A Reference Listening Room for 3D Audio Research

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Abstract

Reference listening rooms for immerisve audio monitoring systems are not yet standardised, so a listening room designed for 3D audio research must be flexible enough to accommodate many possible loudspeaker configurations, while retaining acoustic properties suitable for both performing listening tests and monitoring 3D audio signals, as well as technical tasks such as HRIR measurement. The challenges of designing the acoustic treatment are discussed, including the trade-off between the properties required by standardised listening tests and building advanced reproduction systems. We present the design of such a room, including a description of the acoustic properties and treatment, a selection of measurement results, the design of the flexible loudspeaker mounting system, and a description of the technical equipment, cable structure and routing software used.

Introduction

BBC Research and Development has a long history in evaluating audio quality and designing and building facilities for critical listening (see e.g. [1]). It has recently invested in the refurbishment of one of its listening rooms. This room is designed to be used for a variety of purposes; the main use cases for the new facility are:

- Listening tests according to international standards
- Investigation of immersive audio systems based on loudspeaker and headphone reproduction
- Experimental production and research into the future of production studios and control rooms for object-based audio production
- Measurements and general evaluation of audio content.

Compared to other facilities (e.g. [2]) these diverse use-cases make the designing of such a room quite a challenging task. In contrast to the facilities described in [3], substantial structural changes could not be made to the existing room. This paper gives an overview of the design considerations and the current state of the facility. Most of the design goals have been met and good solutions have been found. Some details are still under investigation and further improvements are on the way.

Design Considerations

Many standardised listening tests follow the relevant recommendations of the International Telecommunication Union (ITU). Listening tests according to Recommendation ITU-R BS.1116 [4], and ITU-R BS.1534 [5] are currently the main approaches being used. [4] sets out the acoustic requirements for performing high quality listening tests. The acoustic properties given in this standard formed the design goals for the loudspeaker layouts specified.

For research into immersive audio systems, it is desirable to have a large number of loudspeakers installed, in order to experiment quickly with different loudspeaker layouts without having to move loudspeakers around. As an initial set-up, we designed such a layout with 34 loudspeakers, to cover layouts A to F and H specified in Recommendation ITU-R BS.2051 [6], as well as layouts with loudspeakers arranged in regular octagons and squares.

With such a large number of loudspeakers in a 3D layout, using loudspeaker stands becomes impractical due to the amount of space used up by each stand and the limited elevation possibilities using stands on the edge of the listening area; therefore a system for mounting the loudspeakers directly to the walls and ceiling of the room has been implemented. This makes the acoustic design more challenging, as it must behave well even with loudspeakers near the perimeter of the room.

Meeting the acoustic requirements specified in [4] for loudspeakers at the perimeter of the room will be difficult, as they are intended for loudspeakers closer to the listening position; although we will compare the measurement results from these locations with the specified requirements, we do not necessarily expect to completely meet them without additional equalisation.

Acoustic Measurements

Acoustic measurements were performed by the authors using Genelec 8030B and Geithain RL940 loudspeakers, an Earthworks M30 microphone, and EASERA 1.2.10 measurement software. Loudspeaker and microphone positions are referenced from the centre of the room at a height of 1.2 m. Azimuth is measured clockwise from the positive y axis (see Figure 8). Impulse responses and reverberation times were measured using a 21.8 s logarithmic sweep. Operational room response curves are measured using pink noise, averaged over 5.5 s.

The room measures 5.05 m × 5.63 m × 2.88 m; this meets the room proportion requirements in [4]. According to the calculation of T_m, the target reverberation time for a room of this size is 0.23 s.

Results

Two sets of measurement results from different loudspeaker positions are presented: ITU-R BS.775 [7] positions, as specified in [4] as positions for 'multichannel stereophonic reproduction', measured using RL940 loudspeakers, and positions representative of those in an advanced sound system according to [6], measured using 8030B loudspeakers close to the perimeter of the room.

The loudspeaker positions for multichannel stereophonic reproduction are shown in Table 1; these are the positions specified in [4], with $B = 1.7\,\mathrm{m}$. Although 1.7 m is outside the preferred range of 2–3 m, this was seen as an appropriate compromise between the loudspeakers' distance to the walls and the listening area for a room of this size.

The full range energy time curves (ETC) are shown in Figure 1. The measurements clearly show that all early reflections are all well below the specified −10 dB threshold in the first 15 ms after the direct sound.

The unequalised operational room response curves are shown with the tolerance curves specified by [4] in Figure 2. Differences in these responses between the front three loudspeaker positions are shown in Figure 3. Above 250 Hz the differences are all within the ±2 dB range; remaining differences may be corrected using light equalisation.

Preliminary reverberation time results are shown in Figure 4. This is the mean of 25 measurements, using loudspeaker positions from Table 1 referenced to the negative x axis (see Figure 8), and microphone positions at the centre of the room and at the corners of a 1.4 m square around the centre of the room, all at 1.2 m height.

The measured loudspeaker positions representative of those in an advanced sound system are shown in Table 2, and the results of these measurements in Figures 5 and 6. The unequalised operational room response curves show the effect of the proximity of the floor and directivity errors. Please also note that these measurement are using the smaller Genelec 8030B loudspeakers. The full range energy time curves show that all wall and ceiling reflections are below the −10 dB threshold, and only some of the floor reflections are slightly above. Measurement B1 is representative of measurements taken with the strongest floor reflections. If these reflections are seen as being problematic for a particular test, additional treatment may be added at appropriate locations.

The background noise was measured between 31.5 Hz and 8 kHz to be below NR15. Although this was difficult to achieve given the existing location and size of the room, the measurements show the noise level to be below NR10 for the frequency range below 2 kHz. Changes to meet NR10 are under investigation.

Loudspeaker	Azimuth	Elevation	Radius
A0	0°	0°	1700 mm
A1	30°	0°	1700 mm
A2	−30°	0°	1700 mm
A3	−110°	0°	1700 mm
A4	110°	0°	1700 mm

Table 1: Loudspeaker positions for measurements in Figures 1 to 3.

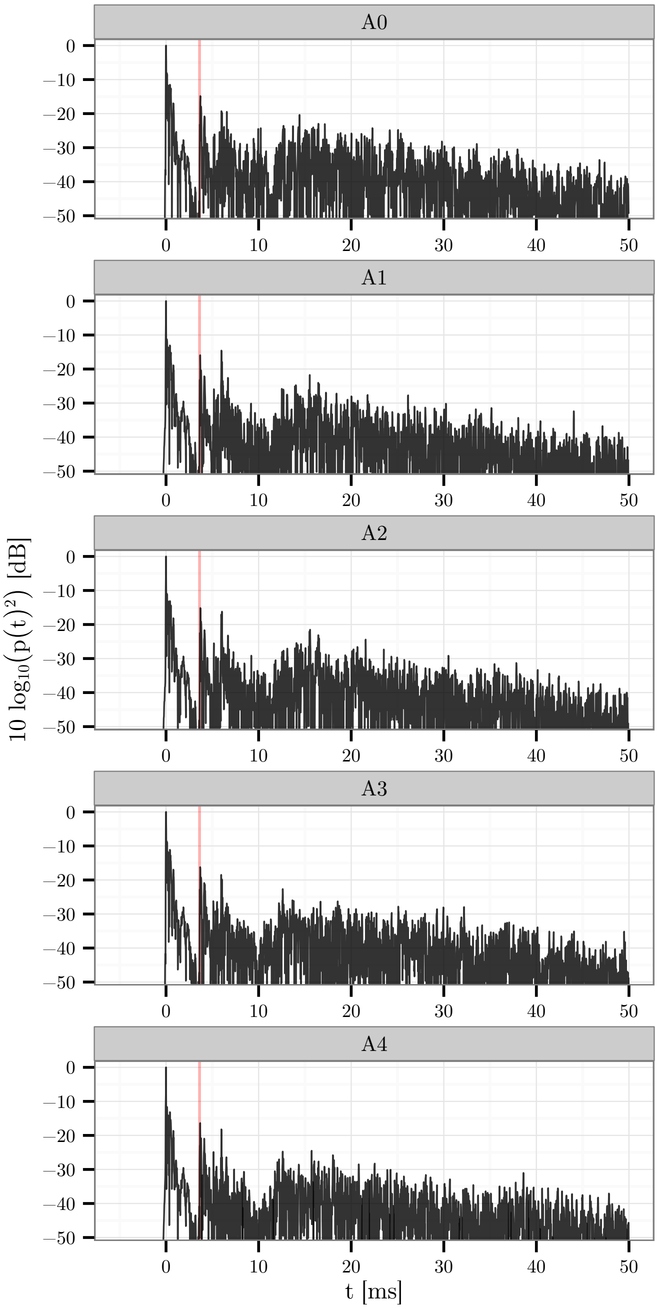


Figure 1: Full-range energy time curves for loudspeaker positions shown in Table 1, measured with a Geithain RL940. $p(t)$ is the sound pressure relative to the direct sound. The red lines indicate the expected time of the floor reflection.

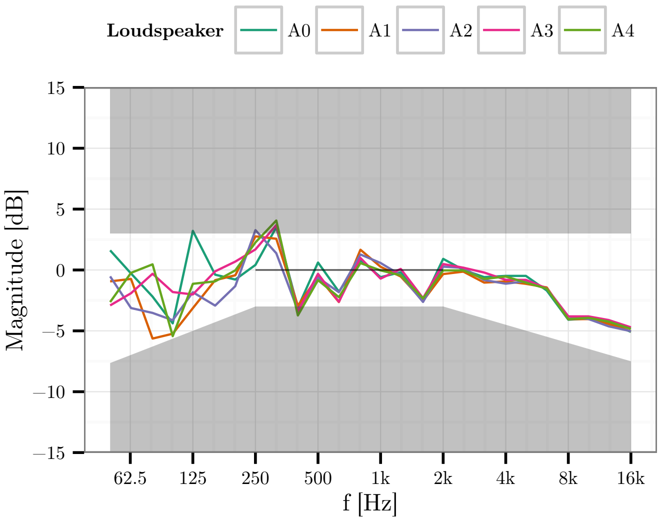


Figure 2: Unequalised operational room response curves with 1/3 octave bands, and tolerance curves specified in [4] for loudspeaker positions shown in Table 1, measured with a Geithain RL940. Magnitudes are normalised such that the mean in the range 250 Hz to 2 kHz is 0 dB.

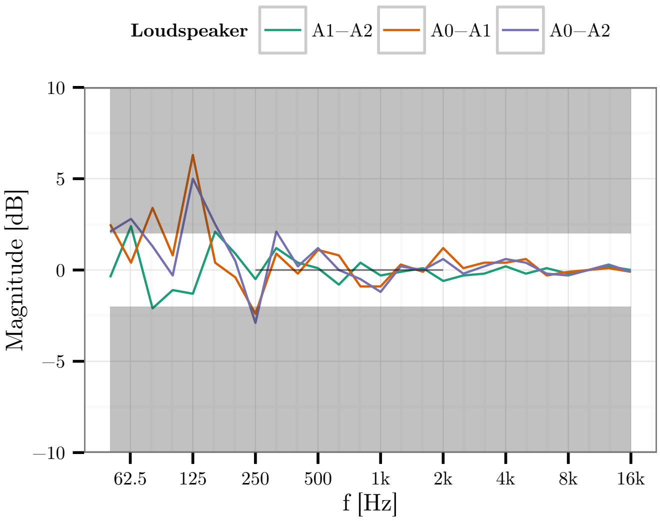


Figure 3: Differences between the operational room response measurements A0, A1 and A2 shown in Figure 2.

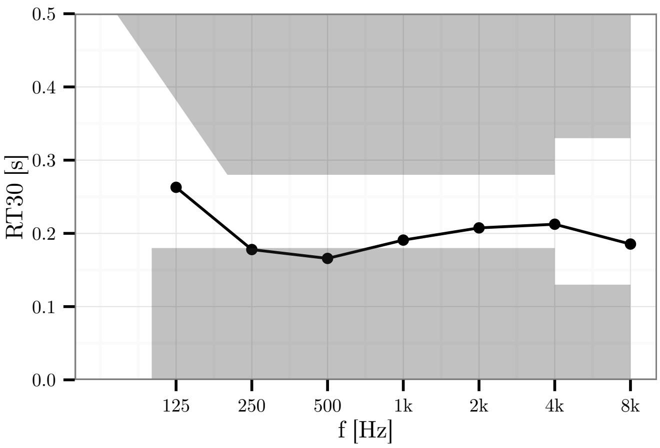


Figure 4: Preliminary mean reverberation time results in octave bands, with the tolerance curves specified in [4].

Loudspeaker	Azimuth	Elevation	Radius
B0	0°	0°	2117 mm
B1	45°	0°	3066 mm
B2	0°	40°	1980 mm
B3	−45°	40°	2019 mm
B4	−90°	−22°	2618 mm
B5	−60°	−22°	3027 mm

Table 2: Loudspeaker positions for measurements in Figures 5 and 6.

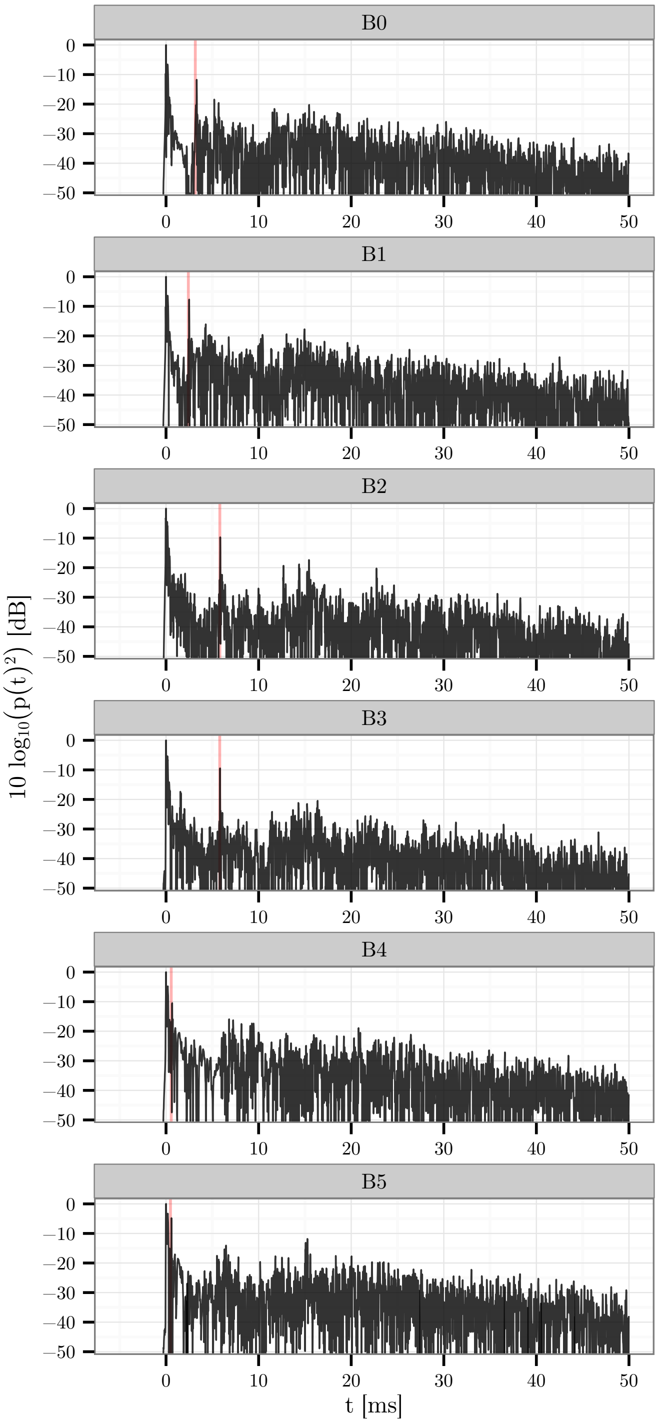


Figure 5: Full-range energy time curves for loudspeaker positions shown in Table 2, measured with a Genelec 8030B. $p(t)$ is the sound pressure relative to the direct sound. The red lines indicate the expected time of the floor reflection.

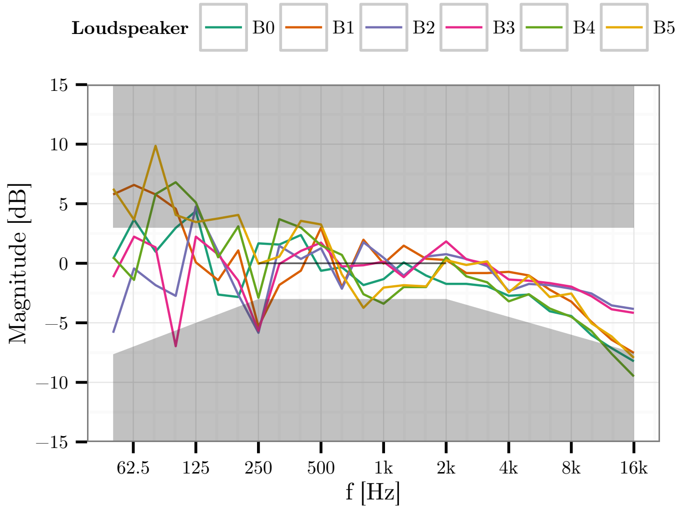


Figure 6: Unequalised operational room response curves with 1/3 octave bands, and tolerance curves specified in [4] for loudspeaker positions shown in Table 2, measured with a Genelec 8030B. Magnitudes are normalised such that the mean in the range 250 Hz to 2 kHz is 0 dB.

Loudspeaker Mounting

For 3D audio research, it is often necessary to place many loudspeakers around and above the listening area. The room is equipped with a flexible mounting system that allows for loudspeakers and other equipment to be mounted at almost any position and angle on the walls and overhead. The system consists of three bespoke parts, the fixed framing, movable horizontal elements and the loudspeaker mounting brackets. The mounting system is built using primarily 45 mm and 90 mm extruded aluminium profiles and components [8]. The overall structure of the framing is shown in Figure 8. The vertical elements are 90 mm aluminium extrusion, with the inside faces flush with the acoustic modules, as shown in Figure 7. The overhead bars are 90 mm × 45 mm extrusion.

Horizontal Elements

To allow mounting loudspeakers between the vertical elements and overhead bars, horizontal elements shown in orange in Figure 8d (45 mm × 90 mm and 45 mm × 45 mm extrusions depending on load) are installed using right-angle brackets and T-nuts. Although in the current configuration the horizontal elements for mounting the ear-level loudspeakers cover almost the entire length of each wall, each section is individually replaceable for maximum flexibility.

Loudspeaker Mounts

Loudspeaker mounts are shown in Figure 9 and consist of an adapter plate attached to the loudspeaker, a joint to allow the loudspeaker to pivot up and down, a short piece of 45 mm × 45 mm extrusion to move the loudspeaker away from the wall, and a joint to allow the loudspeaker to pivot horizontally. The horizontal joint mounts directly to the horizontal elements using a T-nut. A safety wire is installed to reduce the danger should the mounting system fail.

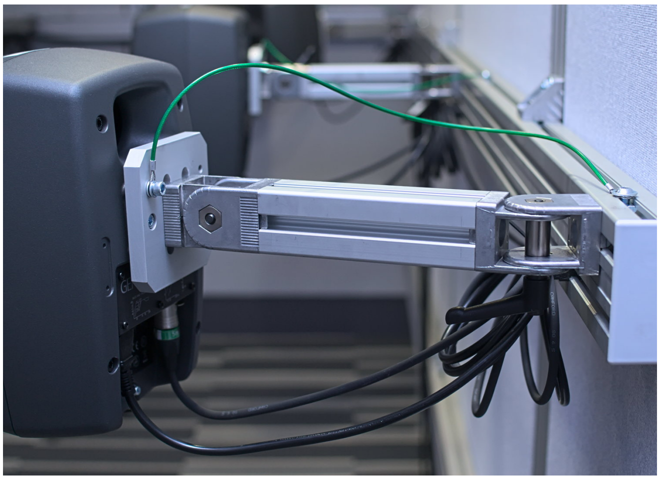


Figure 9: Loudspeaker mounting bracket.

Infrastructure

To support the equipment used in the room a significant amount of infrastructure, in the form of cabling, DACs and ADCs, and a power supply system has been installed.

Connections into the room are distributed to 8 wall boxes, one at the bottom and one at the top of each wall, to allow for neat connections to equipment at all heights. Connections are generally over-provisioned to make the system as flexible as possible.

From the wall boxes, 128 balanced audio connections, 22 75 Ω coax connections, 44 Cat 7 connections and 22 single-mode fibre pairs run to a 19-inch rack outside the room.

In the rack, as well as terminations for the tie-lines, there are 22 75 Ω coax connections, 24 Cat 7 connections and 12 single-mode fibre pairs connecting to the apparatus room, for connections to equipment in the rest of the lab.

All audio connections of the room are routed through a Ghielmetti patch panel, which normally connects each channel to a DAC or ADC channel on one of three 32 channel DACs and ADCs, each connected to a central MADI router.

In day-to-day operation, the patch panels are usually left in their normal state, with loudspeakers wired to their closest wall box, so the loudspeaker outputs are spread across the 3 DACs. Custom software is used to manipulate the channel routing matrix in the MADI router, which normalises this into the order that the rendering software and hardware expects. This allows the definition of virtual ports, which consist of audio channels that may be spread across several real ports on the MADI matrix.

Power System

Using a large number of loudspeakers in an enclosed space poses two power-related problems: dangerously high sound pressure levels may be produced, so an emergency power off system must be installed, and if the loudspeakers are all powered on at once, a large inrush current may occur, so the loudspeakers must be switched on in stages.

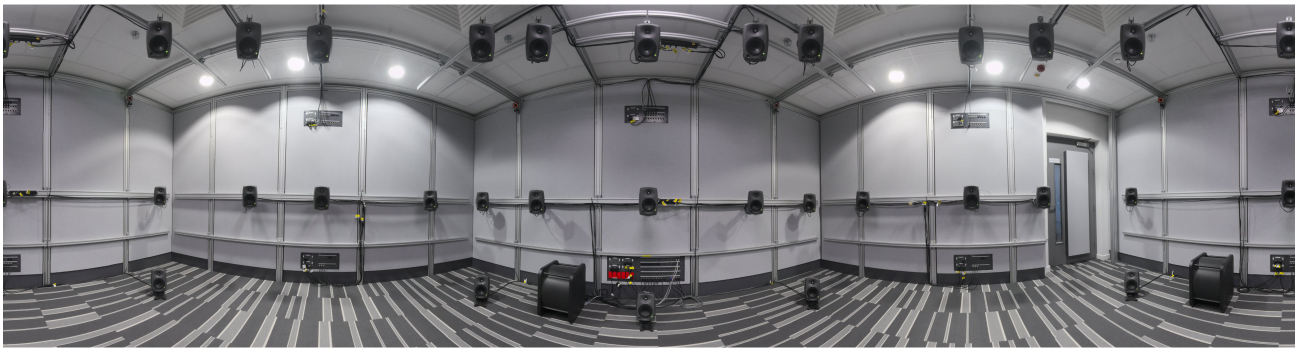
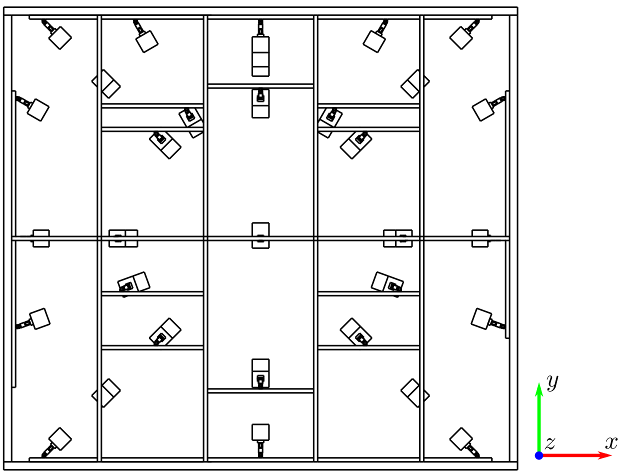
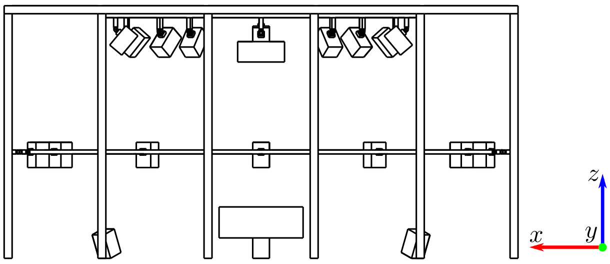


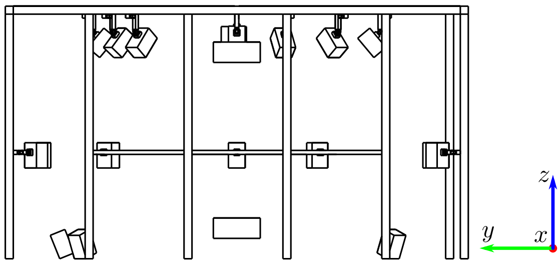
Figure 7: 360° view inside the listening room, showing the current loudspeaker layout, excluding the top centre loudspeaker. The positive y axis (see Figure 8) points towards the centre of the image.



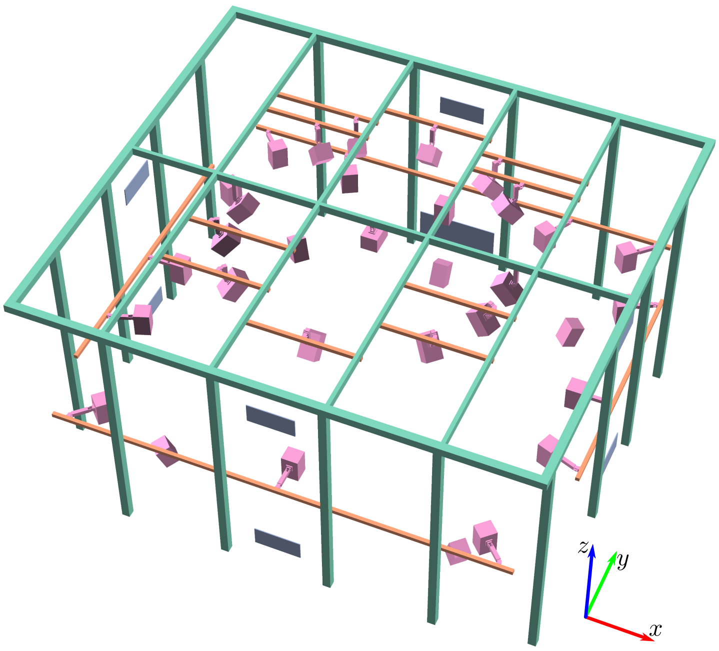
(a) Top View



(b) Front View



(c) Left View



(d) Auxiliary View. The fixed framing is shown in green; horizontal elements are shown in orange; wall box positions are shown in blue; Genelec 8030B loudspeakers and mounts in the current layout are shown in purple.

Figure 8: Flexible loudspeaker mounting system, complete with the currently installed loudspeaker configuration.

The power outlets on each wall box are connected through a separate timer delay module, each with different delays set. This ensures that when the power is turned on to the whole system, power is applied to the sockets in each wall box in sequence.

The emergency power off system cuts the power to the whole system, and may be activated from either a fixed or a movable switch.

In addition to the switched outlets, non-switched outlets are provided to power control equipment that should not be turned off when the emergency power off system is activated.

Audio Systems

The lab is equipped with a variety of digital audio workstations including Avid ProTools, Steinberg Nuendo and a Fairlight system. It also has access to a Barco Spatial audio processor and workstation, the server infrastructure required to run the BBC R&D IP Studio system [9] and the BBC reference object-based audio rendering system. Furthermore it includes a high performance 6 degree of freedom tracking system.

Conclusions

The design and realisation of a flexible reference listening environment have been presented. The facility which was based on an existing room structure does meet all critical acoustic and electro acoustic design goals according to existing ITU standards. The design process has highlighted the need for standardised listening environments for immersive audio as well as the challenges of building a flexible environment to very high acoustic standards.

Acknowledgements

The authors would like to thank all partners and companies involved in building this facility to such a high standard and implementing the requirements for our research work going forward.

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