SUITABILITY OF HI-FI SOUND SYSTEMS IN MEASUREMENTS OF REVERBERATION TIME IN DOMESTIC MULTI-MEDIA ROOMS.

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1 INTRODUCTION

Domestic multi-media rooms (e.g. home cinema rooms) are becoming a common and expected feature in affluent homes and for those of enthusiasts. Multi-media rooms are rooms dedicated to the reproduction of the combined audio and video experience. The scope encompasses dedicated home cinemas to gaming rooms. All have in common a large viewing screen (projector or TV) and a dedicated high fidelity (Hi-Fi) sound system including a set of directional high performance loudspeakers.

For the satisfactory performance of audio-visual system installed in these rooms and to provide the aural experience expected, the acoustics design of the space is critical. This design involves the determination of the reverberation time at several stages in the development.

In the home cinema industry concerned it is common the practice of using the installed sound system as the sound source in the measurement of the reverberation time of finished rooms[1] .The rationale for this, is that the listener position(s), are quite clearly defined, as are the loudspeaker sources.

However, this approach is not contemplated within the relevant international guidance given to measure reverberation time described in ISO 3382-2:2008[2] which requires exciting the room with a sound source that is as omnidirectional as possible.

When an acoustic treatment plan for a multi-media room is being calculated the acoustic materials will have been measured according to ISO 354:2003[3] which also requires exciting the room with a sound source that is as omnidirectional as possible.

The question arises as to whether using the existing Hi-Fi sound systems installed in domestic multimedia rooms can be a suitable and reliable sound source to determine the reverberation time in those spaces.

The worldwide professional body that represents the home cinema installers – Custom Electronics Design Integrators Association (CEDIA)– is currently developing a best practice guidance for design, measurement and subsequent assessment of the room's acoustic performance (document CEB22). The guidance will need to consider suitable and practical approaches to measuring RT using different sound sources.

The purpose of this study is to determine the suitability of employing Hi-Fi sound system loudspeakers as sound sources in measurements of reverberation time in typical home multimedia rooms.
It is hoped that the findings of this study will provide evidence and inform future and relevant guidance.

2 LITERTAURE REVIEW

It is generally accepted that the ideal source for measuring room reverberations times should be omnidirectional. The International standard ISO 3382-1[4] for performance spaces sets out a table for maximum acceptable deviations of directivity. For ISO 3382-2[2] for ordinary rooms this requirement only applies to the precision level of measurements. For engineering and survey levels that are no set parameters for the source directivity, though the standard states the source should be as omnidirectional as possible.

According to ISO 3382-2[2], domestic media rooms and home cinemas of less than 300m² fall under the "ordinary" room classification. For the intended purposes of those spaces, an engineering level of precision was adopted in this investigation.

Nikolaos et al[5] measured the reverberation time in 3 ordinary rooms using in turn cabinet loudspeakers and a dodecahedron. They found excellent agreement in the reverberation time measured with the different sound sources. However, they used the Hi-Fi loudspeaker to emulate a dodecahedron by orientating it in 12 directions and averaging the results together.

A study undertaken by Adrian James in 2000[6] compared the reverberation time measured in a large room employing a dodecahedron loudspeaker and a Tannoy single cabinet loudspeaker. Results from both sound sources showed a close agreement increasing with frequency

The dodecahedron loudspeaker is a specially designed speaker with twelve-sided polyhedron, each side containing a full-range speaker drive unit. This is the most used sound source for accurate acoustic measurements. Apart from lack of omnidirectionality a set of Hi-Fi loudspeakers have all the attributes of a dodecahedron, often with the advantage of higher power handling and lower bass extension. This makes them particularly suitable for Maximum Length Sequence (MLS) based impulse response. measurement which are known for their reliability, accuracy and ability to reproduce the same excitation signal time and again at a high level of Sound Pressure Level (SPL).

3 METHODOLOGY

Measurements of reverberation time were carried out following ISO 3382-2:2008 in a sample set of seven domestic rooms. The rooms selected were representative of a realistic range of domestic media rooms and home cinemas in the UK and their sizes fell under the ordinary room classification.

The Hi-Fi sound systems installed in those rooms and a dodecahedron loudspeaker were used in turn as the sound source in the measurement of reverberation time in each room.

The authors considered that engineering level as set out in ISO 3382-2:2008 was the appropriate level of accuracy for the purposes of this study. This engineering level requires a minimum of 6 source-microphone combinations. Three microphone locations and two source locations were chosen. In the case of the Hi-Fi speakers the left channel and right channel provided the two separate source locations.

To provide a satisfactory range of rooms the study used a residential property with a good variety of room sizes and layout, providing seven test rooms, all with existing Hi-Fi sound systems installed in them.

Attention was drawn to the fact that the Hi-Fi speakers were not in random positions in the room, but carefully place in a good position to work well sonically in the room for the typical listening position.
The positioning of loudspeakers was slightly different in each room, but all conformed to being paired, located near a single wall within 1m, at a height between 600mm - 1m from the floor
This loudspeaker positioning is representative of the home cinema rooms and listening rooms.

3.1 Rooms Description

Below is a photo for each room tested. Table 1 below provides the main characteristics for each room

Figure 1. Entrance Hall

Figure 2. Small Studio

Figure 3. TV Living Room

Figure 4. Kitchen

Figure 5. Projector Living

Figure 6. Cinema Room Empty

Figure 7. Cinema Room with Acoustic Panels

Room Name	*Vol m³*	*Schroeder f (Hz)*	*Description of room*
Entrance Hall	138	133	Closed room with vaulted ceiling
Small Studio	44	213	Closed room low flat ceiling
TV Living Room	136	141	Vaulted room, openings to lobby and kitchen
Kitchen	93	171	Vaulted room, open to TV Living Room
Projector Living	122	157	Vaulted room, open to a corridor
Cinema Empty	80	151	Closed room Concrete floor and ceiling Block walls
Cinema Acoustic Panes	80	123	as above with acoustic panels spread around walls

Table 1. Summary of main characteristics for each room tested

The measurement microphone positions were chosen to always include one position where a listener would be seated. This would always be a key location with a media room acoustics test.

Reverberation Time was determined using an evaluation range or 20 decibels (T20) as per ISO 3382-2:20082. Two T20 measurement methods were used as defined by the test signal used: gated pink noise and impulse response. For the gated pink noise signal seven runs of this signal were utilized per test position and results averaged. For the impulse response method only one three second chirp run was employed per test position.

The background noise and source sound level were measured in each room per octave, to ensure a 35dB minimum signal to noise ratio (SNR) was obtained at each octave band of interest during the course of the measurements.

Unlike the Hi-Fi sound systems installed in each room, it was noted the dodecahedron loudspeaker source could not deliver reliably the minimum 35dB SNR required at 63Hz in every room. Hence the frequency range of interest in this study was established in octave bands of centre frequencies between 125Hz and 4000Hz

The existing furnishing layout and Hi-Fi sound system in each room were all left in place as intended for regular use, and only the testing person was present at the time of reverberation time measurements.

For each room the volume and the Schroeder frequency were calculated. Approximately at this frequency and below is expected that the room is dominated by its modal behaviour. This means that around this frequency and below larger result variations in results can be expected according to the precise location of source and/or microphone.

In small and more furnished rooms the modal behaviour can extend higher in frequency, Floyd Toole[1] has found the original constant of 4000 that Schroeder published in 1954[7] to be closer to experimental results in small residential rooms. However, to comply by convention we have used the 1996 version[8] shown in equation 1, where Fs is the Schroeder frequency, RT is the reverberation time of the room in seconds and V is the volume of the room in m^3

$$Fs \cong 2000\sqrt{\frac{RT}{V}}$$

Equation 1. Schroeder (1996)

4 RESULTS

For the purposes of this study the dodecahedron loudspeaker was taken as the reference sound source and T20 values measured from this source are taken as reference values.

4.1 Comparative per room

The seven graphs below present the measured average T20 per room for the two sound sources.

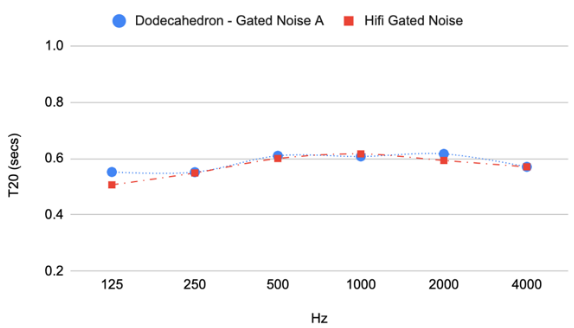

Figure 8. T20 for Entrance Hall

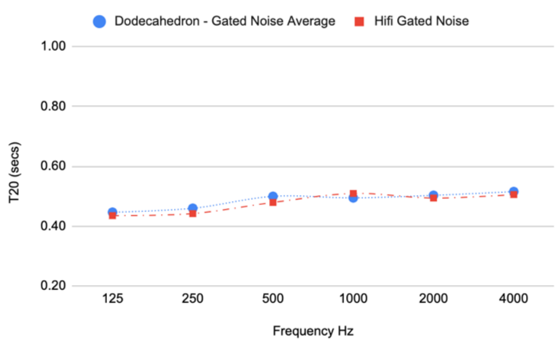

Figure 9. T20 for the Small Studio

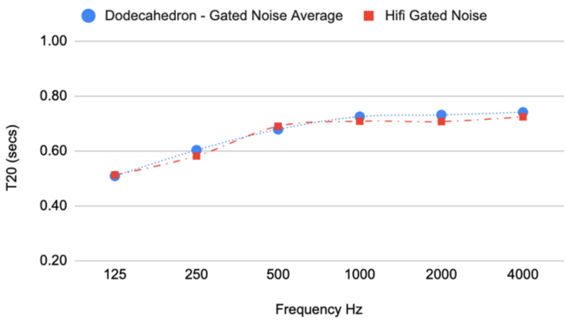

Figure 10. T20 for the TV Living Room

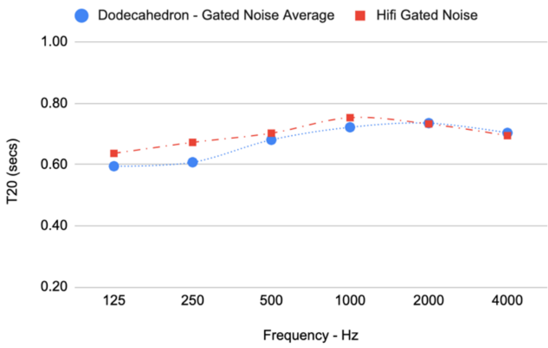

Figure 11. T20 for the Kitchen

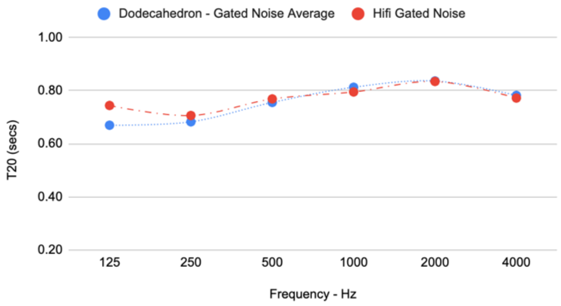

Figure 12. T20 for the Projector Living Room

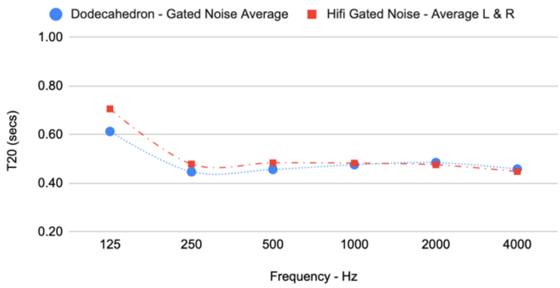

Figure 13. T20 for the Empty Cinema

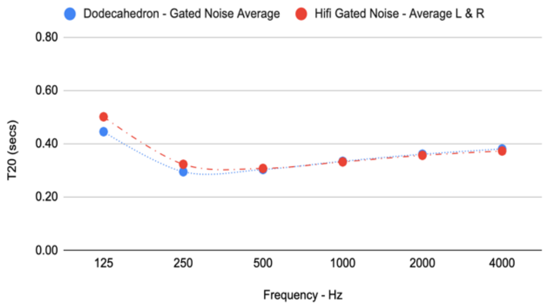

Figure 14. T20 for the Cinema with Acoustic Panels

4.2 Comparative using averaged results

Spatially averaged T20 values for each of the seven rooms tested were averaged for each type of loudspeaker (Hi-Fi and dodecahedron) and presented as a single value per octave band.

Discrepancy is defined here as the percentage difference between the T20 values for the two sound sources.

Fig. 15 shows the T20 discrepancy per octave band relative to the reference values for the two measurement methods.

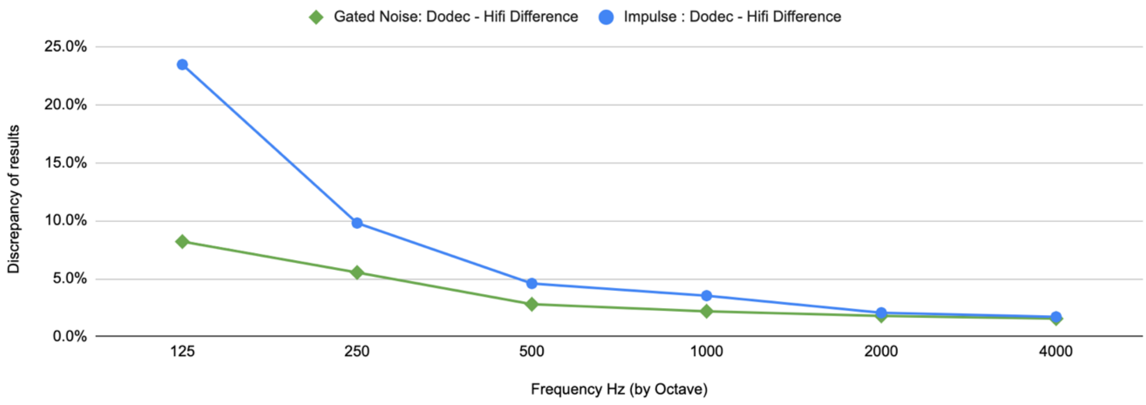

Figure 15. T20 discrepancy between sources depending on the measurement method.

Sound Source	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
Hi-fi Range	3% -11%	8% - 18%	2% -13%	2% -5%	1% -7%	1% -6%
Dodec Range	1% - 25%	2% - 24%	2%-12%	1%-7%	1% -6%	1% -4%

Figure 16. T20 standard deviation ranges observed across the seven test rooms, for the two sound sources.

5 DISCUSSION OF RESULTS

The results for all the rooms consistently showed that RT20 measured utilizing the installed Hi-Fi loudspeakers were in close agreement with those obtained by the dodecahedron loudspeaker. This close agreement occurred both with the gated noise method and with the impulse response.

It was observed that T20 discrepancy of results relative to the reference values was less than 5% for the octave band higher than 250Hz. For the lower octave bands the discrepancy was not notable, ranging between 0% and 13%

The Just Noticeable Difference (JND) for reverberation times is commonly quoted to be 5%. This is based on the Early Decay Time (EDT) JND indicated in ISO - 3382 [2]. However other studies have found this to be higher, from 6% to 39%. This led to the study by Matthew Blevins et al[9] which concludes that the JND of RT is 24.5%.

Based on the JND values found in the literature, the authors took a conservative RT20 JND of 10%. Hence, we observe in the results section that only in two rooms and only at the octave band of 125Hz, discrepancies are above the established JND.

In the octave band of 125Hz all the rooms were dominated by modal behaviour. Considering that these are small rooms with relatively low reverberation, it is likely that the notable variation at 250Hz was also caused by modal behaviour of the room.

In Fig. 16 it can be seen that the standard deviation ranges of T20 as observed in the seven rooms, are low for mid and high frequencies and increasing at lower frequencies bands. The values and the general trend seen is remarkably similar for both sound sources. This further supports the equivalence of both sources for the purposes of measuring T20.

This close agreement of reverberation times using the two sound sources agrees with results found in the literature and discussed in section 2.

6 CONCLUSION

T20 values measured in seven multi-media domestic rooms using in turn the existing Hi-Fi loudspeakers and a reference dodecahedron loudspeaker, were consistently in close agreement at all octave bands. In general discrepancies observed were well below an established JND of 10%.

Very similar T20 values were obtained at all octave bands when both gated pink noise and impulse response measurement methods were employed. Only at 125Hz octave band a significant discrepancy was observed, possibly due to limitations of the dodecahedron, and the modal effect typically present below the Schroeder frequency of the room.

This study has confidently shown that reverberation times can be measured reliably for a useful frequency range (125Hz-4kHz) and for practical purposes in multimedia domestic rooms, when the Hi-Fi sound system installed in them is used as the excitation sound source.

7 REFERENCES

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