Appendix 1

A More Detailed Analysis of the Non-Environment Control Room and its Absorption Systems

Introduction

In 1999, as part of an investigation being undertaken at the Institute of Sound and Vibration Research (ISVR) into the effectiveness of various forms of low-frequency absorption systems, advantage was taken of the opportunity to measure the progressive effects of the acoustic-control treatments being installed in the control room of a new studio in the Basque region of Spain.[1] Tio Pete studios, in Urduliz, near Bilbao, was being built in an overall shell size of 20 m × 12 m × 8 m high. The control room occupied a space of 7 m × 7 m × 4.5 m high, and a series of 11 measurements were taken at four different positions during the different phases of the work, beginning with a bare shell and ending with the finished control room. Only the measurements taken at the listening position are presented here, as they are the most representative, and as Measurement 1 (the bare concrete shell) proved to be of little use due to excessive reverberation, only Measurements 2 to 11 will be discussed.

The general aim of the room design was to create a monitoring environment with a mid band decay time of around 0.2 seconds in a room of about 200 m^3, but one of the prime objectives of the ISVR investigations was to see if anything could be gleaned from the measurements that could aid in the understanding of how the proportion of overall volume consumed by the acoustic control system could be reduced. More effective control in smaller rooms was becoming an important topic, because the great majority of recordings were, and still are, being made using inadequately controlled, small rooms.

A1.1 Room Philosophy

The room that was measured in these tests was of the Non-Environment design concept, with a hard front-wall and highly absorbent rear-wall, in which the room decay-time is source-position dependent. The lowest decay-time is for sources mounted in the hard front wall, which is the normal location for the principal loudspeakers, in order to achieve the greatest overall response flatness at the listening position. However, the rooms become progressively more live as the sound source moves towards the centre, which ensures that the rooms are not oppressive for the personnel working in them.

The principal reflective surfaces are the front wall and the floor, which are typically opposed by a highly absorbent rear wall and ceiling, respectively. As each side-wall is reasonably absorbent, they do not need to be as heavily treated as the rear wall and ceiling (which both face hard, reflective surfaces). A relatively uniform and rather short decay time versus frequency is obviously important if a maximally flat frequency response is to be achieved in the designated listening area around and behind the mixing position. The means of achieving this has been somewhat empirically designed over many years, but the development had been something of a question of trial and error, and very time consuming. Nevertheless, the rooms have now evolved to a state whereby the wideband absorption systems are very effective, but without a greater understanding of the complex interdependence of the absorption systems and their component materials, it would be difficult to predict their effectiveness in other circumstances, or how to reduce their size whilst maintaining the same absorption efficiency. This was the prime motive for the aforementioned investigation programme at the ISVR.

A1.2 Systems of Absorption

In the room under discussion here, the outer shell was made of concrete, with an inner structure based on the old BBC 'Camden' partitioning principle. The 10 cm timber stud frame was covered on the outside with a double layer of 13 mm plasterboard, between which was sandwiched a layer of a 3.5 kg/m^2, plasticised deadsheet (instead of the insulation-board/softboard used in the old, BBC designs). Between the studs, the cavities were filled with 10 cm of 40 kg/m^3 mineral wool; although, usually, two 2 cm layers of a 60 to 80 kg/m^3 cotton-waste felt are used. The studs were then faced with deadsheet, followed by 2 cm of a 60 kg/m^3 cotton-waste felt. The ceiling structure was essentially similar to that of the walls, except for having a 22 cm, depth due to the dimensions of the ceiling timbers.

The floor was a 10 cm floated reinforced-concrete slab, and the front wall consisted of a stud frame with multiple board layers with interspersed deadsheets, faced with 10 cm of irregular-faced granite and cement, to provide a massive baffle extension for the loudspeakers. The remaining treatment consisted of an arrangement of plywood and chipboard panels, covered on one side with a damping layer of 3.5 kg/m^2 deadsheet, and on both sides with a 4 cm (2 × 2 cm) layer of cotton-waste felt. These were hung from chains, both parallel to the wall surfaces and also at various other angles, mounted in a manner which can be seen in Figure A.1.9(e).

It had been known since the 1960s that the solid panels were an important part of the overall effectiveness of these absorption systems, but in way that proved to be incorrect. In three separate investigations in the 1990s, the solid panels themselves had been shown not to be responsible for any significant absorption, though the absorbent materials alone, suspended without the panels, had been found to be far less effective than with the panels inserted.[2,3,4,5] Work by Alistair Walter, at the ISVR in 1998, finally showed the powerful waveguide effect of these panels (see also Figures 23.9 and 23.10), which soon led the way to a more global understanding of the mechanisms.[4]

The following is a list descriptions of the states of construction when each corresponding measurements was taken at the listening position. The photographs in Figure A.1.1 show the room at the time that each measurement was taken, and the layout of that figure corresponds with the layout of Figures A.1.2 to A.1.6, for easy comparison. These figures will be introduced group by group, as each type of measurement is discussed in turn.

Measurement No. 2

The empty shell, with only the framework for the vocal and machine rooms.

Measurement No. 3

Stud frames of the control room walls and ceiling, erected and covered on the outside with plasterboard/deadsheet/plasterboard sandwiches.

Measurement No. 4

Construction of isolation walls around the left and rear of the control room area, using absorbent blocks. (See photograph of acoustically-absorbent concrete block in Figure A.1.1, Measurement 4, and also Figure 4.28.)

Measurement No. 5

All wall frames filled with mineral wool and covered on inside with deadsheet and felt. Front wall boarded, and loudspeaker flush mounted. Vocal and machine rooms lined with deadsheet and mineral wool.

Measurement No. 6

Large (6.5 m $\times$ 4 m) absorbent-covered chipboard panel hung in front of back wall.

Measurement No. 7

Ceiling lined with deadsheet and felt.

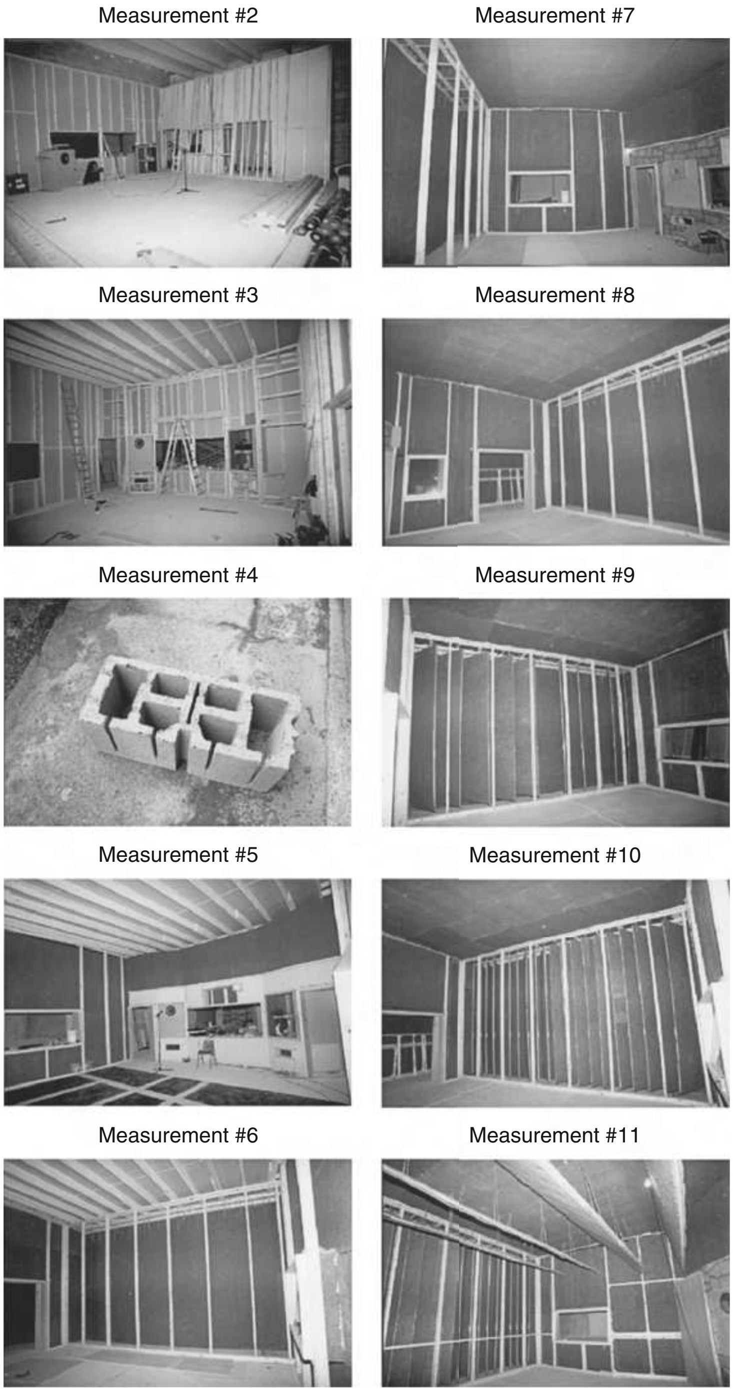


Figure A.1.1: Photographs corresponding to measurement numbers.

Measurement No. 8

Absorbent-covered suspended panels installed next to both side walls.

Measurement No. 9

Ten waveguide panels mounted in front of back wall.

Measurement No. 10

Twenty waveguide panels mounted in front of back wall.

Measurement No. 11

Absorbent-covered suspended panels installed below the ceiling.

A1.3 Discussion of Results

A1.3.1 Waterfall Plots

Figure A.1.2 shows the waterfall plots derived from the frequency response function measured at the intended listening position. Comparing measurements #2 and #3 shows that the introduction of the stud frames of the walls and ceiling, covered on the outside with plasterboard/deadsheet/plasterboard sandwiches, greatly reduces the decay time in the sub-100 Hz frequency range. The frequencies above 100 Hz remain broadly unaffected though. The introduction of the outer, concrete isolation shell between measurements #3 and #4 can be seen to increase the initial low-frequency energy in the room, probably due to loading effects on the loudspeaker, and not until measurement #11 does this early-reflected energy fall back to that shown for measurement #3. These measurements are interesting in that they clearly show the effect of an outer concrete isolation shell on the internal acoustics. As was described at the beginning of Chapter 4, and in Sections 6.3 and 13.7.1, the heavier and more effective the isolation shell, the more difficult becomes the internal low-frequency control.

Measurement #5 was taken after all the wall frames had been filled with mineral wool, and covered with deadsheet and felt. The front wall had also been boarded, resulting in an increase in low-frequency energy being radiated by the loudspeaker (compared to measurements #2 and #4) due to it being flush mounted at this stage. Despite the ceiling still being hard-surfaced, the effect of the treatment on the frequencies between 100 and 1,000 Hz is drastic, having the same order of effect that the plasterboard sandwiches had on the lower frequencies. At this point in the construction, a floor-to-ceiling 'chatter' was quite subjectively pronounced on speech within the room, but only because all the other reflexions had been very much reduced. This is a typical effect at this stage of a construction because of the ear's sensitivity to sounds occurring in isolated

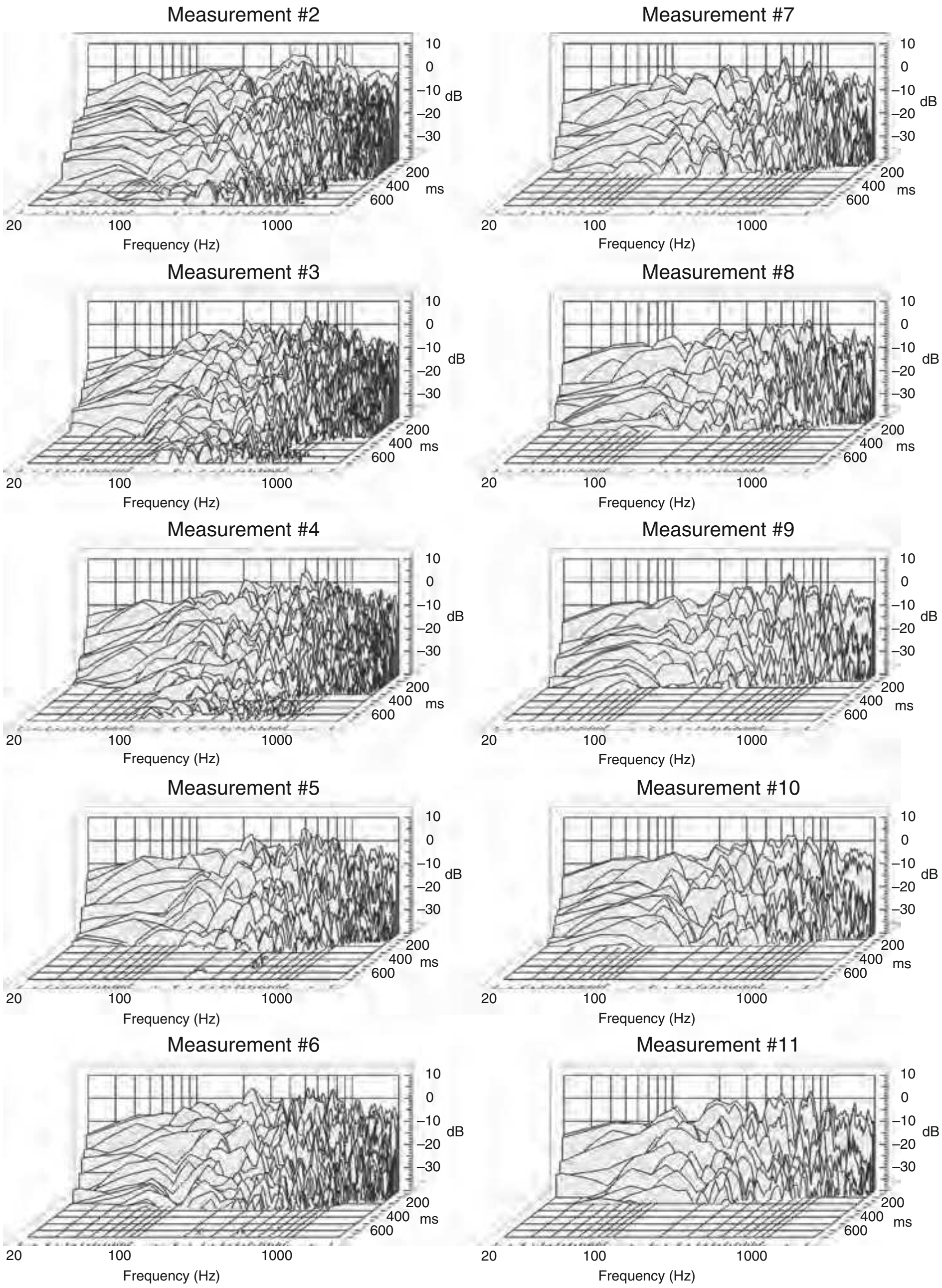


Figure A.1.2: Waterfall plots.

directions. However, it is interesting to note that very little of this significant subjective effect is evident on the plots, presumably because of the position of the source in the hard front wall.

Measurement #6 was taken after a large (6.5 m × 4 m) absorbent-covered chipboard panel was hung in front of the back wall. This produced an unexpected result – *very little* change, except a small *increase* in decay time in the 100 Hz region. Experience over many years had shown that rooms which employed these large panels exhibited more isolation to and from the outside, without the internal acoustics suffering, as compared to rooms without the panels. It seems rather odd that such a large item could be introduced into a room with so little effect on the response (the slight rise in decay time at 100 Hz is presumably due to its masking effect on the deadsheet-covered back wall), but it seems to be the case. Nevertheless, after studying the data presented in this set of measurements, the use of these panels was suspended in rooms where effective isolation shells already existed. Evidence which will be presented in following sections showed that the suspected manner in which they could work as extra panel absorbers in fact did not operate to any significant degree.

Measurement #7 was taken after the lining of the ceiling with absorbent material. All trace of any low-level activity beyond 400 ms, evident in the earlier measurements, had been removed from the plot. The floor-to-ceiling 'chatter', previously heard on speech in the room, also disappeared, but a low-level resonance was still audible. Prior to measurement #8, the suspended panels were installed in the side walls, and the waterfall plot shows little effect except for a decrease in decay time in the 100–500 Hz range.

Measurement #9 was taken after the mounting of 10 of the angled 'waveguide' panels in front of the large panel parallel to the rear wall. The waterfall plot shows that installing these panels (each 1.2 m × 4 m) reduced the decay time in the 200–1500 Hz range by a noticeable amount. Measurement #10 is as measurement #9, but with *20* panels occupying the same space as the previous 10. The increase in the number of panels appears from the waterfall plots to have had almost no effect at the listening position. The spacing of these panels, together with their optimum angle, was, at the time of analysing the measurements, the subject of research by Stuart Colam at the ISVR.[3]

Finally, the ceiling 'trap' system, consisting of five panels, up to 1.2 m deep and 6 m long, was installed prior to measurement #11. The panels were set at angles such that they all pointed their lower edges towards the centres of the monitor loudspeakers. In the past, much importance had been attached to these panels, and it had been noticeable that rooms with insufficient ceiling space for them had been subjectively inferior to rooms with adequate ceiling traps. Measurement #11 clearly shows a very significant reduction in the decay time of the lowest octave, 20–40 Hz. This bears out the subjectively 'tighter' bass attributed to the rooms with adequate ceiling traps. The word 'trap' is perhaps a good choice here, because, being angled edge-on to the expanding wavefront, the panels would appear to offer little obstruction to the *entry* of the sound waves, but the reflected exit routes via the heavily-lined ducts which they form is extremely difficult to negotiate. The arrangement of these panels also serves to interrupt the parallel surfaces of the floor and ceiling, removing all traces of any remaining 'chatter'.

A1.3.2 Reverberation Time (Decay Time) Plots

The reverberation (decay) time (RT) plots shown in Figure A.1.3 are actually point-to-point diagrams, with each point determined by one-third-octave Schroeder integration. As well as the

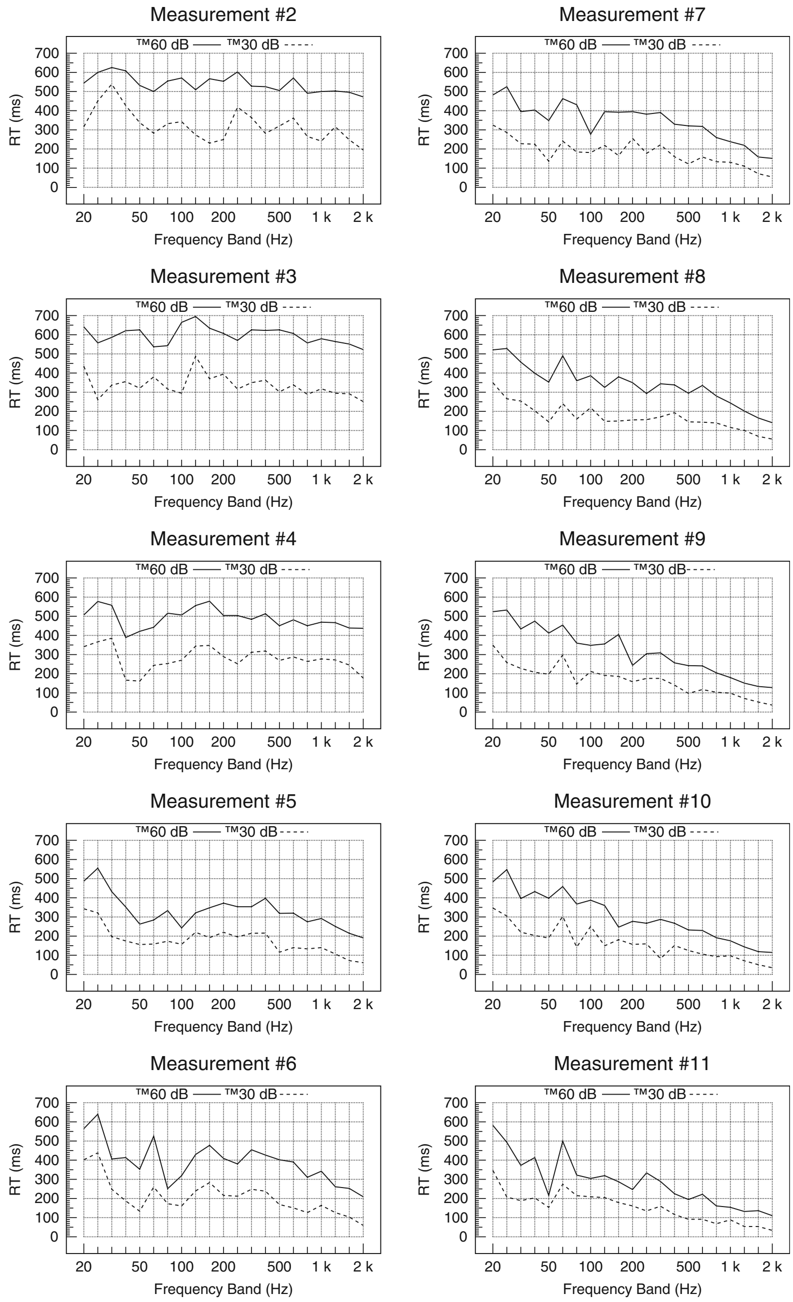


Figure A.1.3: Reverberation time plots to −30 dB and −60 dB.

usual −60 dB decay times, the figures also include the decay time to −30 dB, which can be a useful guide to many subjective effects. One limitation to the accuracy of these plots when applied to rooms with very low decay-times decay times is that of the inherent, low-frequency decay-times of the measurement filters themselves. This 'additional reverberation' is *not* a property of the room but is present in all of the plots, and generally cannot be corrected for. Figure A.1.7 (shown later in the text), demonstrated the equivalent decay time of the filters when combined with a theoretical model of that of the loudspeaker system.

In order to minimise the decay in the actual loudspeaker response, the sound source was a 15 inch, low-resonance (20 Hz) drive unit in a 500 litre sealed cabinet, which was capable of giving a useful output down to 10 Hz with little resonant decay. The waterfall plots in Figure A.1.2 suggest that much low-frequency absorption has taken place by the time of measurement #5; but this is less apparent in the RT plots of Figure A.1.3. Each method of analysis has its strengths and weaknesses. Nevertheless, the trend of the RT plots is generally downwards from measurement #3 onwards.

Two points worth observing from Figure A.1.3 are the reduction in decay time due to the completion of the two concrete isolation walls which fully enclosed the space before measurement #4, and the very noticeable effect that the ceiling panels had at low frequencies (#11). The completion of the concrete isolation-wall, tightly fitted round the rear and left wall of the control room with fibrous material in the gap, actually appears to reduce the RT of the room. This may be partly due to a damping effect on the stud-framed walls, but the two walls also reduced the volume of the space surrounding the control room. As previously mentioned, the addition of the large, rear, suspended panel also caused a small increase in RT to be apparent in measurement #6, although its effect is not obvious in the pressure amplitude response.

A1.3.3 Energy/Time Curves

Not surprisingly, the energy/time curves (ETC) in Figure A.1.4 show details which are not apparent in the waterfall or RT plots, such as discrete reflexions. One such reflexion is that due to the floor. This reflexion appears about 10 dB below the direct signal and about 5 milliseconds later, and is present in all the measurements (although it arrives more rapidly in measurement #2 because the loudspeaker cabinet was still on the floor). In the finished room, its independent nature would be broken up to some degree by the presence of the mixing console. Measurement #3 shows a rise in the level of reflected energy due to the completion of the smaller, inner case of the control room bringing the reflective surfaces nearer to the microphone. However, from then on, the trend of the plots is downwards (except for the previously mentioned effect on measurement #6, and some minor effects due to the completion of the concrete outer isolation shell before measurement #4).

Table A.1 shows the decay times to −20, −30, −40 and −50 dB for the last five plots. Ten milliseconds have been deducted from the time scales to allow for the arrival of the direct signal. Only three reversals take place in the downward trend, but they are largely insignificant. Two are of only 1 ms, but the third reversal is after the strangely low figure for measurement #9, which crosses the −20 dB line. However, this is only due to the spike around the 28 ms mark being on the threshold of the line. If it were 1 dB higher, the anomaly would not exist, and as this is well within the bounds of normal measurement error, it can reasonably be said that the trend is generally downward.

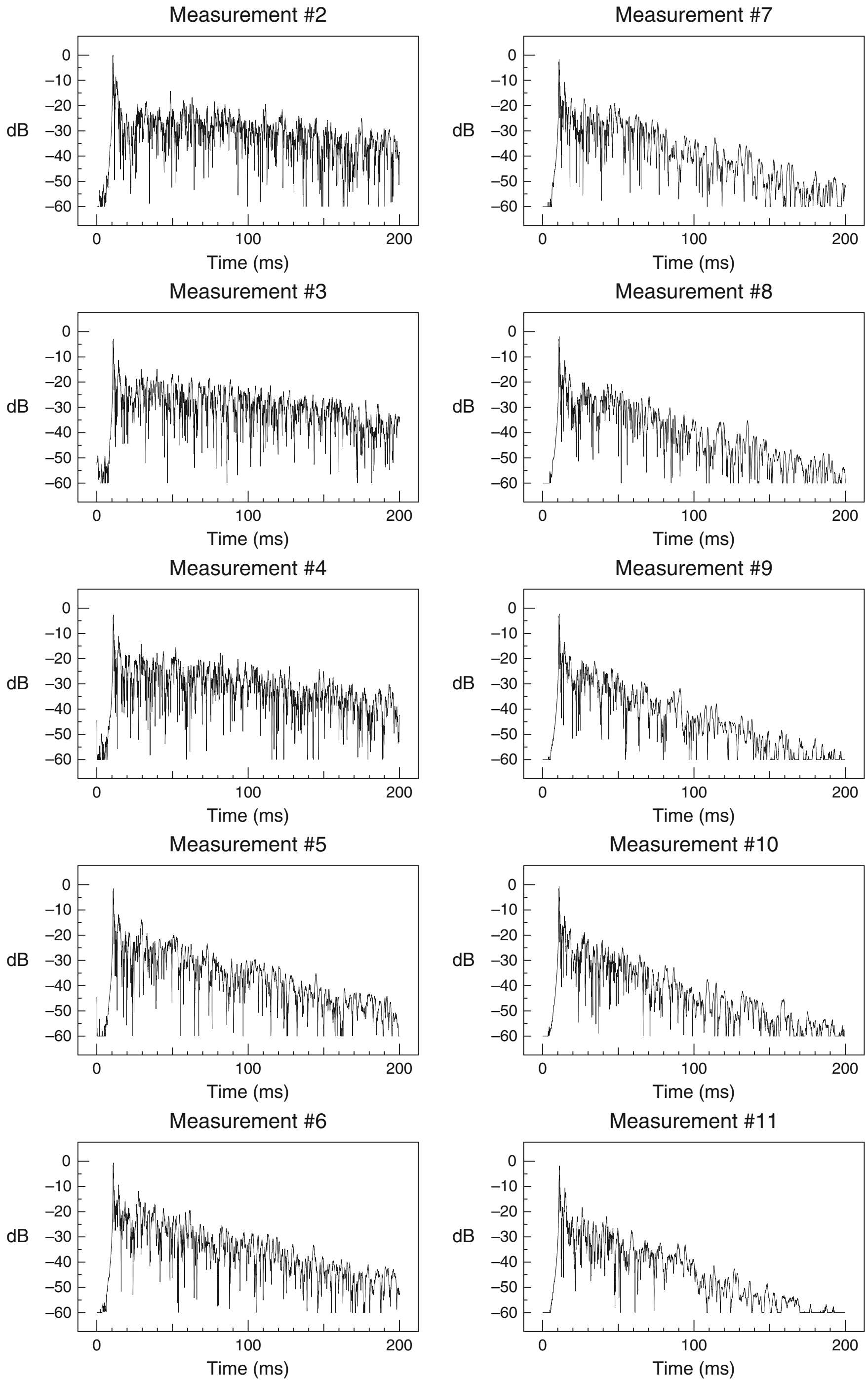


Figure A.1.4: Energy/time plots (ETCs).

Table A.1: Decay times (milliseconds) for measurements #7 to #11

Measurement	–20 dB	–30 dB	–40 dB	–50 dB
#7	33	72	129	190
#8	18	73	127	185
#9	9	58	105	161
#10	18	55	106	149
#11	17	50	90	139

If a diagonal line is drawn from the peak of the direct signal to the −60 dB line at 200 ms, it becomes apparent that the reflected energy has been reduced in measurement #10 from that in #9. This suggests that the closer panel-spacing is absorbing more energy, which is not apparent from the waterfall or RT plots. The most clear indication of the effectiveness of the ceiling panels is shown by the plot of measurement #11, with significantly reduced energy in the 100 to 200 ms region.

A1.3.4 Schroeder Integration Plots

Figure A.1.5 shows a sequence of Schroeder plots, which again clearly indicate a significant overall downward trend in the wide-band decay times as the construction progressed, resulting in a final figure in measurement #11 of about 300 ms if extrapolated from the straighter, −10 to −30 ms section of the curve. However as can be seen in Figure A.1.3, the decay time at 500 Hz met the 200 ms design target. An increase in early reverberant energy is apparent in measurements #3 and #4, after the progressive enclosure of the control room space, and a small increase in decay time can be seen in measurement #6, after the installation of the large, suspended panel next to the rear wall. As mentioned earlier, though, the use of such panels was abandoned soon after these measurements were analysed, except in occasional cases where the extra isolation which they afforded was required.

A1.3.5 Pressure Amplitude Response Plots

Once again, a clear trend is apparent in the pressure amplitude plots of Figure A.1.6, which show a progressive reduction in the irregularities of the response as the room treatment is added. Also, the severe peak and dip in the sub-100 Hz region can be seen to change frequency during the early measurements, especially due to the additions to the structure before measurements #3, #4 and #6. This latter point is a clear indication of how the modal frequencies of a room can be influenced by the outer containment shell, and cannot be reliably calculated from the dimensions of the inner room shell. Beyond measurement #7 there is a stabilisation of their frequencies, which is accompanied by a reduction in their amplitudes as further absorption is added. The addition of the ceiling panels, as shown in measurement #11, can be seen to have a significant smoothing effect on the low-frequency response.

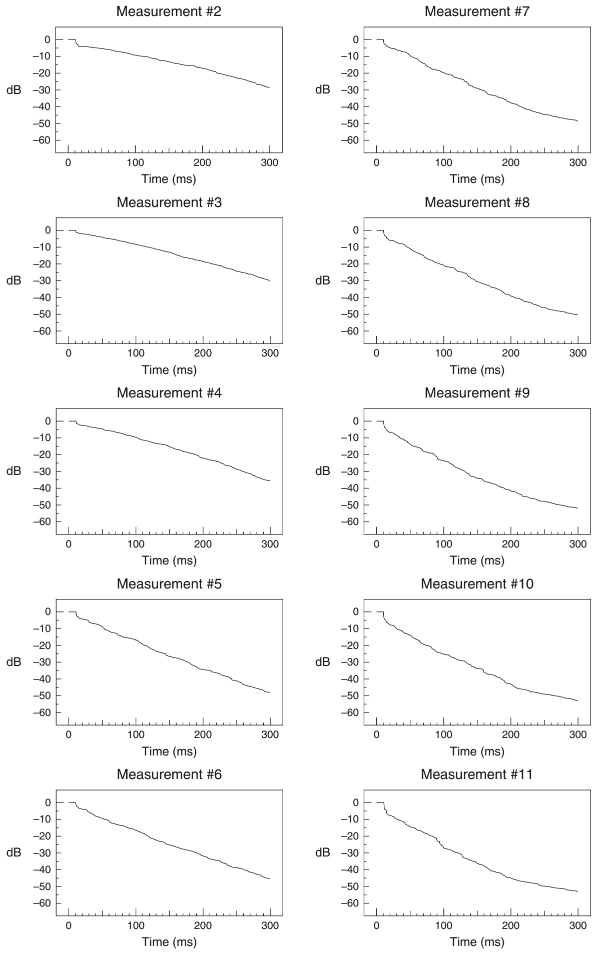


Figure A.1.5: Schroeder integration plots.

Figure A.1.8 shows the pressure amplitude plot for measurement #11, but this time in one-third octave bands and after having been corrected for the low-frequency roll-off of the loudspeaker (using a suitable, theoretical model). The response is seen to lie within ±4 dB from 10 Hz to 2 kHz; a demonstration of the effectiveness of the acoustic treatment.

A1.4 Summary of Measurements

The measurements presented here outline the acoustic control available from a system of membranes, deadsheets, waveguides and fibrous absorbers. It has been shown how a short and well-controlled decay time can be created within a concrete isolation 'bunker'. The effect of the introduction of each group of elements can be seen stage-by-stage. The techniques used are simple, require no special skills to install, and are flexible in their application. The major purpose of the exercise described was to provide a definitive proof of the concept.

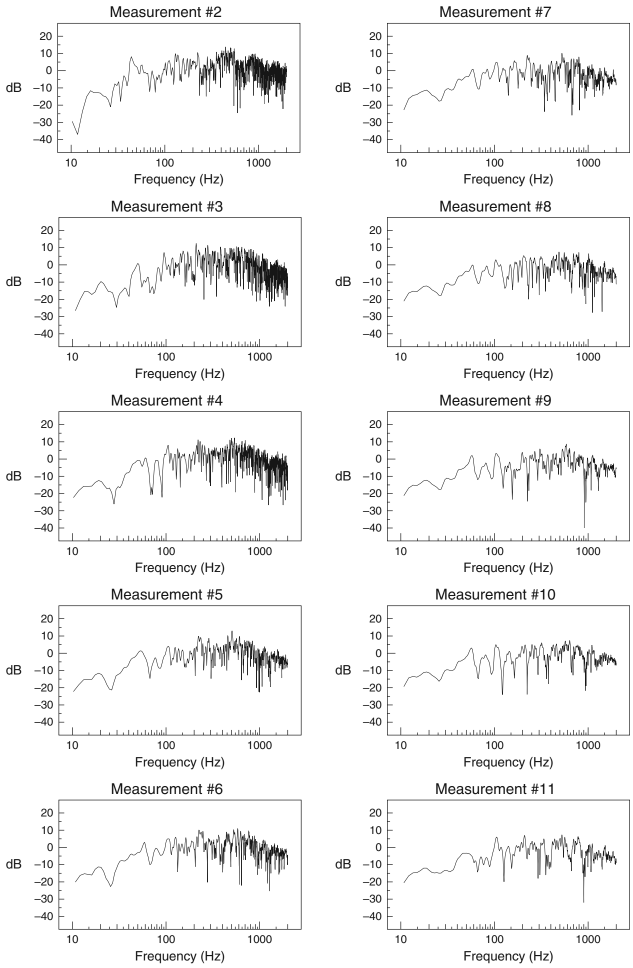


Figure A.1.6: Pressure amplitude plots.

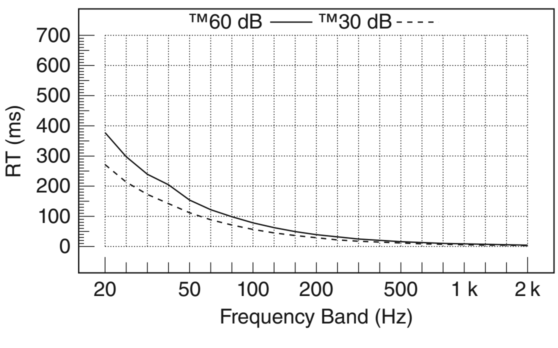


Figure A.1.7: Equivalent reverberation time of one-third-octave filters and loudspeaker combined. These will tend to cause the low-frequency decay times to over-read on the plots in Figure A.1.3.

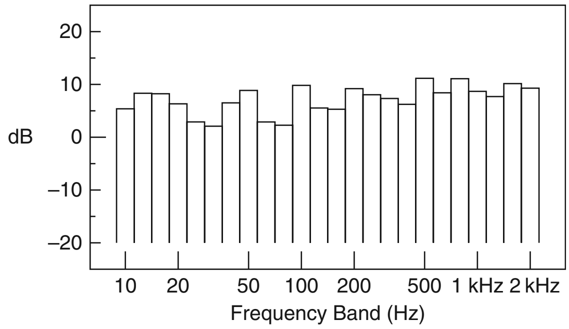


Figure A.1.8: One-third-octave response of completed room (Measurement No. 11) with correction for loudspeaker roll-off.

It can be seen from the complete series of measurements presented in this appendix that each element of the acoustic control system has had a worthwhile effect on the overall room response (or rather the suppression of it) at the stage when it has been installed. Despite the fact that no single measurement technique has been capable of indicating all of the beneficial effects, the cumulative evidence from the whole presentation leaves little doubt that this method of room control is highly effective. The only exception that might apply is the effect of the large rear suspended panel. As previously explained, the origin of the concept of this panel was that it was discovered that it could be used to increase the isolation to and from the outside of the room without noticeably compromising the internal acoustics, but its presumed beneficial effect in terms of low-frequency absorption within the room has been shown to be insignificant.

Figures A.1.9 (a–e) to A.1.13 show various aspects of the construction of this type of room.

A1.5 The Scientific Findings

During the final stages of the production of the first edition of this book, Stuart Colam presented his doctoral thesis on the means by which the so-called 'trap' systems operate. Following on from work by Alistair Walter which clearly showed the waveguide effect (see Figures 23.9 and 23.10), and after his own MSc work[2] which concluded that the suspended panels in themselves (i.e. the wooden cores of the panels) did not contribute to any significant absorption, he made significant discoveries about how the panels functioned in *arrays*. It has now been shown that the *arrays* of panels have absorbent properties which are attributable only to the arrays as a whole, and not to the individual component parts.

It has become clear from this work[3] that the effects of the arrays differ with the angle of incidence of the acoustic wave, and that the side-wall arrays, the rear-wall arrays and the ceiling arrays do not all operate in the same manner. Furthermore, the manners in which they do work are not all equal with frequency. Take the arrays on the side walls, for example. At low frequencies, it has been found that a surface wave exists as the wavefront propagates along the face of the array. It can be modelled by means of an acoustic impedance at the front edge of the array. This would suggest that the inclination of the panels on the side walls, with their leading edges facing the front of the room in Figure 13.7, should be of no consequence to low frequencies, because the

(a)

Figure A.1.9: Various stages of the room construction during the measurements described in Section A1.2.
(a) The Tio Pete control room at the stage of Measurement No 2.

(b)

Figure A.1.9 *(continued)*
(b) The loudspeaker wall framing at the stage of Measurement No 3.

surface acoustic impedance does not depend on the direction of the incident wave. However, at somewhat higher frequencies, where the lined-duct effect is important, things would change significantly if the panels were mounted with their leading edges pointing to the rear of the room.

The rear-wall trap systems receive what is essentially a plane wave, which strikes them perpendicularly. It has been shown that the absorption at lower frequencies can be improved when the panels are set at an angle of about 20° to the rear wall, but placing them at such a relatively flat

(c)

Figure A.1.9 *(continued)*
(c) The front of the room during Measurement No 5.

(d)

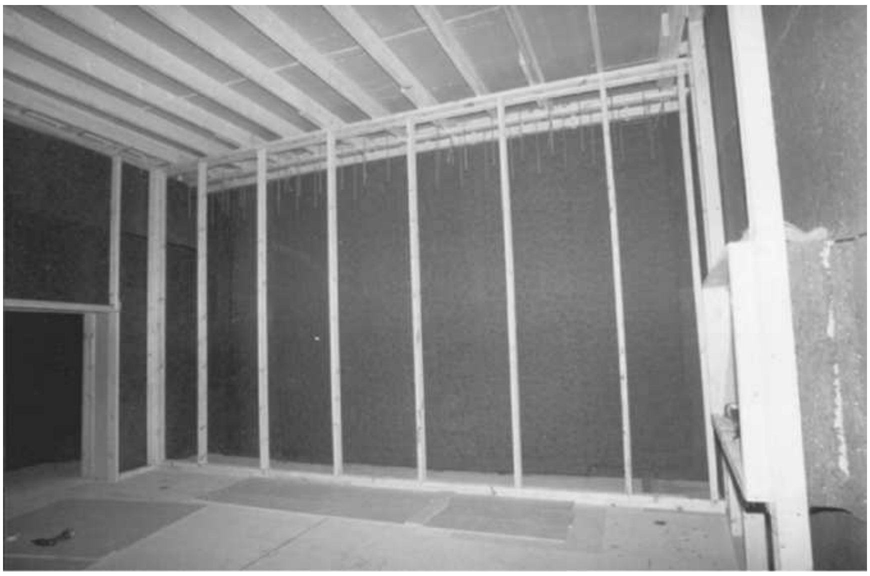


Figure A.1.9 *(continued)*
(d) The rear of the room at the stage of Measurement No 6.

angle tends to make the panels more reflective to the upper-bass and lower-mid frequencies. Experience has shown 45° to be a better compromise in terms of producing a flatter, overall room response.

(e)

Figure A.1.9 *(continued)*
(e) The 20-panel array in place during Measurement No 10.

Figure A.1.10: The completed acoustic treatment, viewed from the monitor loudspeaker wall.

Another aspect of the absorption mechanisms in the trap that is still under investigation is the 'horn effect', suggested by Professor Frank Fahy. In effect, the inclined panels may act like reversed horns, with the high particle velocity at the mouths of the openings giving rise to high

Figure A.1.11: The completed acoustic control system at Area Master Studios (now Planta Sónica 2), Vigo, Spain; viewed from the rear, and showing the closed nature of the ceiling panels from this viewpoint. Compare this with the view in Figure A.1.10.

Figure A.1.12: Discosette 3, Lisbon, Portugal; at the stage of mounting the first fabric panels over the absorber systems. The floor is pink marble. The covering on the waveguide panels is Dacron.

pressure at the throat, where the panels *almost* touch the wall. The phase differences of the wavefronts on each side of the panels, due to their waveguide effect, lead to high particle velocities through the porous material between the panel and the wall as the pressure differences try to equalise themselves. In turn, this appears to give rise to resistive losses due to the tortuosity and friction in the path through the fibrous materials, and hence, in turn, gives rise to considerable absorption. In a highly tuned system, this would be very selective in the frequencies of maximum absorption, but in practice, the effect seems to be quite low Q. Nevertheless, this may be just one of many mechanisms at work in these complex absorber systems.

The ceiling panels have usually been inclined such that their leading edges pointed towards the loudspeakers, in the belief that this provided the easiest access to the labyrinth for the expanding waves leaving the loudspeakers. However, the work by Colam suggested that at low frequencies, the lower edges of the panels may again provide a surface acoustic impedance, which should not be significantly affected by the precise angling. Despite this, further work by the same investigator seemed to show that the beneficial effect at very low frequencies could also be due to the broader spread of the effect created by the different panel depths and angles of incidence with respect to the ceiling. (See Figure 16.2.) Consequently, the pointing of the panel edges towards the loudspeakers, as shown in Figure A.1.11, may still be beneficial, albeit not *only* for the original reason that it was applied.

It should come as no surprise that these absorption systems were initially empirically developed once the true complexity of their operation is better understood.[4] They were conceived and developed by engineers, as opposed to scientists, but progress by engineering 'cut-and-try' approaches was slow, which is why more effort was later made on the scientific front, so that ways could be found to better predict the results of changes, and hopefully speed up the development. The scientific studies brought a better understanding of what the engineers had achieved, which has been a big help to further development, but the complex nature of the overall systems has seriously inhibited their modelling by computer, because sufficient, accurate input data is rarely available. This has also been a block to the more theoretical design approaches to the Non-Environment rooms, because one is simply not going to find how to make the practical, wide-band absorption systems by reading the traditional text books. However, the fact that the Wright brothers did not have any text book to confirm the aerodynamic principles of their first aeroplane did not prevent it from flying. The engineering led to more science, which in turn led to better engineering. The parallel with these absorber systems is very real, and more science and engineering will yield even better results in the future. It will still be useful to improve the efficiency of the absorber systems if their size can be reduced and allow them to be used in much smaller rooms, but there is no guarantee that this will be possible.

Until about 2000, almost everybody involved with the application of these 'traps' had thought that the suspended wooden panels contributed directly to the absorption (i.e., that energy was dissipated in the panels themselves), so when one-tenth scale modelling was carried out in 1990 and failed to detect any absorption, the suspicion was that the modelling technique was flawed.[5] Nonetheless, ten years later, Colam's work at the ISVR confirmed the earlier modelling to have been correct, and that almost no energy is dissipated within the suspended wooden panels. They tend to re-radiate the great majority of whatever vibrational energy they receive, thus behaving in a reactive manner, although when there are deadsheets covering one side of the panels, as is often the case, the added damping may provide a certain amount of absorption.

Figure A.1.13: The completed control room at Tio Pete Studios, Bilbao, Spain, the subject of the measurements presented in this appendix.

Figure A.1.14: The Non-Environment, multi-format listening room in Vigo University, Spain (2004).

A1.6 More Recent Research and Development

Figures A.1.14 to A.1.17 show various views of the 'critical listening room' at the University of Vigo, Spain, which has also been used as a test-bed for much physical measurement of the

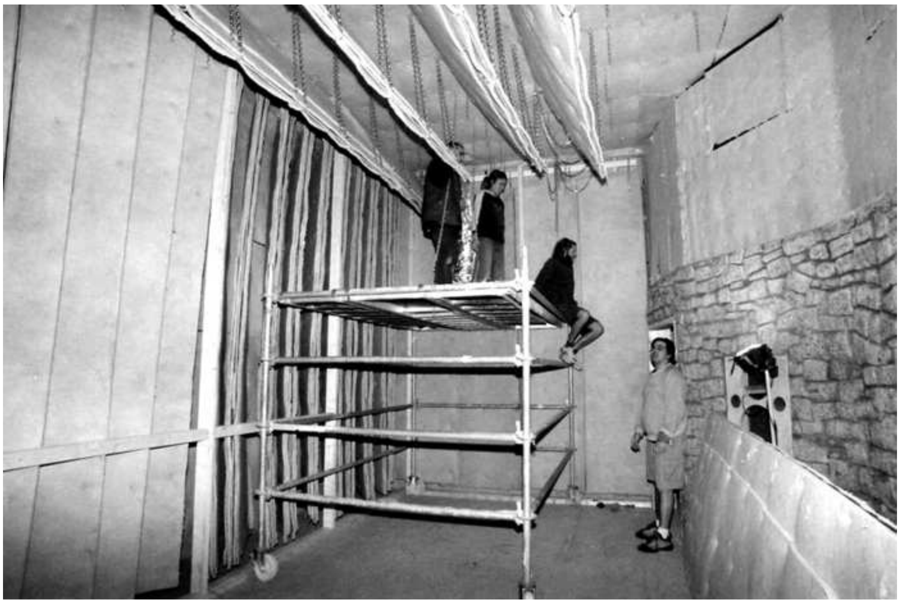


Figure A.1.15: The Vigo University room under construction.

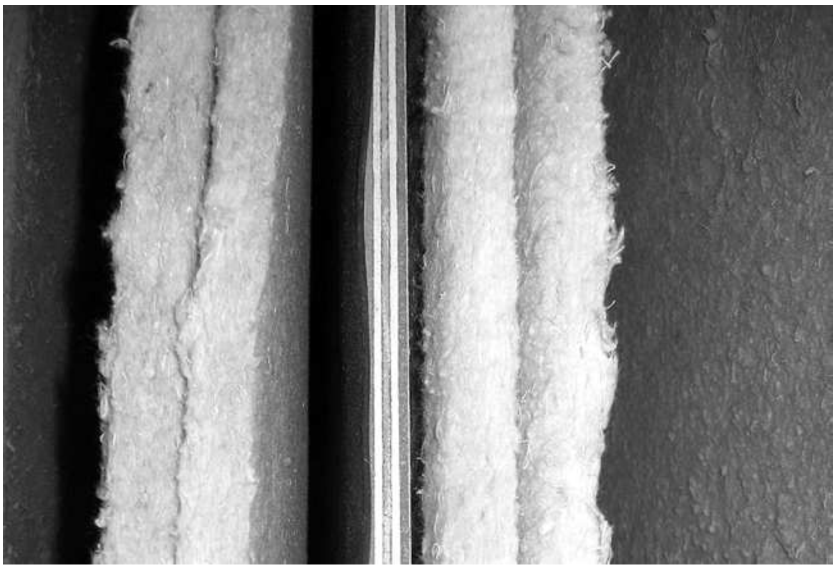


Figure A.1.16: Detail of the panel construction. The central core is of 12 mm plywood, with a layer of a 3.5 kg/m^2 dead-sheet stapled to one side to damp any panel resonances. On either side, loosely fixed, are two 2 cm layers of a flame retardant cotton-waste felt of about 60 kg/m^3.

absorber systems. Some of the results of this work have already been published,[6,7] and Figure A.1.18 shows the averaged absorption across the face of the rear absorber. From Figure A.1.19 it can be seen very clearly that the waveguide effect of the panels is significant,

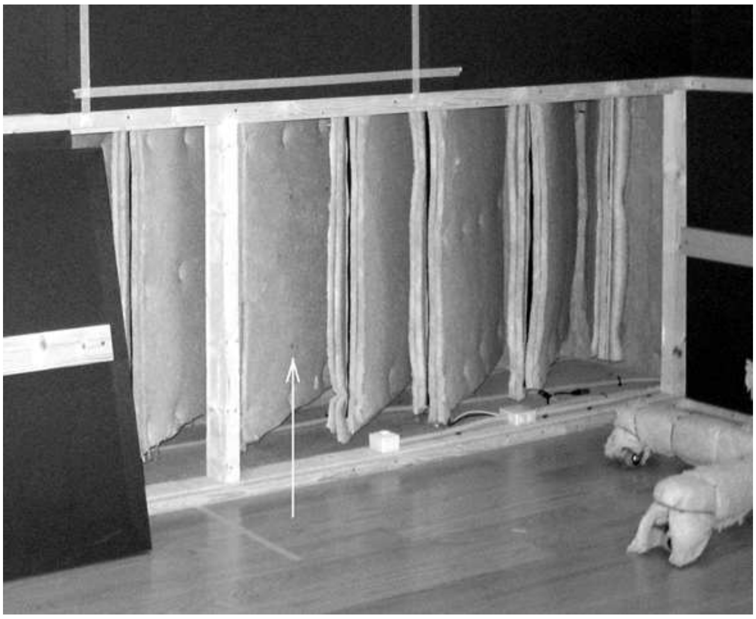


Figure A.1.17: The panel array behind the final, fabric covering.

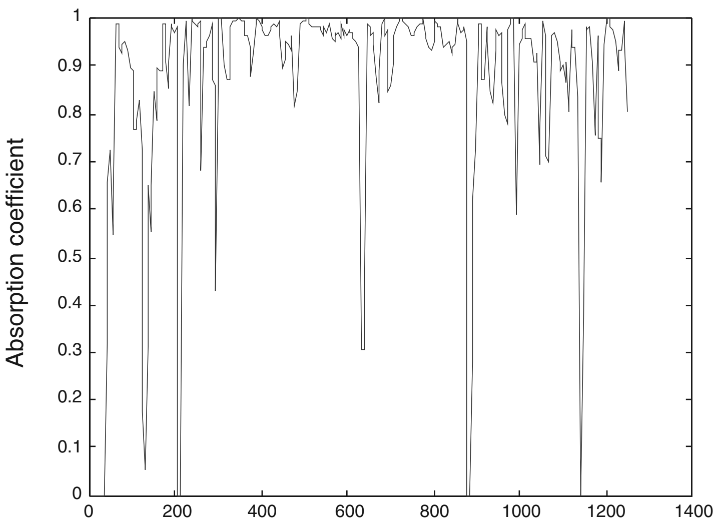
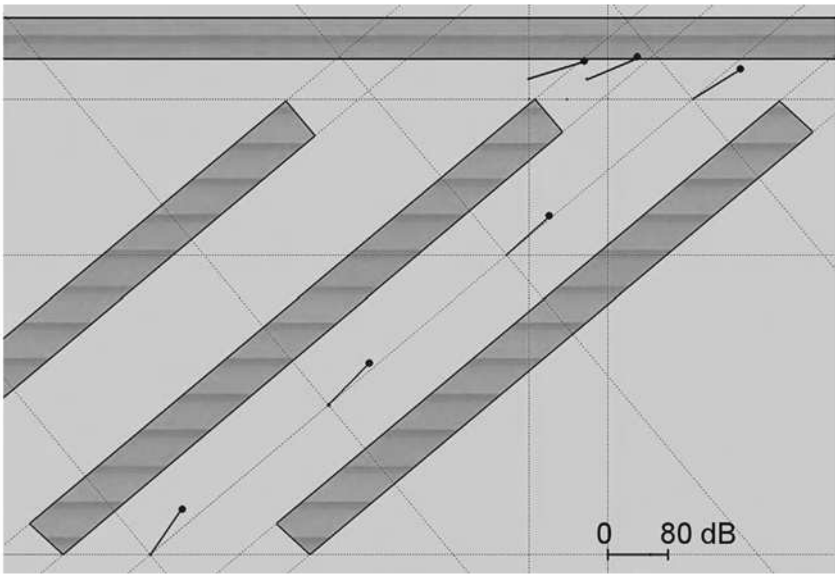


Figure A.1.18: Measured absorption coefficient of the rear wall absorption system. The deep, narrow dips are results of the measuring process.

and that it must lead to phase differences either side of each panel where their felt layers make contact with the rear lining of the 'trap'. This highlights the need for the felt on the panels to touch the felt on the rear surface, because when the out-of-step pressure differences on either side of the panels try to equalise themselves, there will be a flow through this resistive material and the consequent frictional losses will give rise to low-frequency absorption.

(a)



(b)

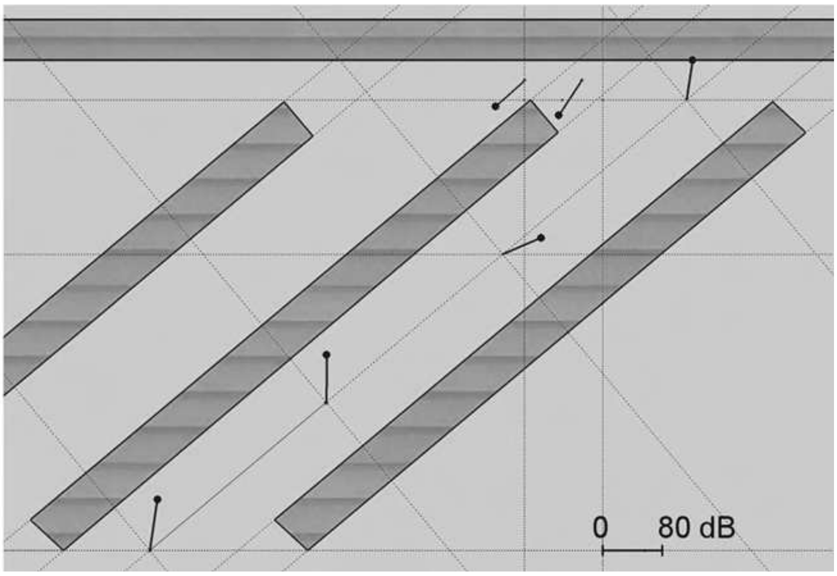


Figure A.1.19: Vector plots of the energy flow, clearly showing that the normally arriving (i.e. perpendicular to the wall) sound wave has been turned to flow parallel to the panels: (a) 63 Hz; (b) 500 Hz.

Evidence has also been found of the cavities between the panels supporting quarter-wave resonances of a highly damped nature. Once again, it is the frictional losses due to the 4 cm fibrous lining that give rise to the absorption, due to resistive losses. Without doubt, there are multiple, overlapping mechanisms at work which all contribute to the general absorption of the 'traps'.

References

1 Newell, P. R. and Holland, K. R., 'The measurement and analysis of a control room acoustic treatment during construction', *Proceedings of the Institute of Acoustics*, Vol. 22, Part 6, pp. 179–91, Reproduced Sound 16 conference, Stratford-upon-Avon, UK (2000).

2 Colam, S. and Holland, K. R., 'An investigation into the performance of a chipboard panel as a low frequency sound absorber'. *Proceedings of the Institute of Acoustics*, Vol. 21, Part 8, pp. 105–12, Reproduced Sound 15 conference, Stratford-upon-Avon, UK (1999).

3 Colam, Stuart, 'An investigation into an empirically designed passive sound absorber for use in recording studio control rooms'. Ph.D. thesis, ISVR, University of Southampton, UK (2002).

4 Newell, P. R. and Holland, K. R., 'The acoustic "trap" absorber systems: a review of recent research', *Proceedings of the Institute of Acoustics*, Vol. 25, Part 7, Autumn Conference, Oxford, UK (2003).

5 Soares, Luis E. B. 'An experimental study of the responses of a recording studio control room at low frequencies using a 1:10 scale model', MSc thesis, ISVR, University of Southampton, UK (1991).

6 Torres-Guijarro, Soledad, Pena, Antonio, Rodrigez-Molares, Alfonso and Degara-Quintela, Norberto, Sound field characterisation and absorption measurement of wideband absorbers, *Presented at the 126th convention of the AES*, Munich, Germany (May 2009).

7 Torres-Guijarro, Soledad, Pena, Antonio, Rodriguez-Molares, Alfonso and Degara-Quintela, Norbero, 'A study of wideband absorbers in a Non-Environment control room: Characterisation of the sound field by means of p–p probe measurements', *Acta Acustica with Acustica*, Vol. 97, pp. 82–92 (2011).