# Room Acoustics Investigations in Hamer Hall at the Arts Centre, Melbourne

**Timothy E. Gulsrud (1), Peter Exton (2), Arthur van der Harten (3), and Larry Kirkegaard (3)**

(1) Kirkegaard Associates, Boulder, Colorado USA (2) Marshall Day Acoustics, Melbourne, Australia
(3) Kirkegaard Associates, Chicago, Illinois USA

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## ABSTRACT

This 2,380 seat performance venue within Melbourne's Arts Centre is scheduled for upgrades to its interiors and acoustics as part of the Southbank Cultural Precinct Redevelopment. Kirkegaard Associates and Marshall Day Acoustics have made collaborative room acoustics investigations in the hall to advice on the acoustic improvements. This paper outlines the listening and measurement investigations in the hall and reports some of the significant results found during the investigations. Comparisons between measurements made with a small directional loudspeaker supplemented with a subwoofer to a standard dodecahedral loudspeaker are presented. Occupied reverberation times measured in the hall, which to our knowledge have not been previously published, are also presented. Variation of measured Early Decay Time is described. The reflected sound from side wall diffusion elements has been analysed and is discussed with reference to boundary element method (BEM) model results.

## INTRODUCTION

Hamer Hall is a 2,380 seat performance venue within Melbourne's Arts Centre. The hall opened in 1982 and the original acoustic design was by Bolt Beranek and Newman [1]. The hall was in fact part of a trio of halls designed by BBN around the same time period: Hamer Hall in Melbourne, Davies Symphony Hall in San Francisco, and Roy Thompson Hall in Toronto. The latter two halls have undergone acoustic renovations, and now Hamer Hall is also scheduled for acoustic improvements as part of the Southbank Cultural Precinct Redevelopment [2].

In 2009 Kirkegaard Associates and Marshall Day Acoustics were commissioned to advice on the acoustic design of the redevelopment, and we have made joint room acoustic investigations in the hall. A series of measurements were made in Hamer Hall to benchmark the existing conditions and provide calibration of computer models incorporating proposed modifications.

The hall has an interior volume of approximately 27,000m$^3$ and seating spread across three levels: Stalls, Circle, and Balcony. The width of the room at the Stalls level is approximately 35m and the room has deep balcony overhangs at the Stalls and Circle seating levels. An adjustable absorption system varies the reverberation time in the hall. Plans and sections of the hall are published in [1], and photographs of the hall interior are shown in Figures 1 and 2.

Our preliminary investigations and discussions with musicians and Arts Centre staff revealed that poor stage communication, weak and un-enveloping sound especially at the Stalls and Circle level, variation in sound quality at different seats, and harshness at high dynamic levels are the principal room acoustics problems in the hall. Accordingly, our investigations were centred on these issues.

In this paper we outline some unique methods employed for the investigations made in the hall, and report on key findings, including values for occupied reverberation times in the hall which to our knowledge have not been previously reported. The design solutions for the issues outlined above are not presented in this paper since the design for the redevelopment project is currently in process.

(source: Author, 2009)

**Figure 1**. Interior photograph of Hamer Hall viewed from the stage.

(source: Author, 2009)

**Figure 2**. Interior photograph of Hamer Hall viewed from the Circle level seating.

## ROOM ACOUSTICS INVESTIGATIONS

### Measurement sound sources

Because of concerns about the limited frequency range and strong lobing of dodecahedral loudspeakers above 1kHz [3, 4], we experimented with a small, moderately directional loudspeaker (Meyer Sound MM-4XP) to study directional impulse responses in the hall. The MM-4XP loudspeaker has an operating frequency range between 120Hz and 18kHz, and an 80 degree conical dispersion pattern between 3kHz and 14kHz [5]. These acoustical characteristics, along with its small size, make it a useful loudspeaker for investigating spatial qualities of a room, since it can easily be aimed in different directions to highlight particular sound reflection paths. For some of the measurements the MM-4XP was supplemented with a Meyer Sound UMS-1P subwoofer in order to extend its low frequency response.

The acoustic investigations in Hamer Hall provided an opportunity to make measurements with both the MM-4XP and a dodecahedral loudspeaker (B&K 4292) in order to compare the two loudspeaker systems. Figure 2 shows a photograph of the two loudspeaker systems placed side-by-side on the Hamer Hall stage during a measurement session.

Figure 4 shows results of reverberation time (T20) measurements made using both loudspeaker systems at various times. The results at middle frequencies are very consistent between the two loudspeakers, and the MM-4XP + subwoofer system allows extension of the measurement frequency range to the 63Hz and 8kHz octave bands. The relatively small variations between different dates can be attributed to slightly different stage configurations and different source and receiver positions used during the different measurement sessions. Each curve is a room average of at least 8 positions and was made using either Dirac or EASERA measurement software.

Note the high degree of correlation between the dodec and MM-4XP + subwoofer curves (red and blue lines in Figure 4). These measurements were made at the same time with all other parts of the measurement system held constant (i.e., acquisition software, microphones, measurement positions, etc.) A small audio mixer was used to route the measurement output signal (logarithmic swept sine) alternatively to either loudspeaker system.

(source: Author, 2009)

**Figure 3.** Photograph of Meyer Sound MM-4XP with UMS-1P subwoofer next to a B&K 4292 Omnidirectional sound source.

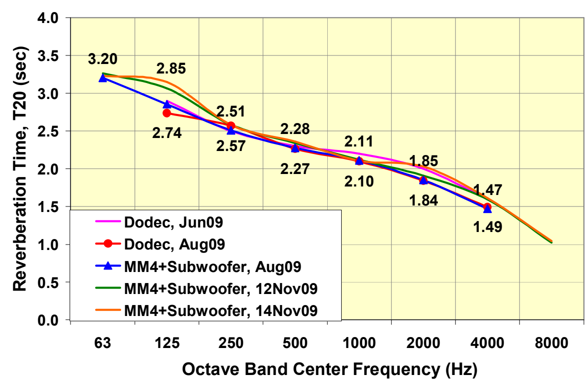


**Figure 4**. Comparison of average unoccupied reverberation time values (T20) measured on different dates and with difference sound sources. The upper figures correspond to the blue "MM4+Subwoofer, Aug09" curve and the lower figures to the red "Dodec, Aug09" curve.

From this we conclude that the MM-4XP loudspeaker system can be used to measure reverberation times that are equivalent to those measured using a standard dodecahedral loudspeaker. Other room acoustics parameters, however, were not found to be equivalent because of the directivity differences between the two loudspeaker systems.

### Occupied reverberation time measurements

Since a seated audience is known to have an important influence on room acoustics, and because relatively little data for occupied halls has been published, we made room acoustics measurements during 3 performances in November 2009.

Occupied room acoustics measurements are often avoided because typical measurement procedures require the (quiet!) cooperation of an audience, and they can intrude on the concert experience for some patrons. In order to minimise these concerns, we developed a strategy to allow the measurement procedure to be as efficient as possible.

8 omnidirectional microphones were placed in seating locations distributed around the hall, and 4 microphones placed on the stage near musicians, for a total of 12 receiver positions. Multichannel measurement software EASERA was used in conjunction with an RME Fireface 400 computer interface in order to measure impulse responses simultaneously at each microphone position. 2 different source positions were used, typically a MM-4XP placed downstage near a concertmaster position and a second MM-4XP with subwoofer placed farther upstage near woodwinds or percussion.

After the orchestra was seated, but before the conductor entered the platform, an announcer described the acoustic tests that were about to occur, and a sample test signal (logarithmic sine sweep) was played for the audience. After this, the audience was asked to remain silent for two sets of 3 sweeps separated by a pause. The first set of sweeps was sent to the first source position, and the next set sent to the second source position. Each set of sweeps was averaged in EASERA, resulting in a set of 24 impulse responses for the occupied condition of the hall. The entire measurement process (not including the introduction speech) took less than 30 seconds, and was viewed sympathetically by most audience members.

The reverberation times measured during two different orchestral concerts are shown in Figures 5 and 6. These values are averages of the 24 source-receiver combinations described above. The values at 63Hz are based only on the source position with a subwoofer. The measurement procedure was rehearsed in the empty hall immediately prior to the concert, resulting in a set of corresponding unoccupied data, which is plotted for comparison. The only difference between the two data sets, therefore, is the presence of people in audience seats and the orchestra members on the platform.

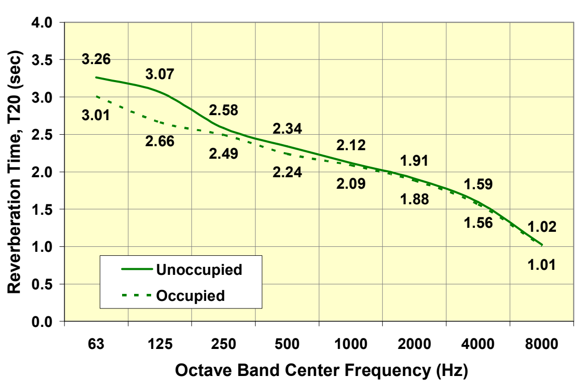


**Figure 5**. Average occupied reverberation times (T20) measured during 12 Nov 09 Melbourne Symphony Orchestra concert.

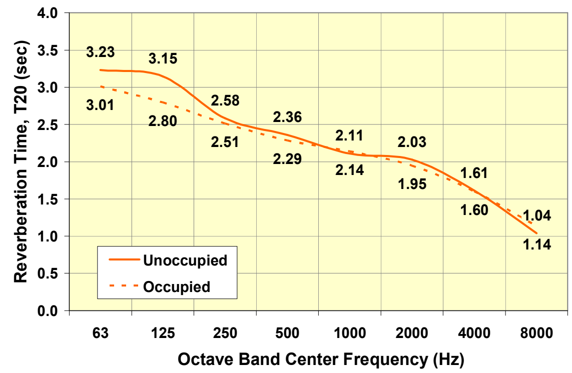


**Figure 6.** Average occupied reverberation times (T20) measured during 14 Nov 09 Melbourne Symphony Orchestra concert.

Despite the lack of capacity audience, the very small difference in reverberation times between the unoccupied and occupied conditions was surprising. Since the ceiling is very high, much of the reverberant sound energy develops in the upper volume of the room, which could explain the relatively small influence of audience on reverberation times. Another possibility is the chair construction, which we suspect is highly sound absorbing because of thick seat cushions. A highly absorbent seat would tend to saturate the total absorption along the seating plane, minimising the influence of the audience itself.

### Spatial variation

During listening investigations it was noted that the sound clarity, strength, and impression of reverberance varies substantially throughout the room, especially underneath the balcony overhangs. To document and explore this phenomenon further we measured the spatial variation of standard acoustical parameters in different seating areas of the room.

Figures 7-9 show the spatial distribution of mid-frequency EDT values across the 3 different seating areas of the hall. The distribution of these values corresponds well with the subjective impression of varying reverberance throughout the hall, especially the very "frontal" and un-enveloping sound experienced under the balcony overhangs. While it is common practice to report room average values for EDT and other parameters [6], these results suggest that it can be misleading to do so. In this case, the wide variation of acoustic character, translating to different aural experiences for audience members seated in different areas, is one of the primary acoustic shortcomings of the room. Relying only on measurements of a room average acoustic parameter would not have revealed this important issue during our investigations.

EDT values reported in Figures 7-9 were measured with a dodecahedral loudspeaker in the unoccupied hall with the adjustable absorption system fully retracted. Values are averages of 500Hz and 1kHz octave bands.

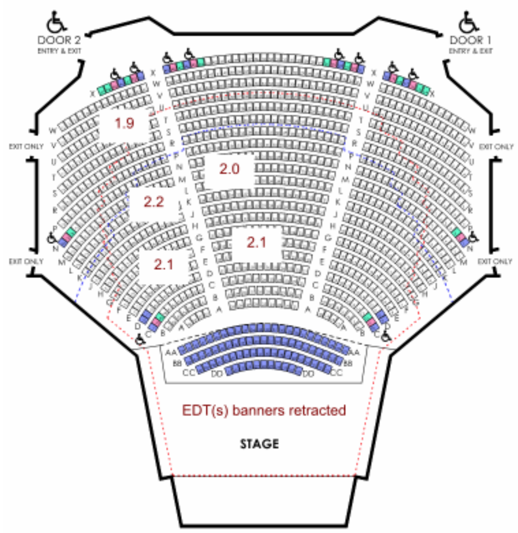


**Figure 7**. Distribution of EDT values at Stalls level.

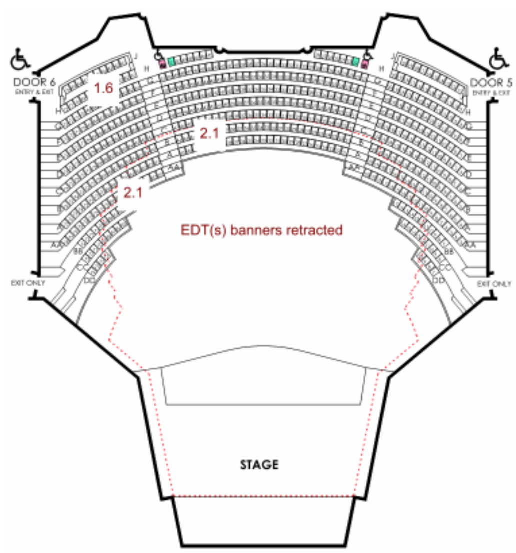


**Figure 8**. Distribution of EDT values at Circle level.

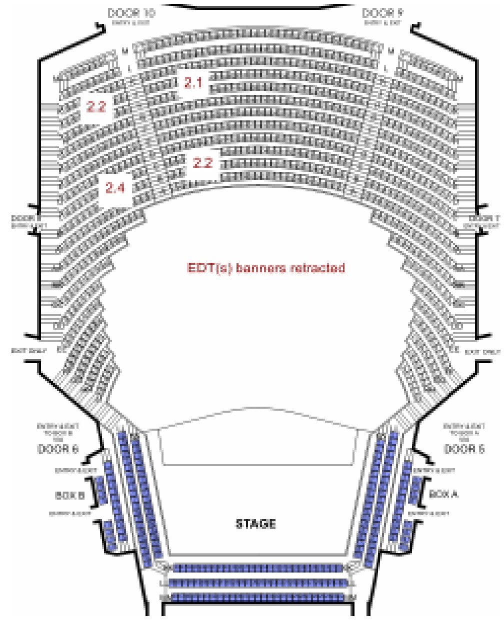


**Figure 9**. Distribution of EDT values at Balcony level.

### Sidewall and ceiling diffusion

As part of the original acoustic design of Hamer Hall precast concrete facets were fitted to the upper side walls to provide sound diffusion [1]. These are illustrated in Figure 10.

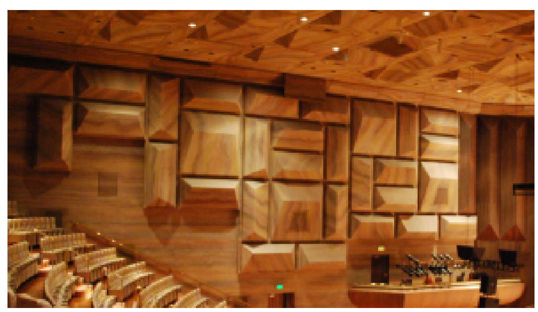

**Figure 10.** Facets fitted to the side walls at balcony level

The ceiling also has deeply faceted shaping constructed with precast concrete panels.

Listening to orchestral performances in the balcony, we observed harsh sound quality and unnatural apparent source directions at *fortissimo* dynamic levels. Since we could localise strong reflections from the upper sidewalls and ceiling, we suspected that the facets were contributing these undesirable qualities experienced in the balcony seating area.

To investigate this we used the MM-4XP placed on the stage aimed at the facets on one side of the auditorium. A parabolic microphone in the balcony seating was aimed at the upper side wall in a position to receive a strong lateral reflection. An omnidirectional microphone was mounted beside it as a reference. The recorded impulses were frequency filtered into octave bands and overlaid to reveal differences. The intent was to amplify the reflections coming from the facets with the parabolic dish, in order to highlight and identify these reflections in the omnidirectional microphone responses. Results are shown in Figures 11-12.

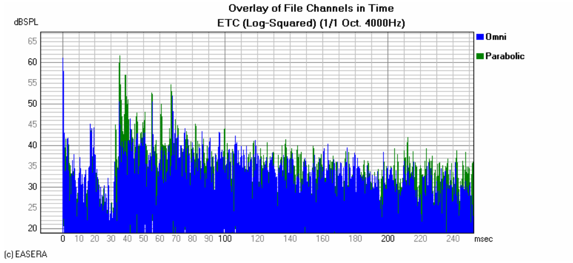


**Figure 11**. Parabolic and omnidirectional impulse responses filtered at 4kHz.

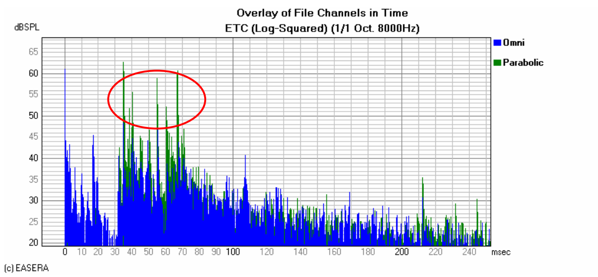


**Figure 12.** Parabolic and omnidirectional impulse responses filtered at 8kHz

The process was repeated after slightly rotating the parabolic microphone perpendicular to the side wall, and away from the expected specular reflection path. The corresponding impulses are shown in Figures 13-14.

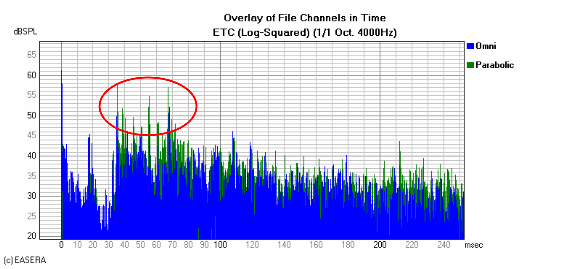


**Figure 13.** Parabolic and omnidirectional impulse responses filtered at 4kHz

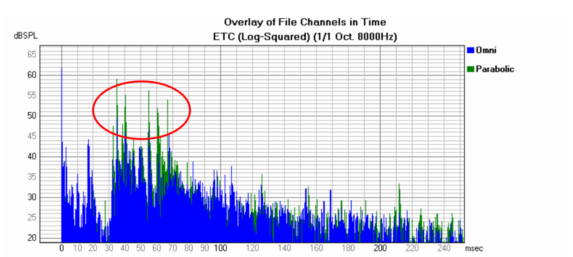


**Figure 14**. Parabolic and omnidirectional impulse responses filtered at 8kHz

Figures 11-14 show several peaks in the impulse response for this balcony seating position arriving from the side walls between 40 and 70ms after the arrival of the direct sound. We suggest that these high frequency features arriving from the side wall are due to scattering from several facet surfaces. The arrivals after 40ms must come from facets adjacent to the one with the shortest reflection path (i.e., the strong 40ms reflection in Figure 11) since they would have slightly longer travel times.

We have looked for support for this theory using boundary element method (BEM) calculations for the two dimensional case with the profile shown in Figure 15.

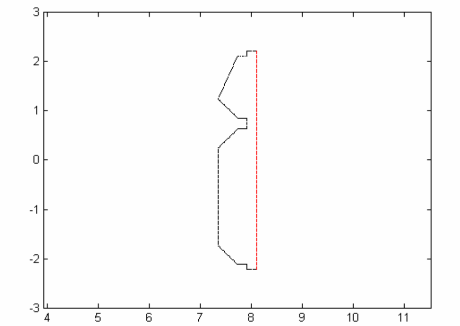

**Figure 15.** Profile of the facet used in the BEM reflection study. Dimensions in meters.

The software employed was the OpenBEM library for Matlab [7]. For information concerning benchmarking of the OpenBEM library, see reference [8]. The concrete facets were first modeled assuming an ideally reflecting boundary at the exposed side (black lines) and an ideally absorptive boundary at the rear (red lines).

Calculations were made at single frequencies across a 16m x 16m grid in order to visualise the spatial pattern of sound pressure reflected from the facets. Because of limited computational resources and time, a compromise between grid resolution, grid size, and maximum calculation frequency was made. The distributions of scattered sound pressure predicted at 2 kHz, 4 kHz and 8 kHz are shown in Figures 16-18. The images are plotted on a logarithmic colour scale and include only the scattered sound component (i.e., direct sound is not included). In each case the source is located at (-8, -16).

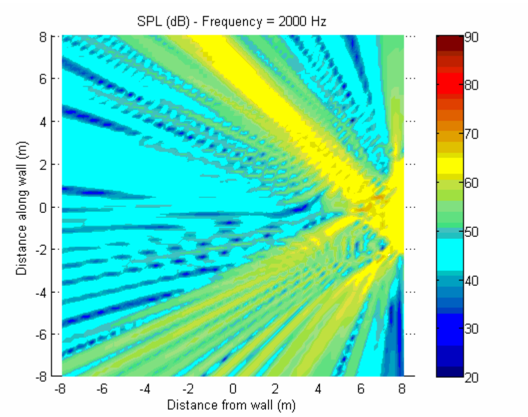


**Figure 16**. Calculated 2 kHz reflection pattern from facet profile.

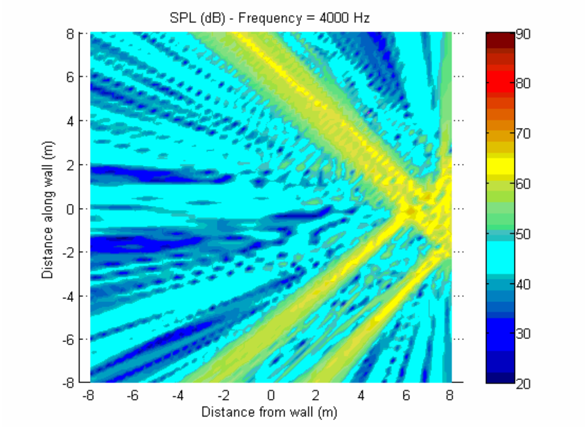


**Figure 17.** Calculated 4 kHz reflection pattern from facet profile

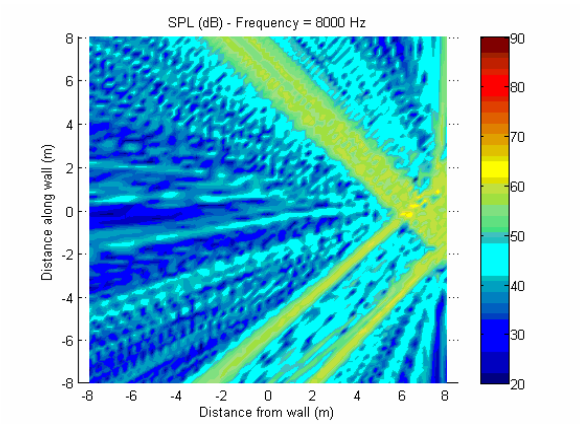


**Figure 18.** Calculated 8 kHz reflection pattern from facet profile

From these plots, we observe increasingly specular reflections from individual facets as the frequency increases. Interference fringing resulting from the diffraction from the facet profile is most strongly visible at 2 kHz (Figure 16). We note that the predicted patterns suggest that the concrete facets do not provide an ideally "diffuse" reflection, but instead scatter sound energy strongly in particular directions. We conclude that the measurements shown in Figures 11-14 include the superposition of these scattered reflections from many facets, resulting in the harsh sound quality observed in the balcony.

As a treatment option we have investigated applying frequency-limited absorptive material to various portions of the facet surface with the aim of reducing the intensity of the reflection peaks. The impedance of treated facets was chosen to resemble an absorptive, non-reactive treatment, such as fabric or felt adhesively applied to concrete.

The results at 2 kHz are shown as Figures 19-21. These figures should be compared to Figure 16 (i.e., the perfectly reflecting condition).

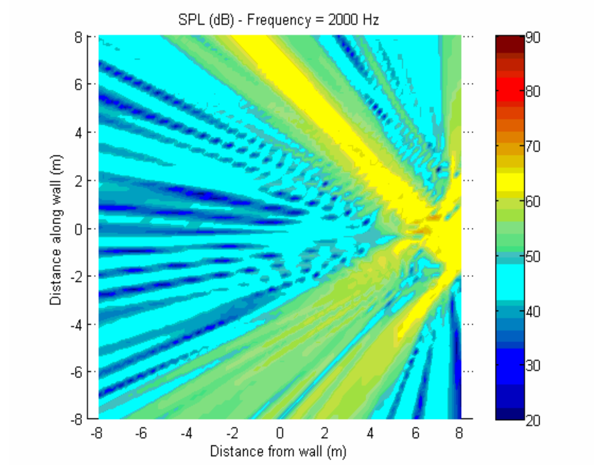


**Figure 19.** Calculated 2 kHz reflection pattern from facet profile with absorption applied to deep slots in between panel segments.

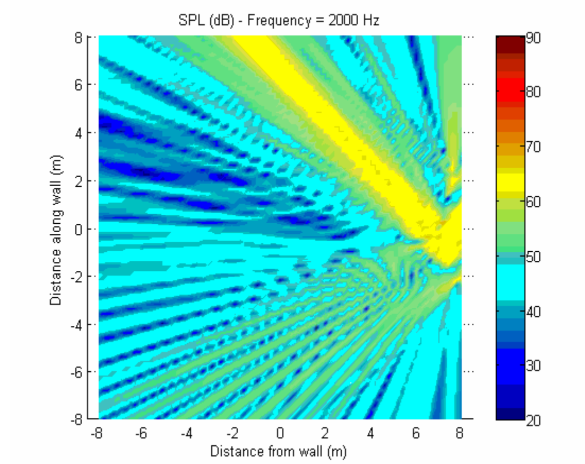


**Figure 20.** Calculated 2kHz reflection pattern from facet profile with absorption applied to downward facing facets.

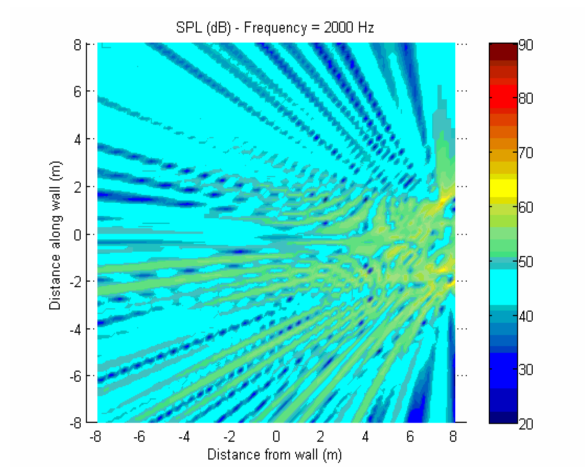


**Figure 21.** Calculated 2 kHz reflection pattern from facet profile with absorption applied to all facets except for a 100mm extent along either side of all exposed corners and edges, thereby indicating the scattered sound only from the exposed corners and edges.

The application of high frequency absorption to the facet surface significantly reduces the intensity of the reflected sound for treated panel facets.

## CONCLUSIONS

Collaborative room acoustics investigations have been made in Hamer Hall at The Arts Centre, Melbourne. We used a small loudspeaker for making directional high frequency measurements, and found that reverberation times measured with this sound source were compatible with those measured with a dodecahedral loudspeaker.

We made room acoustics measurements in the occupied hall and found very little change in reverberation times with audience and orchestra members in place. The occupied measurement procedure was described in detail in order to encourage further studies of occupied halls.

After noticing marked differences in sound quality at different seating positions during listening evaluation, we measured the spatial variation of acoustic parameters and found the variation of EDT to correlate very well with the listening experiences.

Finally, we measured high frequency reflections from the upper side wall facets and have described a mechanism for the tonal harshness caused by the facets. A treatment for the correction of the tone quality of the reflections has been proposed.

## ACKNOWLEDGEMENTS

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