pattern may still be helpful when assessing the presence of lateral energy but as with clarity it is anticipated that shorter integration periods would be more relevant for control rooms.

4.4.4. Future Parameters

The use of modern microphone arrays and digital processing enable enables the sound field to be assessed using an infinite array of virtual patterns. It is anticipated that new parameters could be developed, utilizing time and direction variables, that can more effectively quantify different control room characteristics.

These parameters would be able to be post-processed on the existing B-format impulse response measurements, such as the ones analyzed in this paper.

5. CONCLUSION

Measurements were undertaken in a variety of control rooms with 3D impulse response measurements. The system proved very successful in identifying the source of individual reflections as well as providing a visual overview of the high frequency sound field.

The comparison of the 3D plots with traditional acoustic parameters indicated that in addition to reverberation time new parameters are needed to describe the spatial and temporal characteristics of the reflections in small rooms. Imaging is a primary concern and therefore directional information will play an important part in the development of these new parameters.

6. FUTURE WORK

Further subjective testing is proposed.

Subjective evaluation of control room environments in combination with 3D impulse measurements has exciting possibilities for further understanding the control room environment.

7. ACKNOWLEDGEMENTS

The authors would like to thank the studio owners and operators for assisting us with the measurements.

8. REFERENCES

[1] Kishinaga, S. Shimizu, Y., Ando, S and Yamaguchi, K. "On the Room Acoustic Design of Listening Rooms", 64th Convention, *Audio Eng. Soc.*, Preprint 6594. 1979.

[2] Davies, D. and Davies, C. "The LEDE concept for the control of acoustic and psychoacoustic parameters in recording control rooms". *J. Audio Eng. Soc.* 28, 9, pp. 585/595. 1980.

[3] D'Antonio, P and Konnert, J H. "The RFZ/RPG approach to control room monitoring". 76th Convention, *Audio Eng. Soc.*, Preprint 2157. 1984.

[4] Walker, R. "A new approach to control room monitoring". 94th Convention, *Audio Eng. Soc.*, 1993

[5] Angus, J A. "Controlling Early Reflections Using Diffusion", 102nd Convention, *Audio Eng. Soc.*, Preprint 4405. 1997.

[6] Toole, F E. *Sound Reproduction – Loudspeakers in Rooms*. Published by Elsevier Ltd. 2008.

[7] ITU. Recommendation ITU-R BS.1116-1 *Methods for the Subjective Assessment of Small Impairments in Audio Systems including Multi-channel Sound Systems*. 1994-1997

[8] EBU Tech. 3276 – 2nd edition May 1998 *Listening conditions for the assessment of sound programme material:monophonic and two–channel stereophonic*

[9] AES Technical Council Document AESTD1001.1.01-10 *Multichannel surround sound systems and operations.*

[10] Walker, R. "Room Acoustics for Multi-channel Listening : Early Reflection Control". *Audio Eng. Soc.* 22nd Uk Conference, 2007

[11] International Standard Organization, ISO 3382-1:2009, Measurement of Room Acoustic Parameters – Part 1 : Performance Spaces (2009).

[12] Tervo, S. Laukkanen, P. Jukka, P and Lokki, T. "Preferences of Critical Listening Environments Among Sound Engineers". J. *Audio Eng. Soc*., Vol 62, No.5, 2014.

[13] Iris.co.nz

[14] R. Thiele, "Richtungsverteilung und Zeitfolge der Schallrückwürfe in Räumen", *Acustica* 3, 291-302 (1953)

[15] E. Meyer and R. Thiele, "Raumakustische untersuchungen in zahlreichen konzertsälen und rundfunkstudios unter anwendung neuerer messverfahren," *Acustica* 6, 425-444 (1956).