

# Performance Comparison of Graphic Equalisation and Active Loudspeaker Room Response Controls

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## ABSTRACT

We compare the room response controls available in active loudspeakers to a third-octave graphical equaliser. The room response controls are set using an automated optimisation method presented in earlier AES publications. A third-octave ISO frequency constant-Q graphic equaliser is set to minimise the least squares deviation from linear within the passband in a smoothed acoustical response. The resulting equalisation performance of the two methods is compared using objective metrics, to show how these standard room response equalising methods perform. For all loudspeaker models pooled together, the room response controls improve the RMS deviation from a linear response from 6.1 dB to 4.7 dB (improvement 22%), whereas graphic equalisation improves the RMS deviation to 1.8 dB (improvement 70%). Both equalisation techniques achieve a similar improvement in the broadband balance, which has been shown to affect a subjective lack of colouration in sound systems. The optimisation time for a graphic equaliser is up to 48 times longer compared to that for active loudspeaker room response controls.

## 1. INTRODUCTION

The purpose of room equalisation is to improve the perceived quality of sound reproduction in a listening environment. Electronic equalisation to improve the subjective sound quality has been widespread for at least 40 years (an early example is [1]). Equalisation is prevalent in professional sound reproduction such as recording studios, mixing rooms and sound reinforcement. In-situ response equalisation is often implemented using third-octave equalisers, which are normally set with the help of real time analysers. This measurement and equalisation combination is cheap, readily available and a relatively simple concept to grasp with a little training [2-4]. Room response correcting equalisers are now also increasingly built into active loudspeakers, but these equalisers have an entirely different approach as to how the equaliser addresses any acoustic problems of the reproduction.

Since the loudspeaker-room transfer function is of substantially higher order than the equalisation filters, the effect of either type of equalisation is to gently shape the acoustic response [5]. The room transfer function is position dependent, which poses major problems for all equalisation techniques. At high frequencies the required high-resolution correction can become very position sensitive [6,7]. Even with these limitations, in-situ equalisers have the potential to significantly improve perceived sound quality. The practical challenge is to find the best compromise for the parameters in the in-situ equaliser. An acceptable equalisation is typically a compromise to minimise the subjective coloration in the audio due to room effects. Despite advances in psychoacoustics, it is difficult to quantify what the listener actually perceives the sound quality to be [8-10], or to optimise equalisation based on that evaluation. Because of this, in-situ equalisation typically attempts to obtain the best fit to some objec-

tively measurable target known to relate to the perception of sound as being free from coloration, such as a flat third-octave smoothed magnitude response.

The purpose of this paper is to investigate how the standard room response controls available in active loudspeakers [11] compare to the industry standard method for sound system equalisation, i.e. a 31-band third-octave graphic equaliser. It is obvious that a graphical equaliser has many more adjustment degrees of freedom compared to the standard room response equalisers employed in active loudspeakers – there are 31 gains with fixed  $Q$ 's and centre frequencies in a graphical equaliser compared to some three to five separate settings with two to seven discrete values in the room response equaliser. This would appear to suggest that a graphical equaliser should achieve a superior outcome if set properly. However, the centre frequencies, and fixed  $Q$ , of a graphical equaliser are not designed to cope with typical room response problems and it is rather naïve to simply suggest that the higher degrees of freedom alone could be taken as an indication of how much better or worse one method is compared to another.

This paper presents a performance comparison of a room response control set available in active loudspeakers and a standard 31-band graphic equaliser. Optimisation algorithms are used to set both equalisers to achieve the best possible fit to the desired flat in-room magnitude response. To make possible this comparison, an optimisation algorithm was developed to set the gains of a 31-band graphical equaliser. This method is described. The performance of the equalisations and optimisation algorithms is investigated by studying the statistical properties of 67 in-situ magnitude responses before and after equalisation.

## 2. IN-SITU EQUALISATION

The room response controls were previously described in [12-14]. A constant- $Q$  type 31-band DSP graphic equaliser [15] was constructed using bi-quadratic transfer functions of the form,

$$H(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}} \quad (1)$$

where the scaling of the transfer function is given by the coefficients,

$$a_0 = 1 + \frac{\sin(2\pi f_0/f_s)}{2QA} \quad (2)$$

$$A = \sqrt{10^{G/20}}$$

with the centre frequency  $f_0$ , sampling frequency  $f_s$ , gain of the resonance  $A$ , calculated from the dB-gain value  $G$ , and the resonance goodness  $Q$ . The filter coefficients are then defined as,

$$\begin{aligned} b_0 &= \frac{\left(1 + A \frac{\sin(2\pi f_0/f_s)}{2Q}\right)}{a_0} \\ b_1 &= \frac{-2 \cos(2\pi f_0/f_s)}{a_0} \\ b_2 &= \frac{\left(1 - A \frac{\sin(2\pi f_0/f_s)}{2Q}\right)}{a_0} \\ a_1 &= \frac{-2 \cos(2\pi f_0/f_s)}{a_0} \\ a_2 &= \frac{\left(1 - \frac{\sin(2\pi f_0/f_s)}{2QA}\right)}{a_0} \end{aligned} \quad (3)$$

where  $f_0$  is set to the centre frequency of each of the 31 filter bands according to ISO and IEC [16,17]. These standards do not explicitly define the  $Q$ , instead a magnitude response tolerance is given to allow for design differences between manufacturers. For this study  $Q = 4.33$ ,

$$Q = \frac{f_0}{B} = \frac{10^n}{10^{n+0.05} - 10^{n-0.05}} = 4.33 \quad (4)$$

where  $n$  is a value that gives the third-octave band centre frequency, e.g.  $n = 3$  for 1 kHz, and  $B$  is the bandwidth of the third-octave resonance.

As is common practice in most commercially available hardware, the gain  $G$  is bound between 0 and -12 dB. Note that contrary to most hardware solutions, no positive gain is allowed and there is no overall make-up gain to compensate for broadband attenuation. Engineers commonly use this technique to avoid overloading the loudspeaker.

## 3. OPTIMISATION OF THE EQUALISATION

### 3.1. Room Response Control Optimiser

The five-stage algorithm previously described in [12,14] to find optimal settings for room response control exploits the heuristics of experienced system calibration engineers, thereby achieving computational efficiency by avoiding unrealistic filter setting combinations. A fast optimisation time is also achieved by breaking down the process into stages.

### 3.2. Graphic Equaliser Optimiser

With  $Q$  and centre frequency  $f_0$  fixed for each third-octave band, the remaining variable available for adjustment is the gain  $G$ . This is bound between 0 and  $-12$  dB. A least squares method, Matlab's "lsqnonlin" function [18], minimises the objective function,

$$\min_m E = \int_{f=f_1}^{f_2} \left| \frac{a_m(f) x(f)}{x_0(f)} \right|^2 df \quad (5)$$

where  $x(f)$  is the third-octave smoothed [19] magnitude of the loudspeaker in-situ frequency response,  $a_m(f)$  is the graphic equaliser magnitude response,  $x_0(f)$  is the target response and frequencies  $f_1$  and  $f_2$  define the optimisation band, i.e.  $-3$  dB lower cut-off frequency for the loudspeaker in question and the high frequency limit for the optimisation at 15 kHz.

The optimised filter values are rounded after optimisation to the nearest 0.1dB, as this is the typical gain resolution found in commercially available DSP graphic equalisers [20]. These values are used to filter the in-situ loudspeaker response prior to statistical analysis.

Visual inspection of the optimised responses shows that the algorithm is robust to finding the global minimum.

### 3.3. Computational Load

Optimisation speed was tested on a Pentium M 1.6 GHz based computer. The room response equaliser optimisation algorithm runs in about 1.5–3 s depending on the loudspeaker model, whereas the graphical equaliser optimisation algorithm takes 30–60 s, i.e. 10...20 times longer. The longer run time is explained by the higher degrees of freedom in a graphical equaliser. The large optimisation time variation is due to differing in-situ responses causing variations in the run time because the optimisation continues until the required fitting tolerance is achieved.

## 4. METHODS

### 4.1. Statistical Data Analysis

To assess the performance of the combination of optimisation algorithm and equalisation in the loudspeakers, the analysis compares the unequalised in-situ magnitude response to the equalised response.

The third-octave smoothed magnitude response was calculated. The optimal room response control settings were calculated for each loudspeaker response. Statistical data was recorded for each magnitude response measurement before and after equalisation to study

how the objective quality was improved. Further statistical analysis is conducted on all measurements in three frequency bands (Table 1) "LF", "MF" and "HF", collectively called "subbands" and corresponding roughly to the bandwidths for each driver in a three-way system.

Table 1. Frequency band definitions the statistical data analysis:  $f_{LF}$  is the frequency of the lower  $-3$  dB limit of the frequency range.

Bandwidth Name	Frequency Range Limit	
	Low	High
Broadband	$f_{LF}$	15 kHz
LF	$f_{LF}$	400 Hz
MF	400 Hz	3.5 kHz
HF	3.5 kHz	15 kHz

For each loudspeaker, the broadband median pressure is calculated. Pressure deviations from this median are recorded within each subband and for the broadband. These deviations are then used to describe the properties and extent of deviations from a flat response. Medians calculated for subbands, defined above, are recorded. The differences from the broadband median to subband medians are calculated and then used as an indicator for broadband balance of the frequency response. Both statistical descriptors are recorded before and after equalisation for each frequency band and each equalisation method.

The quartile difference and RMS deviation are calculated for the four loudspeaker categories determined by the type of built-in room response controls in the loudspeakers. Both the quartile difference and RMS deviation values represent two slightly different ways to look at the deviation from the median value of the distribution. The quartile values are more robust to outlier values while the RMS values include these effects.

### 4.2. Data Analysis Case Study

Figure 5 in Appendix C shows the third-octave smoothed and unsmoothed in-situ response of a large soffit mounted system [5]. The measurement technique is detailed in [12,14].

#### 4.2.1. Room Response Control Equalisation

Appendix A shows a case example where the room response control settings are calculated according to the optimisation algorithm [12-14]. The equalisation target is a flat magnitude response, i.e. a straight line at 0 dB level. The loudspeaker's passband (triangles) and the frequency band of equalisation (crosses) are

indicated on the graphical output (Figure 2). The control settings and before and after equalisation responses are shown. The treble tilt, midrange level and bass tilt controls have been set. The equalisation corrects the low frequency alignment and improves the linearity across the whole passband.

Figure 3 in Appendix A shows a statistical analysis of the same loudspeaker presented in graphical form. The upper three plots were calculated before equalisation and the lower three plots after equalisation. The three types of plot display outliers and percentiles in the magnitude value distribution (box plot), the histogram of values, with a 1 dB resolution, and the fit of the magnitude values to a normal distribution. These plots show that the distribution in the magnitude data has been reduced. This is illustrated by the reduced range in the box plot and the value histogram and a steeper curve in the normal probability plot. The fit to a normal distribution is shown but not discussed further. The time taken for the optimisation was 2.43 s.

#### 4.2.2. Graphic Equalisation

Appendix C shows the same case example as above, but using a graphic equaliser with settings calculated according the algorithm detailed in Section 3.2. The settings are shown in Table 2 and plotted in Figure 6. The effect on the in-situ response can be seen in Figure 7. Most of the equalisation takes place below 100Hz but some minor adjustment in the in-situ response is also made in the midrange to compensate for resonances due to room modes or constructive interference due to reflections. An improved linearity across the whole passband is seen and, in particular, the low frequency alignment has become better. The statistical analysis shown in Figure 8 demonstrates that the magnitude distribution has been reduced. This is illustrated by the reduced range in the box plot and the value histogram, and the steeper curve in the normal probability plot. The time taken for the optimisation was 29.66 s.

#### 4.2.3. Equalisation Comparison

Comparing the two equalisation techniques, the box plot, histogram and steeper line in the normal probability plot all indicate that the distribution of the data is smaller when graphic equalisation is used. The room response controls do achieve a good broadband balance (Figure 2) but the finer detail is not corrected. In addition to an improved broadband balance, graphic equalisation is able to correct for local features in the response (Figure 7) but only with limited success. Resonances due to room modes or constructive interference due to reflections in the response cannot be corrected accurately when the frequencies

do not coincide with the centre frequencies of third-octave filter bands. A good example of this can be seen at 600 Hz.

In the room response control equalisation, bass boost caused by soffit mounting the loudspeaker is corrected using a single bass tilt filter control set to  $-8$  dB. Graphic equalisation requires seven filters for this although better low frequency linearity is seen. It is clear that accurately setting a combination of seven filters is not a trivial task, especially if time is at a premium.

The distribution of the room response control equalisation's magnitude response (Figure 3) differs from the graphic equalisation's magnitude response (Figure 8). In the latter, there is a skew towards negative values as only negative gain can be applied to the response. In other words, the upward deviations (resonances or constructive interference) are equalised and the downward deviations (antiresonances or destructive interference) are not.

The graphic equaliser optimisation took 12.2 times longer than that for the room response equalisation optimisation.

## 5. RESULTS

A total of 67 loudspeakers were measured before and after equalisation. Of these, 12 were small two-way systems, 22 were two-way systems, 30 were three-way systems and three were large systems.

### 5.1. Room Response Control Equalisation

The detailed results of a statistical analysis for the individual loudspeakers were discussed in detail in [13]. The subband median levels (Figure 1) illustrate the broadband frequency balance between the subbands. Loudspeaker loading from nearby boundaries is reflected in the LF subband median level before equalisation, especially in the often flush-mounted three-way and large models. Cancellations from nearby boundaries are reflected in the low median value of the LF subband of the small two-way and two-way systems.

High median levels in the LF subband are reduced after equalisation, which indicates that equalisation compensates well for the loudspeaker loading, however cancellations cannot be equalised. Improvements in the flatness across subbands of the average subband median level demonstrates that equalisation can improve the broadband flatness. The largest improvement is seen in the three-way and large systems. The broadband flatness improvement is mainly the result of better alignment of the LF subband with the MF and HF subbands, and a reduction of variation in the

LF subband as indicated by the smaller errors bars. For all loudspeakers pooled together (Figure 1), the equalisation reduces the variance in the median level for the LF subband. In Figure 4, Appendix B, the results are pooled for all products and for each product type. The change in quartile difference and RMS deviation for the broadband and the subbands is illus-

trated. Across all models, the broadband flatness is improved by 1.4 dB and the mean reduction in the LF subband RMS deviation is 2.0 dB.

The average time taken for room response control optimisation is  $1.83 \text{ s} \pm 0.68 \text{ s}$ . The best case is 1.12 s and the worst case is 2.97 s.

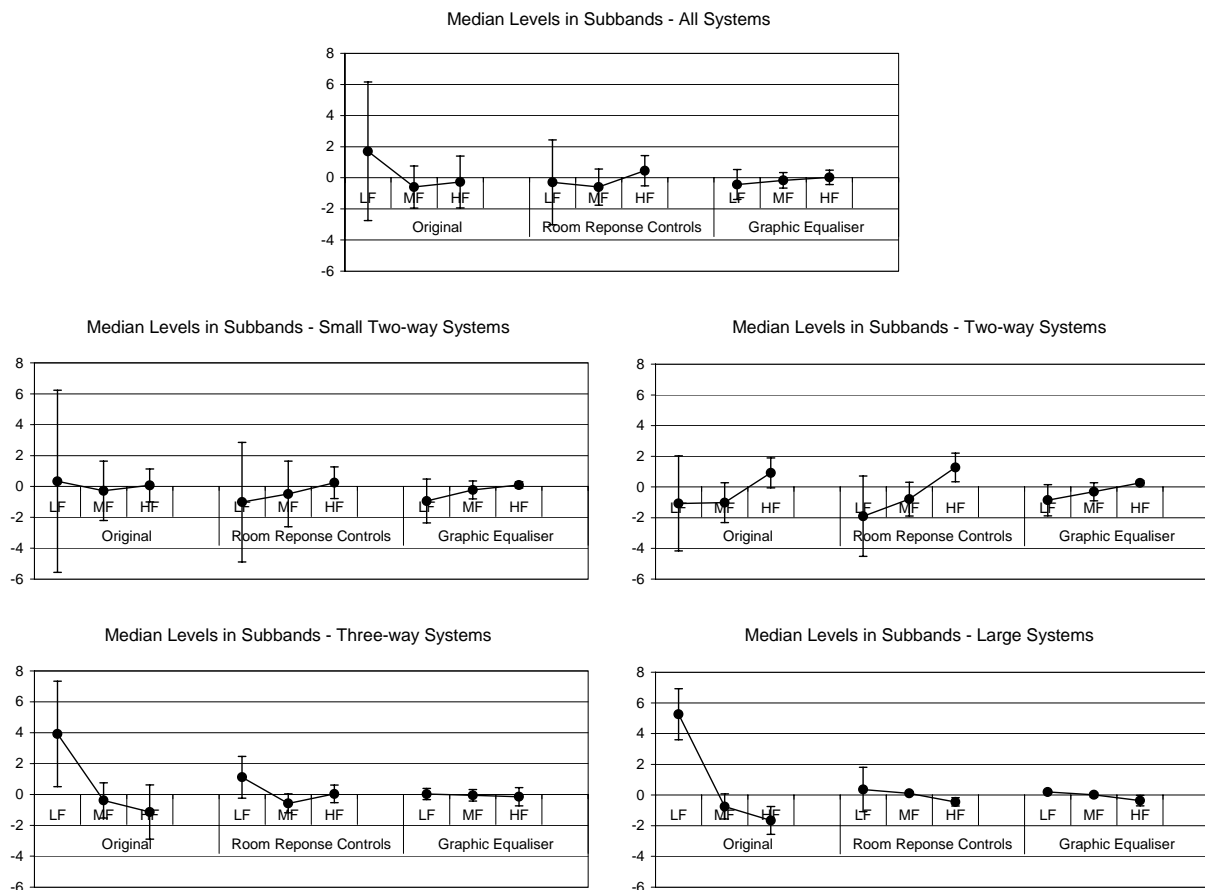


Figure 1. Mean and standard deviation of subband median levels before and after room response control and graphic equalisation.

### 5.2. Graphic Equalisation

Appendix D (Figures 9-13) depicts the use of the equaliser controls for each loudspeaker group. The upper graph (a) shows how the graphic equaliser is used including the use of 0 dB settings. The lower graph (b) shows how it is used excluding the use of 0 dB settings and therefore demonstrates how much EQ is required when it is used. Values for the 16 kHz and 20 kHz bands can be ignored as they are outside the optimisation frequency range in all cases.

The small two-way models (Figure 9) show a general trend of bass reduction,  $-3$  to  $-5$  dB, but with some additional large midrange adjustments and small high

frequency balancing. The standard deviations are large, indicating that there is little consistency in the required equalisation across loudspeakers.

The two-way models (Figure 10) show a general trend of bass reduction,  $-2$  to  $-4$  dB, slightly less midrange reduction,  $-1$  to  $-2$  dB, adjustment and small high frequency shelving too. Equalisation is required in lower frequency bands as these systems have a deeper bass extension. The standard deviations are small indicating that there is more consistency in the required equalisation across loudspeakers. In general, less equalisation is required than for the small two-way systems.

Similar trends are seen for the three-way systems (Figure 11) except that the bass reduction averages  $-3$  to  $-5$  dB and some additional roll-off shape is seen at the very lowest frequencies of the loudspeakers.

As there were only three large system responses (Figure 12), all taken from same room, the standard deviations indicate the equalisation consistency.

Across all of the loudspeakers (Figure 13), the general trend is a need for approximately 3 dB to 4 dB of bass attenuation, 2 dB from 200 Hz to 500 Hz and only 1 dB above 500 Hz. A 0 to  $-12$  dB gain range is sufficient. Across the whole study, only one of the third-octave bands inside the optimisation frequency range was set to the maximum attenuation,  $-12$  dB.

The subband median levels (Figure 1) demonstrate that a high median level in the LF subband is reduced by the equalisation. This indicates that equalisation compensates for acoustical loading of the loudspeaker. The better match across subbands of the average subband median level demonstrates that equalisation has improved the broadband flatness, and the largest improvement is seen in the three-way and large systems. The broadband flatness improvement is mainly the result of better alignment of the LF subband with the MF and HF subbands. The equalisation has reduced the variation between subbands and also improved the broadband flatness of the acoustical response. For all loudspeakers pooled together, the equalisation reduces the variance in the median level for the LF subband.

In Figure 14, Appendix E, the results are pooled for all products and for each product type. The change in quartile difference and RMS deviation for the broadband and the subbands is illustrated. For all models, the broadband flatness is improved by 4.3 dB and the mean reduction in the LF subband RMS deviation improvement is 5.9 dB. The graphic equaliser is able to compensate, to some extent, the severe anomalies attributable to extremely bad room acoustic conditions seen within some of the pre-equalisation responses.

The average time taken for graphic equalisation optimisation is  $31.40 \text{ s} \pm 16.64 \text{ s}$ . The best case is 14.61 s and the worst case is 116.29 s.

### 5.3. Equalisation Comparison

Appendix F, Figure 15, represents the difference between the change in sound level deviation due to the room response controls and the graphic equalisation techniques. For each subband, quartile difference and RMS deviation from the median are plotted. A value below 0 dB indicates that graphic equalisation achieves a response closer to the target. For all loudspeaker models pooled together, the room response controls improved the RMS deviation from 6.1 dB to 4.7 dB (improvement 22%), whereas graphic equalisa-

tion improved the RMS deviation to 1.8 dB (improvement 70%). The main improvement is seen at low frequencies. The better performance by the graphic equaliser is achieved by using between five (large loudspeakers) and ten times (small two-ways) more equalisation stages and far longer optimisation times.

The additional time it takes to perform the graphic equalisation optimisation compared to room response equalisation optimisation is  $18.54 \pm 8.49$  times longer. The best case is 8.35 times longer and the worst case is 47.97 times longer.

## 6. DISCUSSION

The room response controls in active loudspeakers implement discrete filter parameter values rather than a continuous parameter value range. A 31-band graphic equaliser typically allows for control of the gain in each of the third-octave centred bands over a range of  $\pm 12$  dB and an overall make-up gain over the same range. In this study the gains were constrained to a range of 0 to  $-12$  dB and a least squares optimisation algorithm designed for selecting the optimal settings.

The statistical analysis of 67 in-situ loudspeaker responses shows that both equalisation methods achieve a smaller RMS deviation from the target response. The improvement is limited by the equalisers' inability to correct for narrow-band deviations in a magnitude response. There is little improvement in the quartile differences and RMS deviations in the MF and HF subbands. This is because room related response variations are too narrow band to be corrected by a third-octave graphic equaliser or the room response control equaliser. The largest improvement is seen in the three-way and large systems. This suggests that better room acoustics, leading to a reduced loudspeaker-room interaction, allows the equalisation methods to operate more effectively.

The room response controls in the active loudspeakers achieve a good broadband balance but the fine detail is not corrected. Correcting fine detail may not be very significant because human hearing is more sensitive at detecting wideband imbalances than narrow band deviations in the magnitude response [21, 22].

In an acoustically good room, the room response controls built into an active loudspeaker allow for good control of the broadband balance. A good example of this can be seen in averaged median values of the large systems (Figure 1) where the three responses show good balancing and relatively little variance. Even the three-way systems show a balancing within a 1.5dB window with relatively low variance. This is

also the probable cause for improving performance towards larger systems (Figures 4 and 14) shown by a similar trend across both equalisation methods. This underlines the importance of primarily solving acoustical problems by treating the room before trying to use equalisers.

Graphic equalisation can yield a somewhat flatter response, but multiple filter bands may be required to correct for large features in the response. Some upward deviations in the response, due to resonances or constructive interference, cannot be corrected accurately when they do not coincide with the graphical equaliser's centre frequencies. This complexity of graphical equalisers makes manual gain setting complex and therefore more prone to operator error. When using computerised optimisation, the time to calculate a graphical equaliser's settings was 8-48 times longer than the time to select the best room response control settings.

Graphic equalisation achieves LF subband results closer to the target. Both equalisation techniques achieved a similar improvement in the broadband balance, which has previously been shown to determine a subjective lack of colouration in sound systems.

## 7. CONCLUSIONS

The objective of this paper is to compare the performance of the industry standard 31-band graphic equaliser to the room response controls built into active loudspeakers. Both equalisation techniques achieved a similar improvement in the broadband balance, which has previously been shown to determine a subjective lack of colouration in sound systems. For all loudspeaker models pooled together, the room response controls improved the RMS deviation from 6.1 dB to 4.7 dB (improvement 22%), whereas graphic equalisation improved the RMS deviation to 1.8 dB (improvement 70%). The graphical equaliser achieves this improvement by using between eight (large loudspeakers) and ten times (small two-ways) more equalisation stages, 8-48 times the optimisation time and considerable increases in the financial cost.

## 8. ACKNOWLEDGEMENTS

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APPENDIX A – ROOM RESPONSE CONTROL CASE STUDY, STATISTICAL GRAPHS

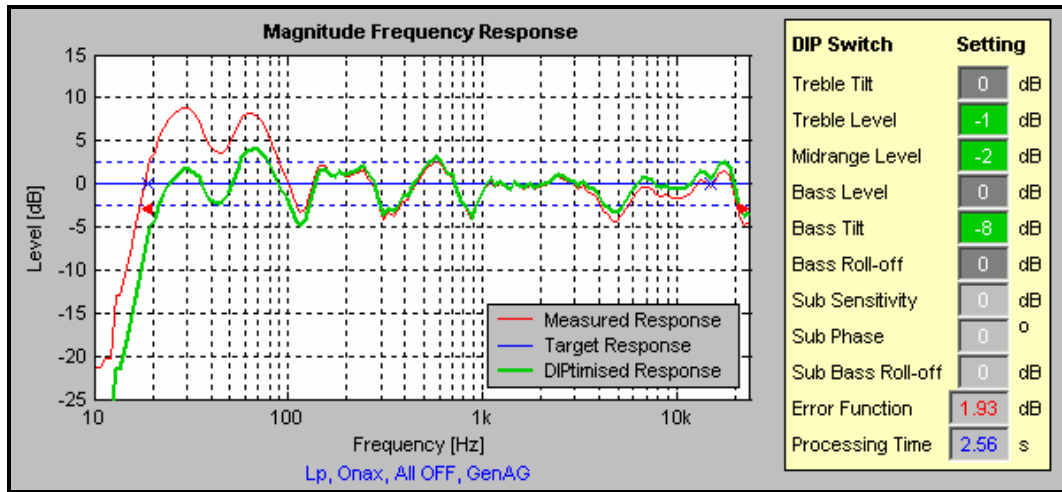


Figure 2. Case study optimisation results using room response control equalisation.

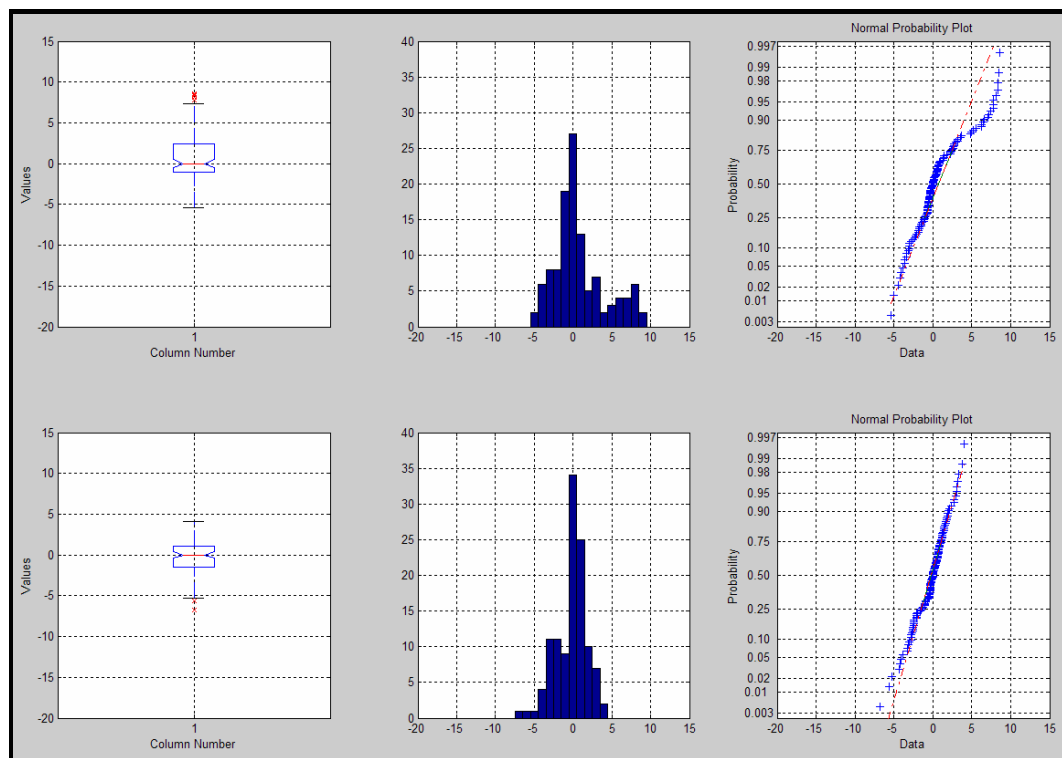


Figure 3. Case study statistical output – box plot, histogram and normal probability plot before (upper) and after (lower) optimised room response control equalisation.

APPENDIX B – MODEL GROUPED ROOM RESPONSE CONTROL EQUALISATION SUMMARY

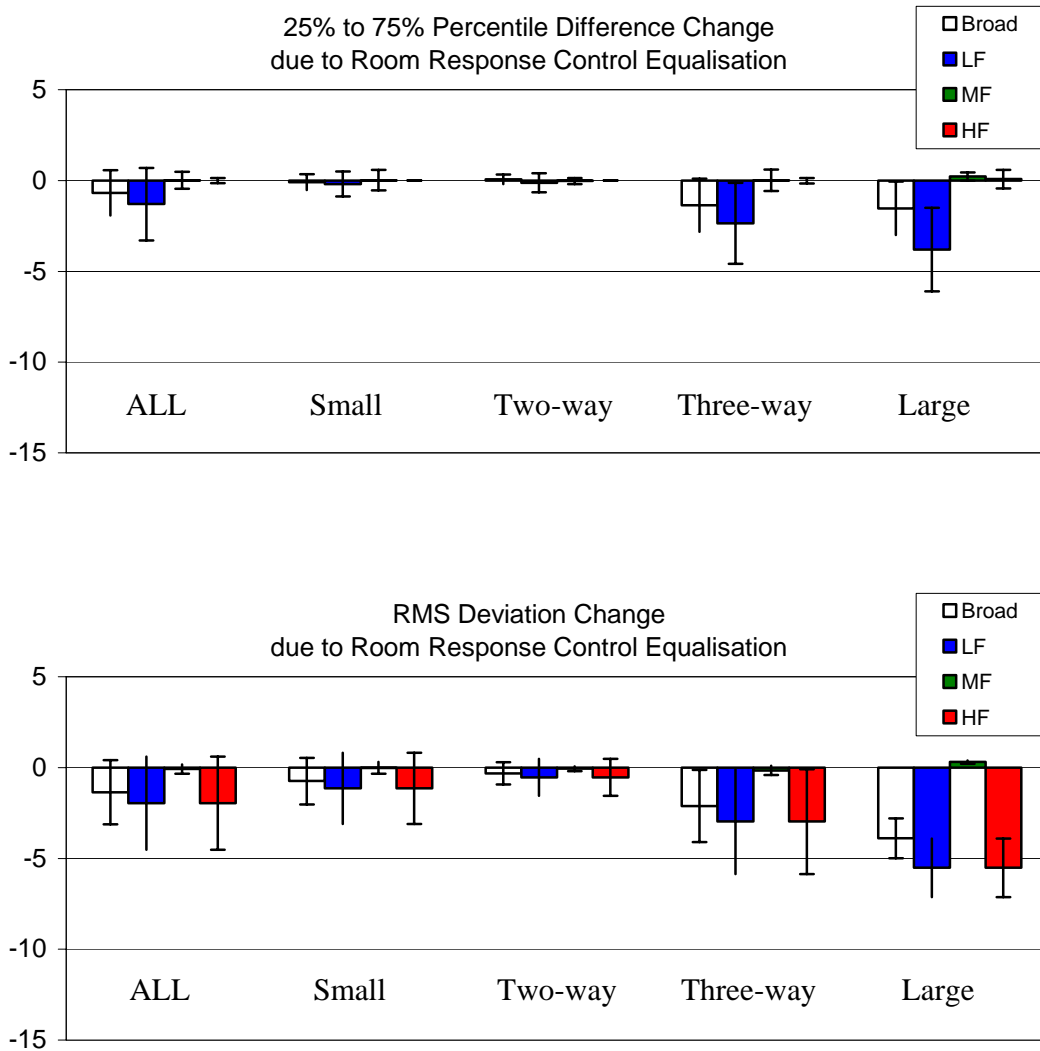


Figure 4. Change in sound level deviation due to Room Response Control equalisation for each subband and the broadband, quartile difference and RMS of deviation from the broadband median. The error bar indicates the standard deviation.

**APPENDIX C – GRAPHIC EQUALISER CASE STUDY, STATISTICAL GRAPHS**

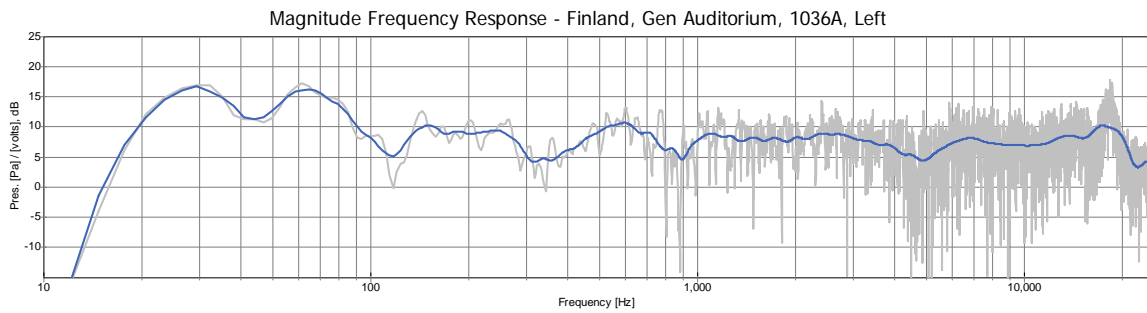


Figure 5. Unequalised in-situ acoustic measurement with smoothed and unsmoothed data.

Table 2. Graphic equaliser settings.

Centre Frequency, Hz	Gain, dB	Centre Frequency, Hz	Gain, dB	Centre Frequency, Hz	Gain, dB	Centre Frequency, Hz	Gain, dB
20	-1.6	200	-0.7	2,000	0.0	20,000	0.0
25	-6.6	250	0.0	2,500	-0.1		
32	-7.7	315	0.0	3,150	0.0		
40	-1.4	400	0.0	4,000	0.0		
50	-2.1	500	-0.2	5,000	0.0		
63	-8.2	630	-1.3	6,300	0.0		
80	-3.3	800	0.0	8,000	0.0		
100	0.0	1,000	0.0	10,000	0.0		
125	0.0	1,250	0.0	12,500	0.0		
160	-0.9	1,600	0.0	16,000	0.0		

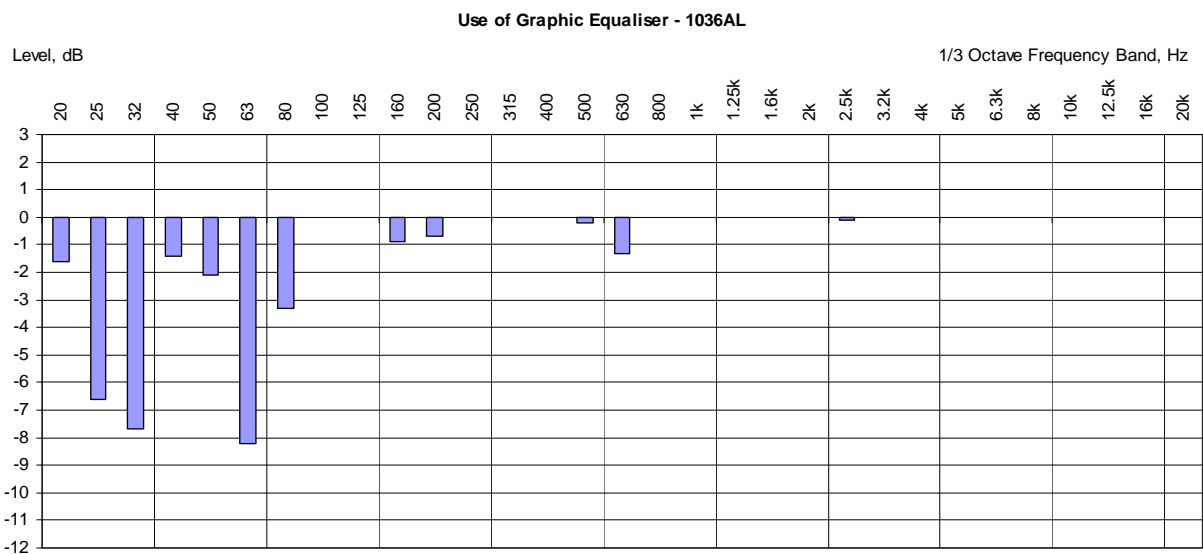


Figure 6. Graphic equaliser settings.

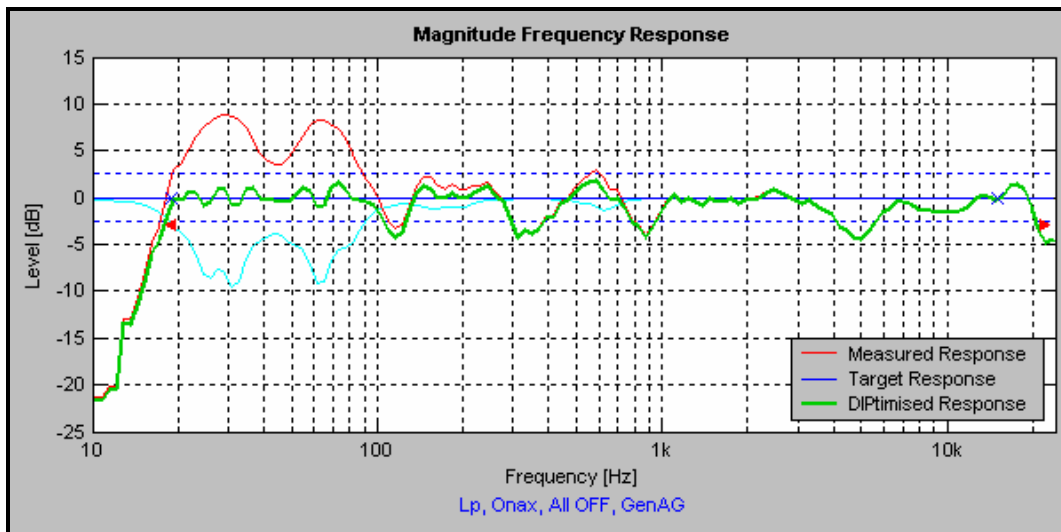


Figure 7. Case study optimisation results using graphical equalisation.

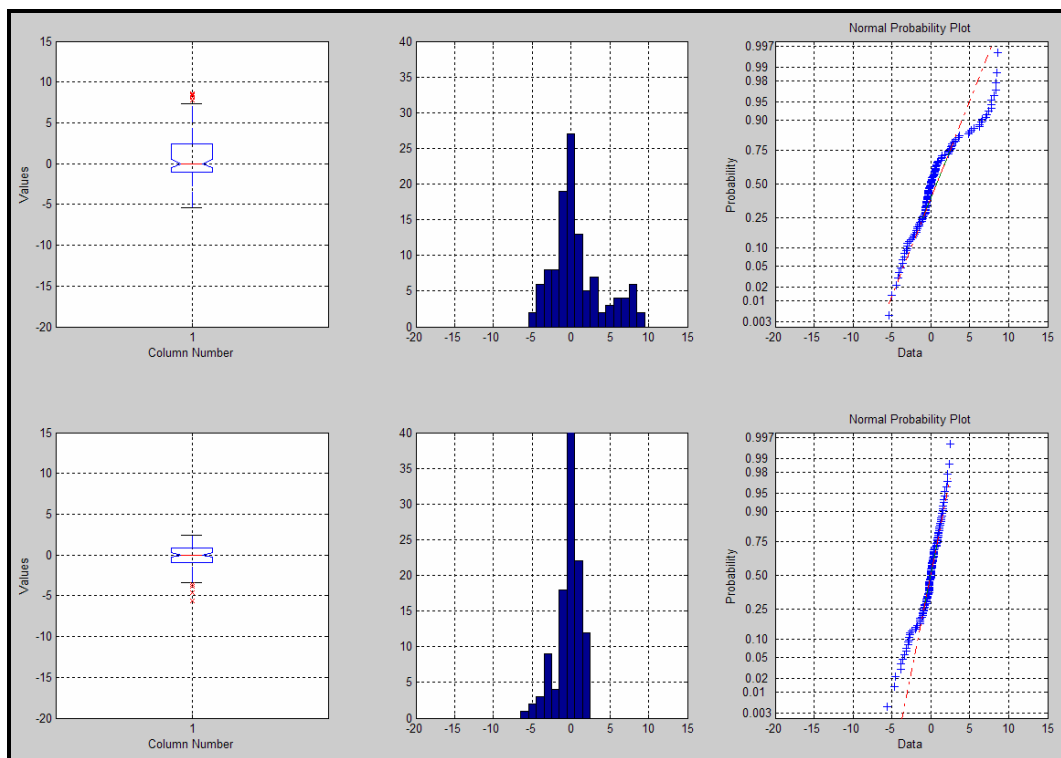


Figure 8. Case study statistical output – box plot, histogram and normal probability plot before (upper) and after (lower) optimised graphical equalisation.

APPENDIX D – GRAPHIC EQUALISER STATISTICAL GRAPHS

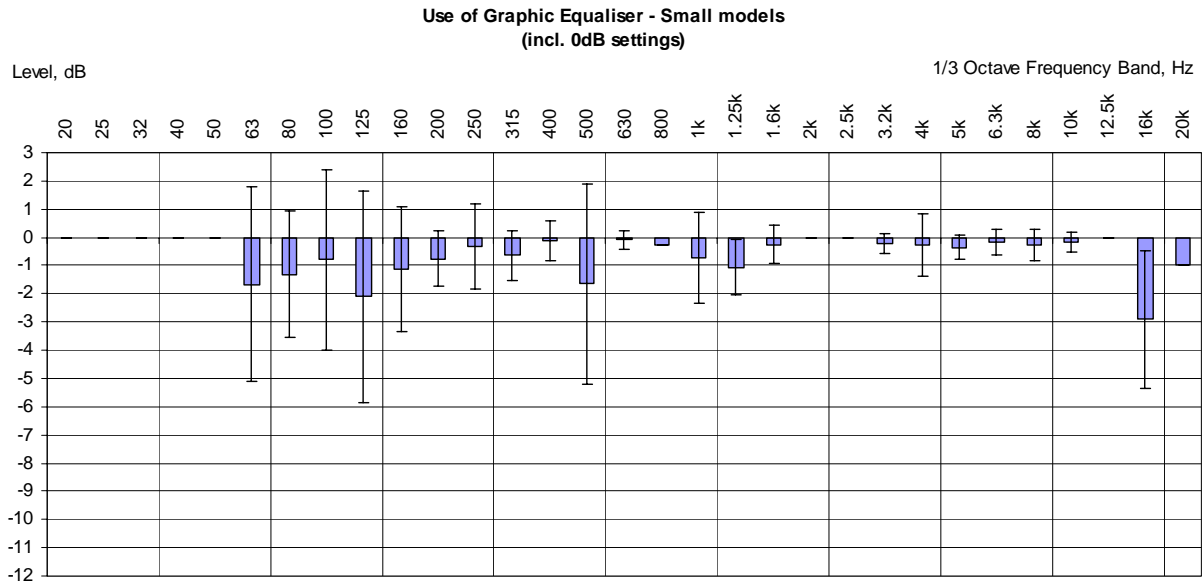


Figure 9a. Use of the graphic equaliser for small 2-way systems – including 0dB settings.

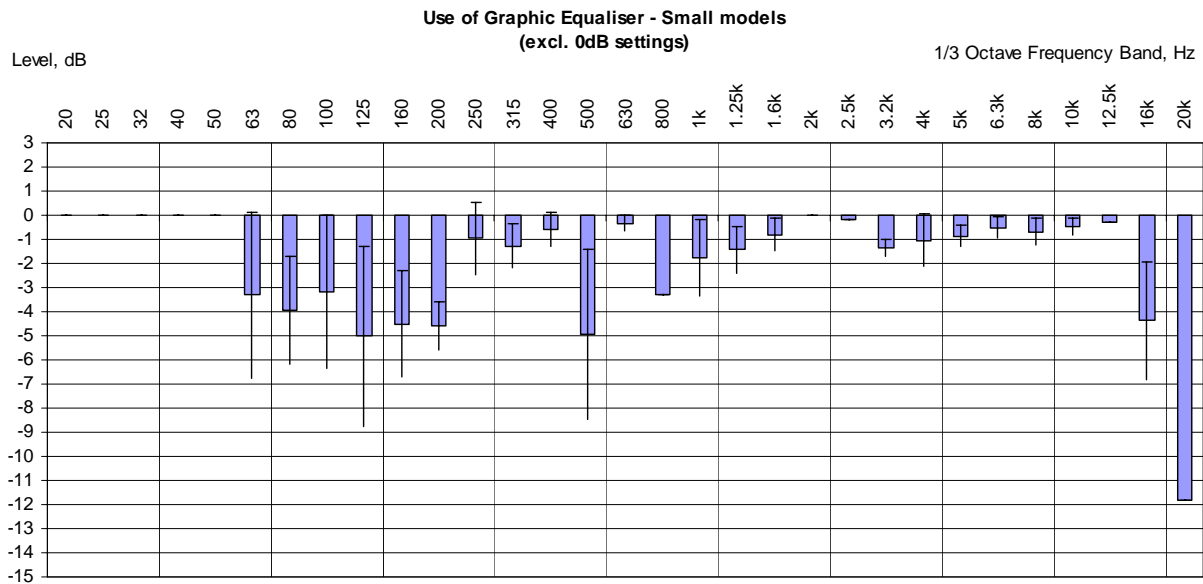


Figure 9b. Use of the graphic equaliser for small 2-way systems – excluding 0dB settings.

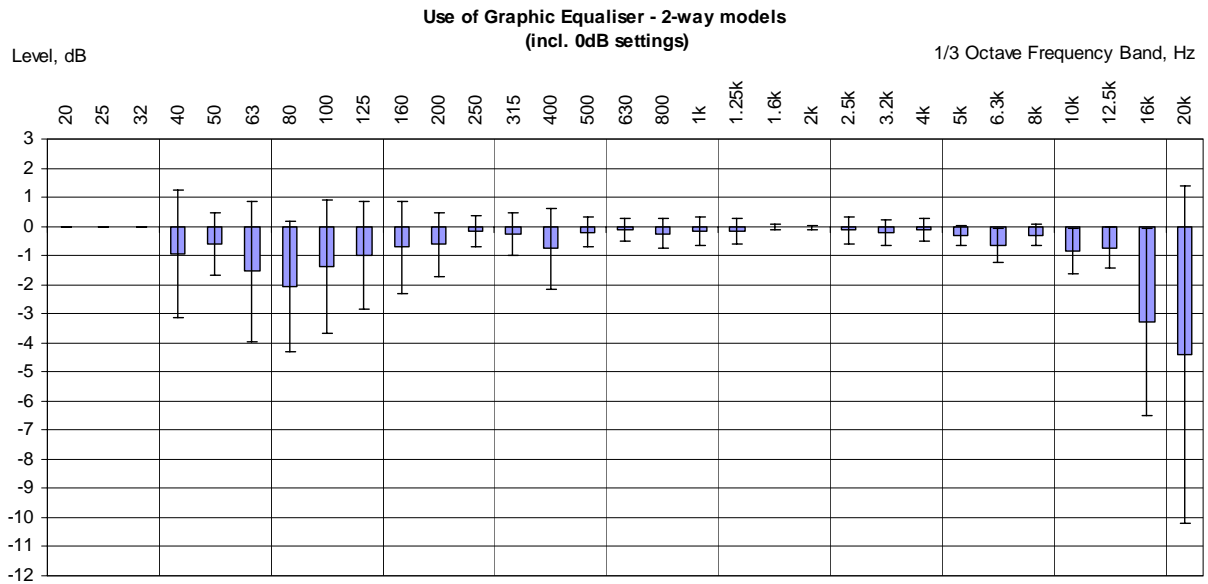


Figure 10a. Use of the graphic equaliser for 2-way systems – including 0dB settings.

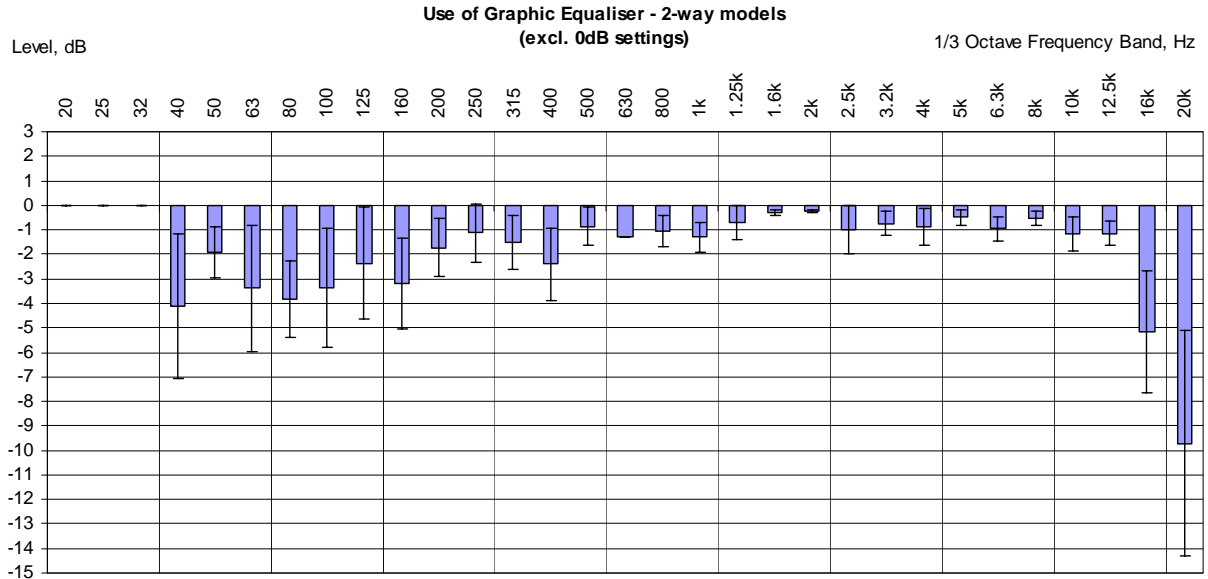


Figure 10b. Use of the graphic equaliser for 2-way systems – excluding 0dB settings.

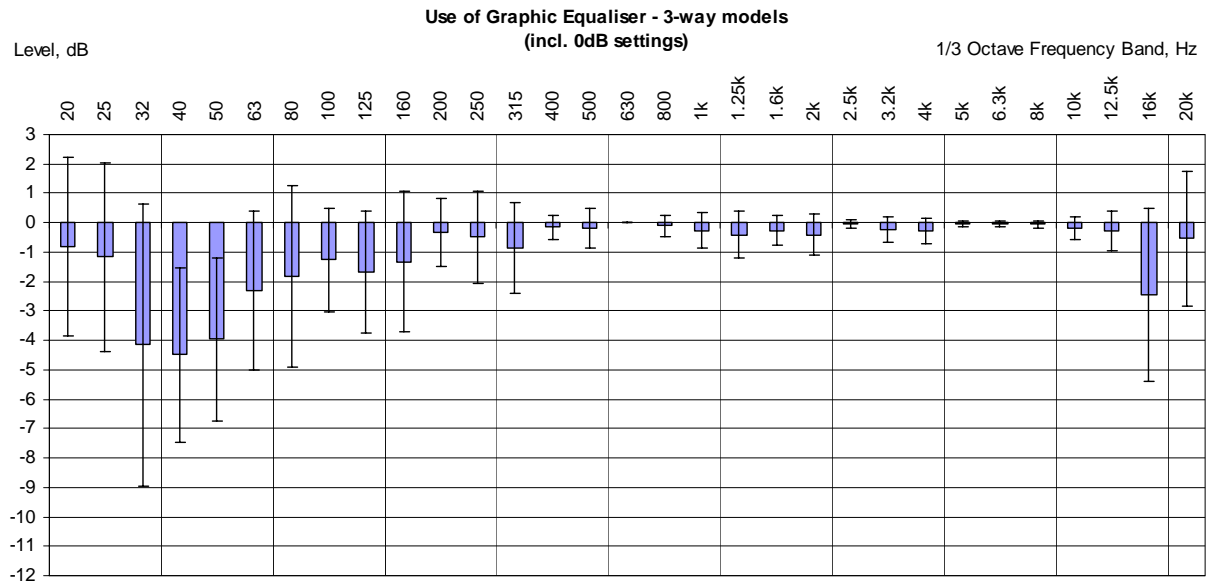


Figure 11a. Use of the graphic equaliser for 3-way systems – including 0dB settings.

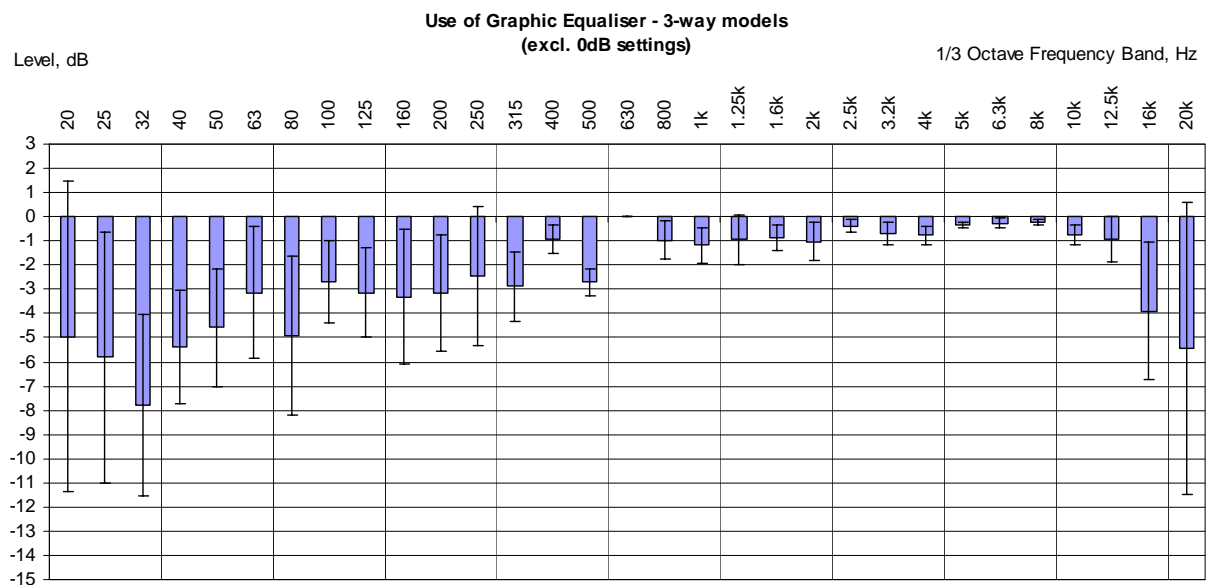


Figure 11b. Use of the graphic equaliser for 3-way systems – excluding 0dB settings.

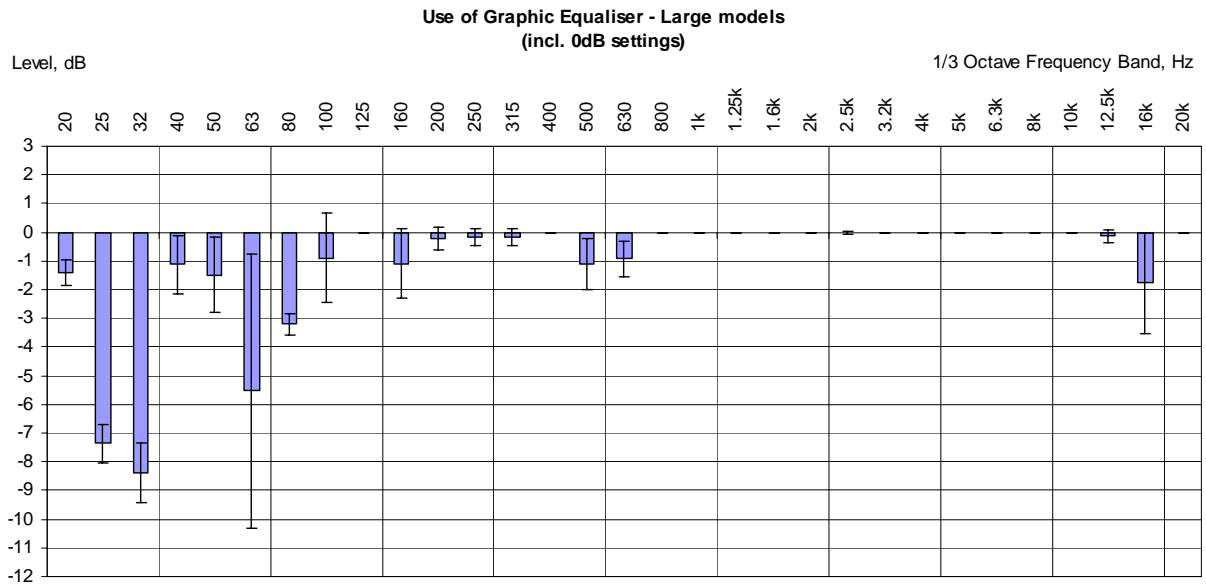


Figure 12a. Use of the graphic equaliser for large systems – including 0dB settings.

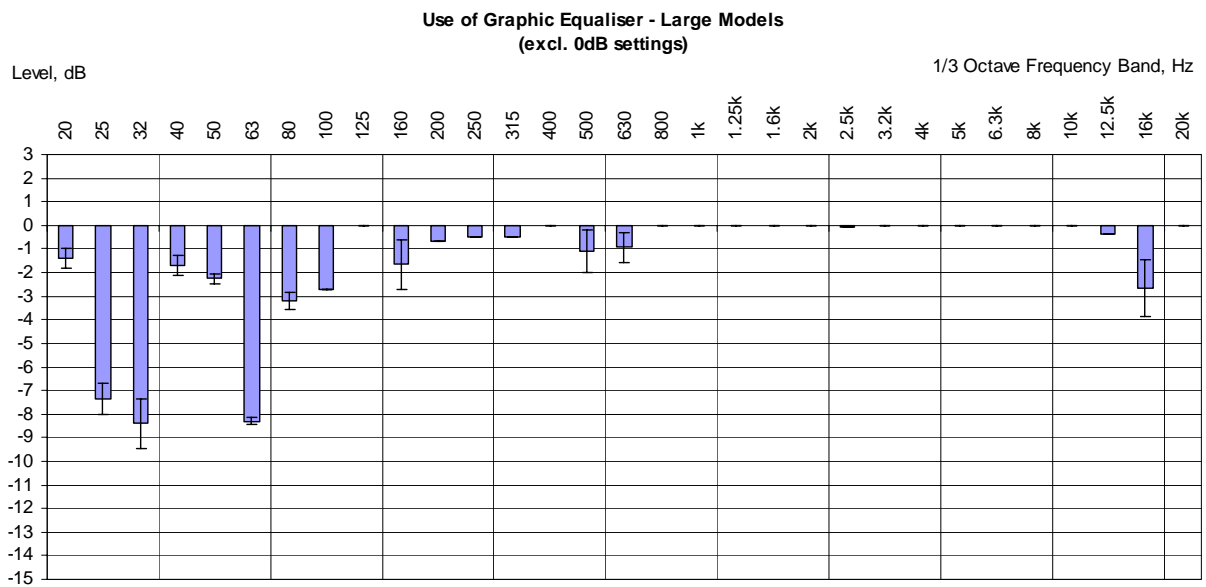


Figure 12b. Use of the graphic equaliser for large systems – excluding 0dB settings.



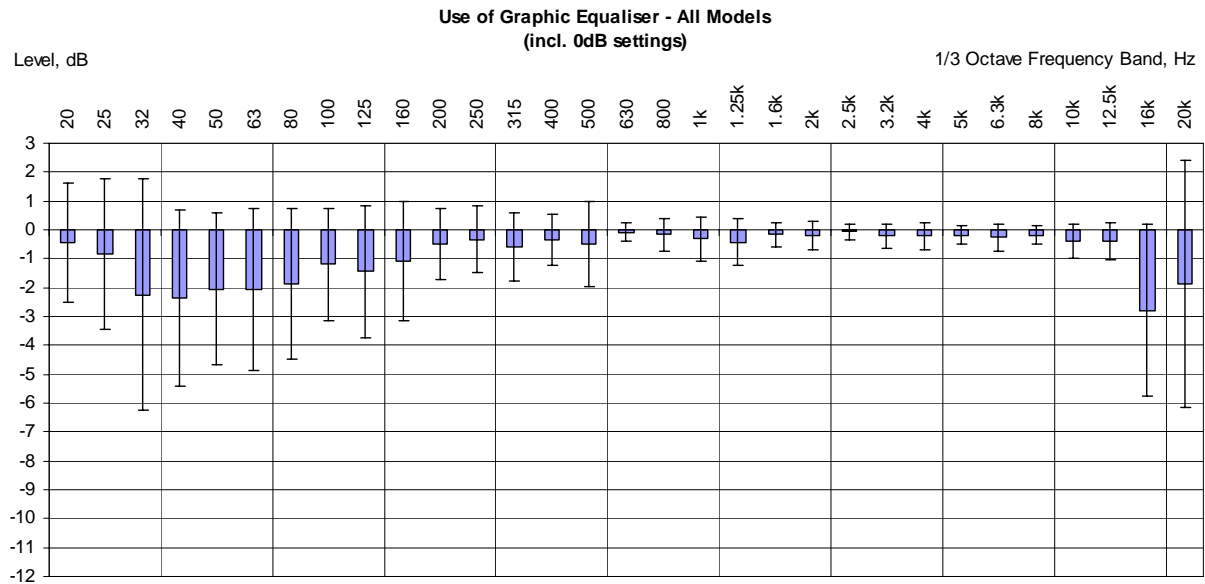


Figure 13a. Use of the graphic equaliser for all systems – including 0dB settings.

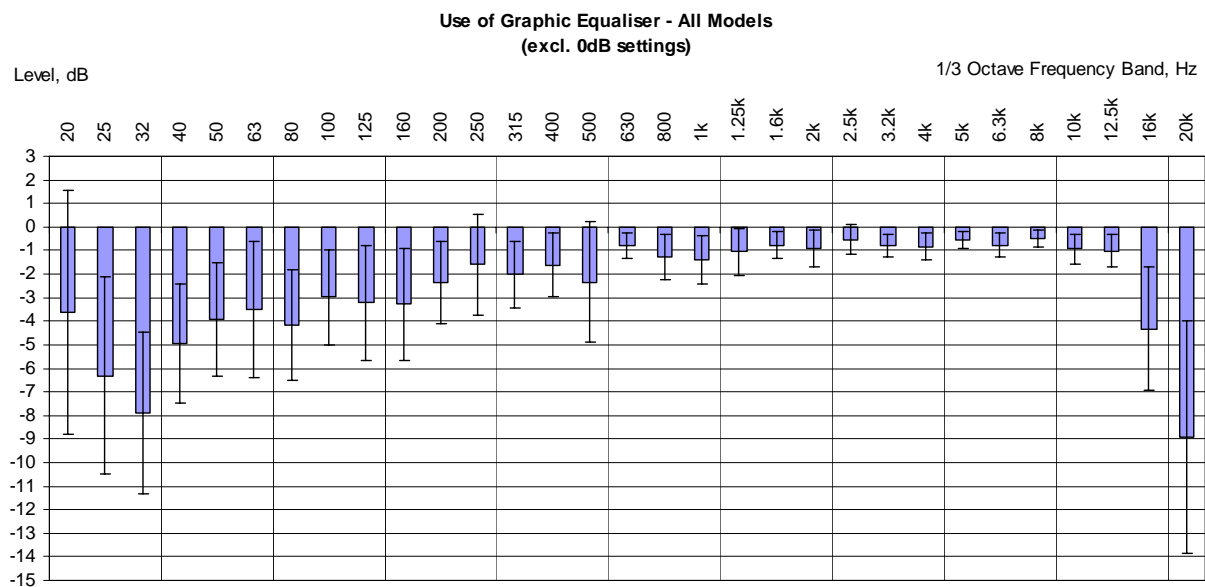


Figure 13b. Use of the graphic equaliser for all systems – excluding 0dB settings.

APPENDIX E – MODEL GROUPED GRAPHIC EQUALISATION SUMMARY

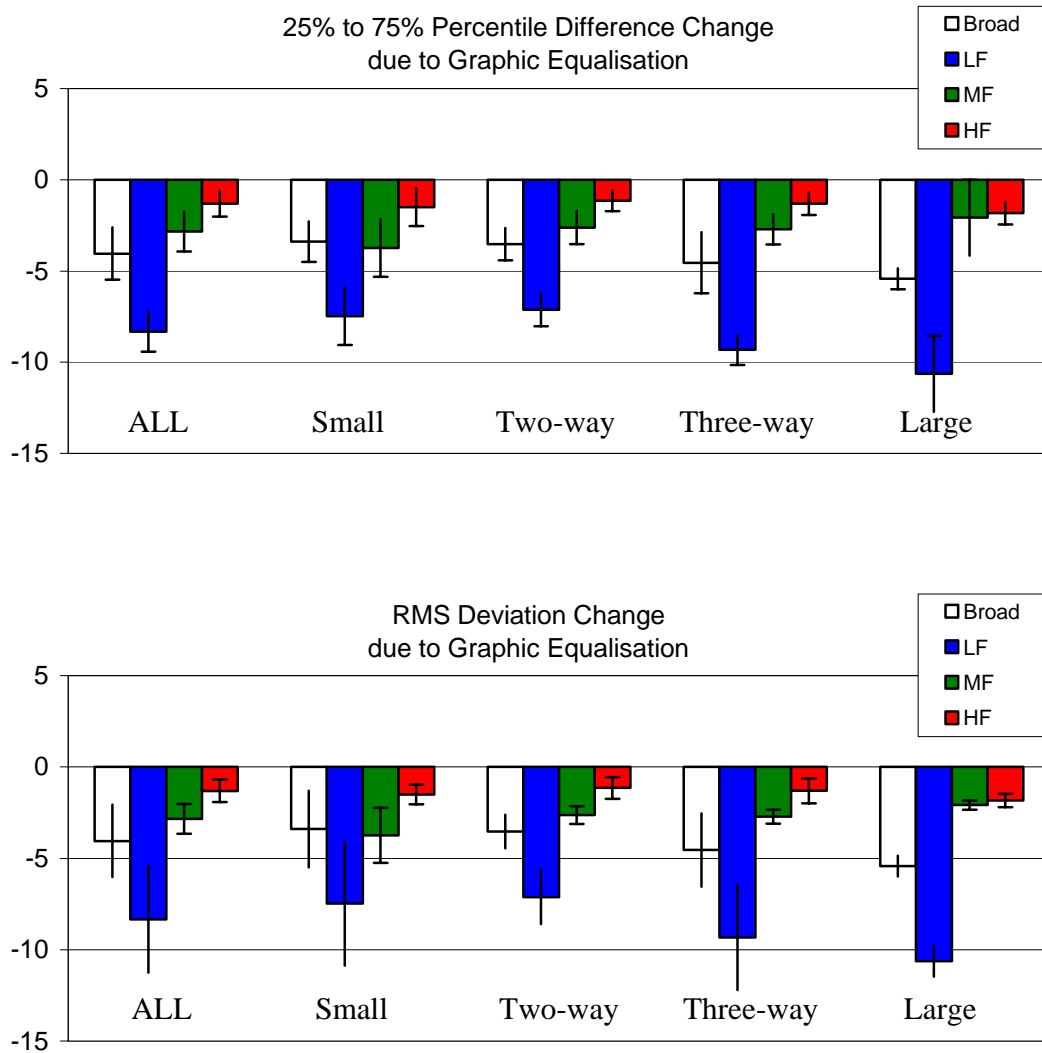


Figure 14. Change in sound level deviation due to graphic equalisation for each subband and the broadband, quartile difference and RMS of deviation from the broadband median. The error bar indicates the standard deviation.

APPENDIX F – COMPARISON OF EQUALISATION TECHNIQUES SUMMARY GRAPHS

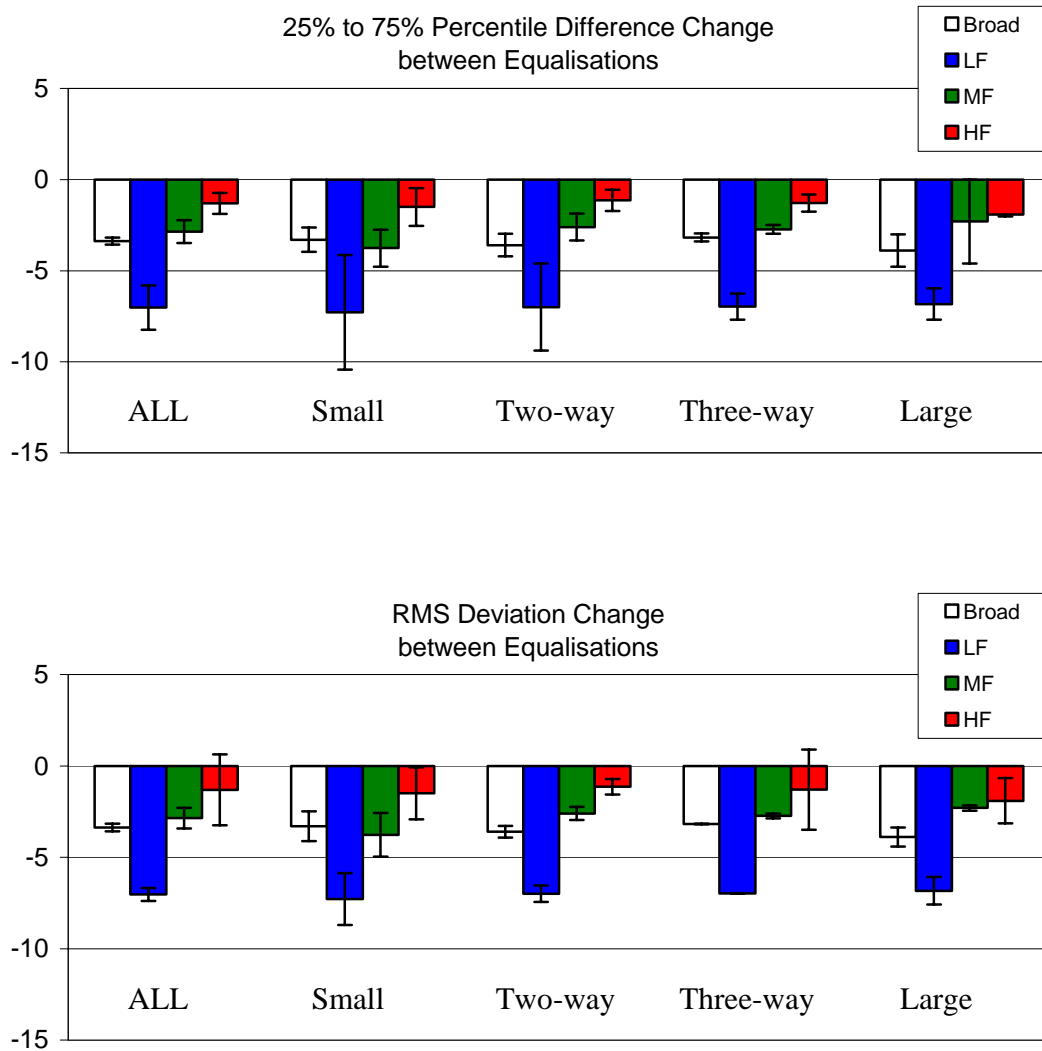


Figure 15. The difference between the change in sound level deviation for the room response control and the graphic equalisation techniques for each subband and the broadband, quartile difference and RMS of deviation from the broadband median are plotted. A value below 0dB indicates that graphic equalisation achieves a response closer to the target.