Audiophile Recordings Trust

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Section 4: Listening Room Treatment for Accurate Music Reproduction

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Summary

- This article is intended to apply to rooms of a domestic size for critical listening situations. The reader should be aware that typical guidelines for auditoriums, theaters or other types of halls are not applicable in this application.
- Room treatment methods are summarized and examples of calculations and material properties.
- Room responses of speakers in treated rooms are discussed and explained.
- Suggestions to minimize room effects through driver selection are given.
- Simple **low cost room testing** is made possible using sound meters and test tones available on a cd.
- A **further article** is available concerning speaker responses in highly absorptive rooms

Links to various sections

If you find your expensive hi-fi system does not sound right when played loud, or you have just moved it to another room, added some new costly upgrade with disappointing results, the chances are it is the room acoustics that are the cause.

Room treatment is normally at the bottom of, or not even on the list of the typical audiophile's 'must have' list. Years of marketing emphasis on sources, amplifiers, interconnects and speakers have left the last remaining audio frontier, the listening room, sadly neglected.

TABLE 1:THE LISTENING ROOM

The usual domestic listening room is a multi-purpose environment or, perhaps increasingly with the growth of home theater, a dedicated entertainments room. Whatever the situation, all rooms have the same problems to a greater or lesser extent, and all rooms problems have the same solutions.

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	Problem	Reason	Effect on listening	Solution
A	Low frequency resonances 30 - 150Hz	Confined LF in a non absorbent environment .	Large audible peaks and dips in response with long reverberation decay times. Gives muddled bass lines referred to as 'one note bass'.	Install bass traps (bass absorbers) or wide range absorbers.
B	Early reflections off walls 500 - 10000Hz	All walls, masonry or plaster board, act as good plane reflectors.	Delayed image of each speaker produces confused stereo / spatial imaging. Flutter echoes between adjacent walls.	Install sound diffusers or sound reflectors.
C	Incorrect room reverberation times.	Too much or too little sound absorption.	Listener fatigue, masking of fine detail, poor speech intelligibility, limited dynamic range.	Diffusers and bass traps introduce some absorption. Install absorption panels, curtains and soft furniture if required.
D	Room colouration	Mismatched absorption across the audio spectrum	Excessive lower mid range (200 – 500Hz) , treble loss	Careful selection of room treatment products to equalize

				absorption across the critical audio spectrum.

NEAR FIELD / FAR FIELD AND THE REVERBERANT FIELD

Generally, we do not listen to music through speakers at a distance of less than 1 meter. 2 meters is a more typical distance and at this point it is generally accepted that the reverberant sound field dominates the direct radiation from a traditional speaker such as a two or three way unit including a dome tweeter.

Room measurements of this kind of speaker in the reverberant field may show a significant treble roll off beginning at around 1500Hz with a typical slope of 3dB/octave. The response is controlled by the room absorption characteristics and the polar response of the speaker drivers hence the requirement for a predictable room response in critical applications.

Another alarming effect in over-reverberant room conditions is the rise and fall times of transient signals, especially at lower frequencies. Resonating bass notes may take 200 - 300ms to rise (and even longer to decay). This must have a deleterious effect on music reproduction.

DIPOLE SPEAKERS AND RIBBON SPEAKERS

Room measurements of speakers with ribbon (and membrane) drivers do not display the same treble roll off characteristics of dome tweeters. This somewhat surprising result is due to the fan like distribution of sound from long, thin drive units. The overall effect is to make the speaker characteristics in the active region of the driver more independent of room characteristics, generally a desirable characteristic.

Is this also partly why dipole bass speakers are preferred ? The answer is undoubtedly yes. The polar characteristics of a dipole give a forward and reverse gain of 4dB placing the listener in a more intense near field and reducing the domination of the room reverberant field.

REVERBERATION TIME

This is the time taken for the sound level in a room to drop to1/1000th or 60dB below its initial value.

Of the three main categories of room effects, LF resonances, incorrect room reverberation times and room colouration can be investigated partially by calculating and measuring reverberation times in rooms.

In practice, there is no one value for a room since it changes markedly with frequency.

This looks relatively easy to measure with simple equipment i.e. a sound generator, microphone, and an oscilloscope to monitor the decay time. However, as always with practical measurements, there are a number of complications that throw a few spanners in the works.

1	Calculations and measurements of reverberation time assume that the sound source and the sound in the room are completely diffuse. This means that the sound is traveling in equal intensity in all

directions and that absorbing surfaces are somehow spread uniformly about the room. This is clearly never going to be the case.

2 Small rooms in particular (normal playback listening rooms as opposed to a concert room) are dominated by low frequency standing waves below 130Hz. Pairs of opposing walls differ markedly in their acoustic properties. Carpets and soft furnishings often dominate absorption characteristics between floor and ceiling. Floor and ceiling materials may be relatively soft at low frequencies if constructed of floor boards and joists.

The indications are that reverberation time estimation is not accurate at low frequencies in small rooms, where the sound is present as standing waves, We are not aware of a standard alternative at present but static measurement of the relative size of peaks and troughs in the frequency response of the room should indicate the absorption present, that is the Q of the resonance.

3 A further practical consequence of 1). and 2). above is that since untreated opposing walls may have quite different sound absorption rates, the assumption that sound in a room decays at a constant rate may not be true. For example, flutter echoes may be heard between vertical walls but not between a carpeted floor and ceiling. This is a consequence of a normal untreated room environment and leads to a compound decay rate as shown in figures 1 to 4.

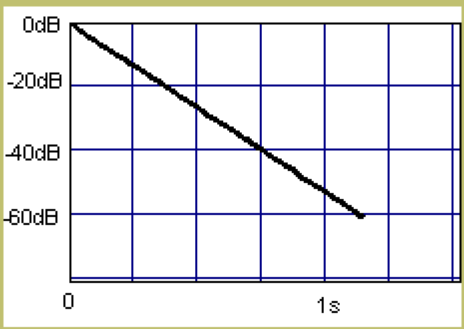


Fig. 1 Floor to ceiling decay

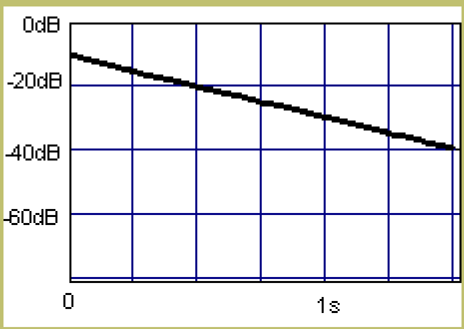


Fig. 2 Wall to wall decay

Fig. 3 Combined decay

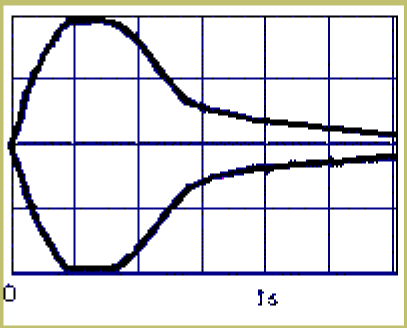


Fig. 4 Linear oscilloscope measurement of tone burst waveform

The effect is more apparent in figure 4 which is a linear scaled oscilloscope waveform where we see a discontinuity in the decay rate of the waveform. This leads us to 3 more conclusions:

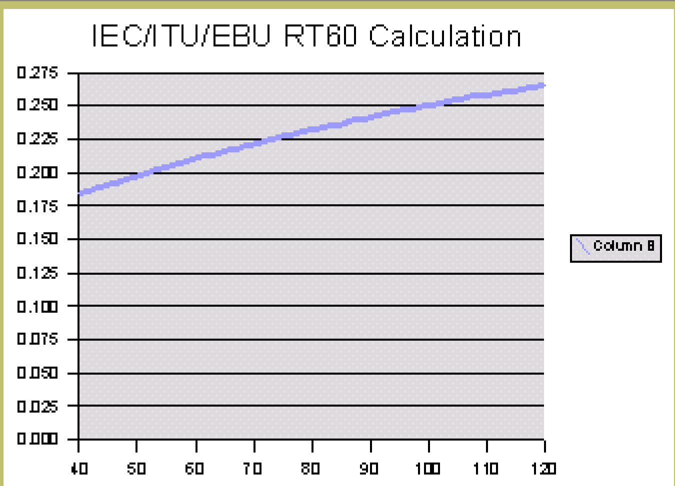
1	Measurement methods using extrapolation have to be used with care.
2	The Early Decay Rate (EDR) is the more significant for listening purposes.
3	Equal decay rates in all axes is probably preferred.

Calculations shown below highlight the potential range of variation in a typical room.

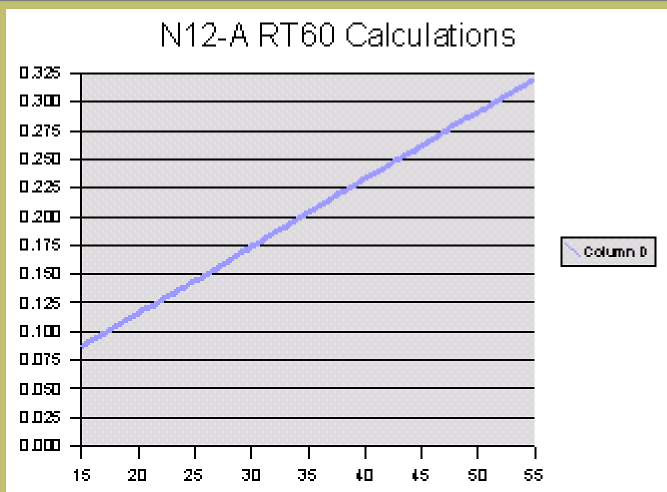
It is clear that the preferred lower range indicated of below 0.25s is not normal in an untreated domestic room even at frequencies above 500Hz. Bass reverberation times will also be much higher

TABLE 2: OPTIMUM REVERBERATION TIMES FOR LISTENING ROOMS
Surprisingly, this is quite difficult to establish as there is only partial agreement between listening room standards as shown below.

Standard	Formula	RT60 for 70 cu m room	Notes
AES20-600	RT(60) = 0.45	0.45s	Intended for typical listening rooms, fixed value, an old standard
IEC 268-13 (Standard for a listening room for speaker testing)	RT(60)=0.25(V/100)^.333 V=room vol. cu m	0.22s	Intended for typical listening rooms
EBU / ITU	RT(60)=0.25(V/100)^.333	0.22s	Drafted for broadcasters with larger rooms
NR-12A (Nordic broadcasting standard)	RT(60)=0.35(S/60)+-0.05 S=floor area, sq m	0.14s Assumes S=24	Drafted for broadcasters with larger rooms



x axis, room volume cubic meters
y axis RT(60) in seconds



x axis, room floor area square meters
y axis RT(60) in seconds

CALCULATING REVERBERATION TIMES FROM SOUND ABSORPTION DATA

This is a very simple process as developed by Sabine late in the 19th century. In most cases, absorption coefficients are easy to understand. For example 25 mm of rockwool absorbs approximately 80% of the incident sound over the 1000 – 4000 Hz range. Its absorption coefficient is therefore defined as 0.8 Sabines per square meter. Its effectiveness falls off below 500 Hz and so the coefficient reduces accordingly.

An upholstered auditorium chair has an absorption of 3 Sabines which is a combination of the area of the chair and the coefficient. If we can sum all the absorption rates for the items in a room, the reverberation time can be calculated using Sabines formula:

RT(60) = 0.16 x V/S where V = volume of the room in cu m, S = total absorption in Sabines

As stated above, this formula works best with diffuse sound, evenly spread absorption across all surfaces and with relatively low average absorption coefficient (<0.2). The simple formula gives a shorter RT(60) than measured.

There are a number of more complex calculation methods that take into account different conditions in each axis and where absorption coefficients are higher. They are all based on Eyring's more general formula.

RT(60) = 0.16 x V/(S x ln(1-a)) where S=total surface area of the room, a = mean absorption coefficient, ln = natural logarithm

This formula is used in the calculations that follow.

TABLE 3: ABSORPTION COEFFICIENTS USED IN CALCULATIONS (50Hz estimated figures)

Absorption coefficients	50Hz	125Hz	250Hz	500Hz	1000Hz	2000Hz
Painted brick walls	0.01	0.01	0.01	0.01	0.01	0.02
Thin carpet tile floor on concrete	0.05	0.05	0.15	0.2	0.2	0.25
Carpet with underlay	0.02	0.08	0.24	0.57	0.69	0.71
Lath & Plaster ceiling	0.03	0.03	0.03	0.03	0.03	0.03
Absorbers, 100mm rockwool	0.1	0.35	0.45	0.63	0.8	0.8
Medium weight curtain	0.2	0.07	0.31	0.49	0.75	0.7
Slatted type absorber	0.1	0.2	0.5	0.4	0.3	0.2
Diffusers	0.05	0.2	0.2	0.2	0.2	0.2
Bass Traps (plasterboard)	0.35	0.29	0.15	0.05	0.05	0.05
Audience / Person	0.15	0.23	0.32	0.45	0.62	0.76
Glass window double glazed	0.2	0.35	0.25	0.18	0.12	0.07
Auditorium chair upholstered	0.07	0.15	0.31	0.3	0.32	0.34

We will now consider a room dimensions 5 x 3.3 x 3 m with solid brick walls and floor, carpet tiled floor and lath and plaster ceiling. This represents our listening room in the basement of a large Victorian property with 15” walls and no windows. It is perhaps an extreme case with little absorption, when completely empty, despite carpet tiles on the floor.

TABLE 4: INITIAL CONDITIONS - NO TREATMENT									
Wall Areas		Quantity	Area	**50Hz**	**125Hz**	**250Hz**	**500Hz**	**1000Hz**	**2000Hz**
left side wall	L x H 1	1	16.5	0.17	0.17	0.17	0.17	0.17	0.33
right side wall	L x H 2	1	16.5	0.17	0.17	0.17	0.17	0.17	0.17
end wall 1	End 1	1	9.9	0.1	0.1	0.1	0.1	0.1	0.1
end wall 2	End 2	1	9.9	0.1	0.1	0.1	0.1	0.1	0.1
Floor		1	18.15	0.91	0.91	0.91	3.63	3.63	4.54
Ceiling		1	18.15	0.54	0.54	0.54	0.54	0.54	0.54
Total Sabines				1.98	1.98	1.98	4.7	4.7	5.78
Reverberation time, seconds				**4.4**	**4.4**	**4.4**	**1.85**	**1.85**	**1.51**

Clearly this is totally unsuitable. Even if listeners and upholstered chairs are added, the room is too lively, has major modal peaks at 30, 60, 90Hz and 120Hz with all the expected problems.

TABLE 5: FINAL SUGGESTED TREATMENT									
Wall Areas		Quantity	Area	***50***	***125***	***250***	***500***	***1000***	***2000***
Sides	L x H 1	1	10.02	0.2	0.2	0.2	0.2	0.2	0.3
	L x H 2	1	10.02	0.2	0.2	0.2	0.2	0.2	0.2
	Diffusers	10	0.72	0.36	1.44	1.44	1.44	1.44	1.44
Plain	Absorber	0	0.72	0	0	0	0	0	0
Small Bass traps		8	0.72	1.73	1.73	0.86	0.29	0.29	0.29
Ends	End 1	0		0	0	0	0	0	0
	End 2	0		0	0	0	0	0	0
Curtain	Absorber	18	1	0.54	1.26	5.58	8.82	13.5	12.6
Bass traps, plasterboard		18	1	5.4	5.4	2.7	0.9	0.9	0.9
Floor	Carpet tiles	1	18.15	0.91	0.91	0.91	3.63	3.63	4.54
Ceiling	Ceiling	0		0	0	0	0	0	0
Slatted	Absorber	20	1	2	4	10	8	6	4
Plain	Absorber	6	1	0.6	1.8	3	4.8	4.8	4.8
	Bass traps	0	0.72	0	0	0	0	0	0
	Audience / Person	2	1	0.3	0.46	0.64	0.9	1.24	1.52
Auditorium chair		0	1	0	0	0	0	0	0
Auditorium chair upholstered		2	1	0.14	0.3	0.62	0.6	0.64	0.68
			Total Sabines	12.38	17.7	26.15	29.78	32.84	31.27

Reverberation time	**0.65**	**0.44**	**0.28**	**0.24**	**0.21**	**0.23**

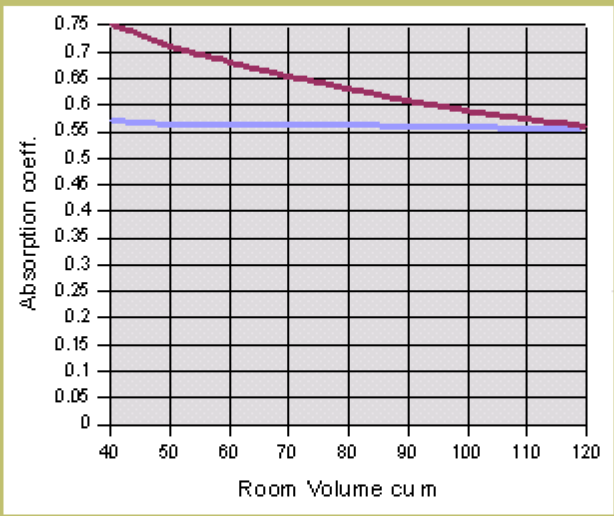
Simple ray tracing suggests areas where diffusers will have most effect in diffusing early reflections. A number of products, each designed on a modular 0.6 x 1.2m (2ft x 4ft) are included in the reverberation time analysis.

Significant extra absorption in the form of curtains placed over plasterboard bass traps was used and a number of optional slatted absorbers may be used to increase lower mid range absorption.

IDEAL ROOM CALCULATIONS

This section investigates the ITU and N12-A recommendations and answers the question: what is the average absorption coefficient required in an ideal room of typical dimensions. These results assume the following:

1. The room height is 2.7m
2. The room length is 1.4 x the room width
3. The Eyring extended formula is used to calculate the reverberation time



RED PLOT: Nordic N12-A (curve)

BLUE PLOT: ITU (straight line)

The obvious unexpected conclusion from this exercise is the almost constant and high average absorption coefficient required to satisfy the ITU recommendation regardless of the room size.

It is our experience that rooms having such high average absorption characteristics may not make ideal listening environments for the reproduction of multichannel panned stereo recordings. However, Panambiophonic recordings contain all the required ambiance accurately recorded and therefore do demand maximum absorption. This leads us neatly to the next consideration.

FURTHER CONSIDERATIONS

The most troublesome room mode, in rectangular rooms, seems to be where a full wavelength occurs between the opposite walls along the longest dimension of the room. This produces a pressure node at the center of the room (hence a boomy response) where listeners may prefer to be or a null (a strong dip in the response) ¾ down the length of the room, another favored listening position.

In our listening room this occurs at 62 Hz and since we have concrete and brick surfaces, the effect is very pronounced. A considerable amount of bass trapping at this frequency is required to bring this under control.

ELECTRONIC EQUALIZATION

To be equivalent to room treatment, electronic equalization , either digital or analogue, will have to provide compensation for the following:

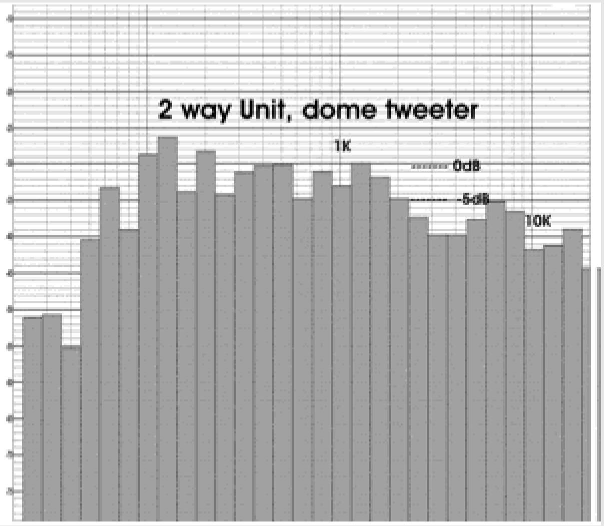
1	Bass peaks and troughs as great as 20dB (100 fold increase in power). Peaks are easy to deal with using parametric equalizers, troughs usually demand too much power.
2	Bass rise and fall times of 200ms in the reverberant field. (Equalization may be able to remove large resonance effects and the effect on bass rise times is theoretically perfect but in practice the result is uncertain due to unpredictable phase effects).
3	Cancellation of direct early reflections but maintaining diffuse reverberant fields.

However, gentle equalization of speakers in treated rooms is desirable and necessary.
See **Article 2** of this series for more details.

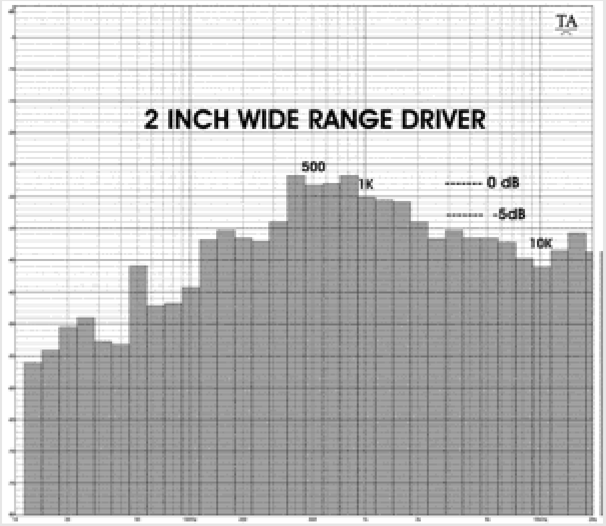
DIFFUSION or ABSORPTION ?

Speaker response measurements in a room correctly treated with absorption may yield a gentle roll off of HF. Both speaker responses in the graphs below, measured at 2m distance, demonstrate this. The speakers are both essentially flat in anechoic or near field conditions.

With high levels of absorption, more complex speaker response problems may occur totally unbalancing the response of the speaker. Again, see **Article 2** of this series for more details.



In room response of a small 2 way system placed away from room boundaries, normal listening distance.



Laboratory check of a small aluminium coned full range driver in a small baffle

Both the above HF responses are typical of dome tweeters in rooms with absorption as room treatment not diffusion. The roll off is a function of the polar response of the HF driver in these circumstances.

See **Article 2** of this series for more details.

Similar measurements in our listening room, dominated on the left and right walls by quadratic diffusers, show a much less, almost non-existent HF roll off.

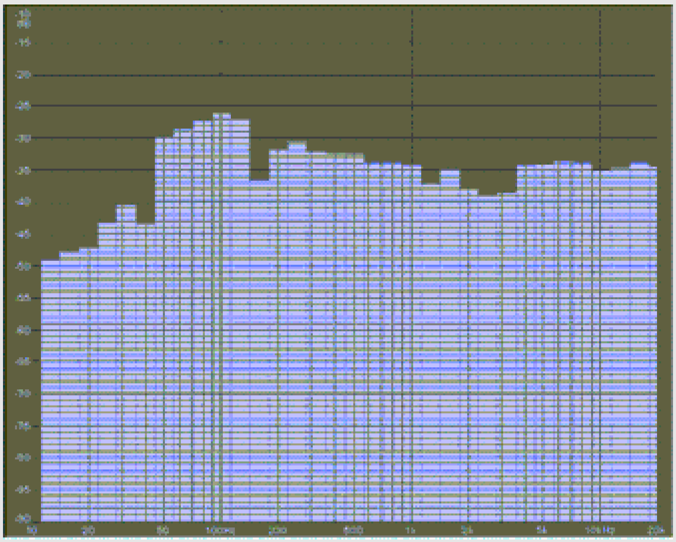
The audible effect of a significant change of tonal balance shown above is clearly going to be quite marked and the question it poses is "in what listening conditions was the original source material in the studio finally processed". In other terms, "what was intended by the producer and mixing engineer ? "

Significant diffusion in a normal listening room, as opposed to absorption, is preferred to avoid the room colouration effects seen above and to provide an altogether more comfortable environment. (Note this conclusion may change as more work is done on Ambiophonics systems which benefit from more absorption.)

Speaker Responses In The Marshall Choong Listening Room

The plots below show loudspeaker responses in our listening room ***equipped with diffusers***, bass traps and some absorption.

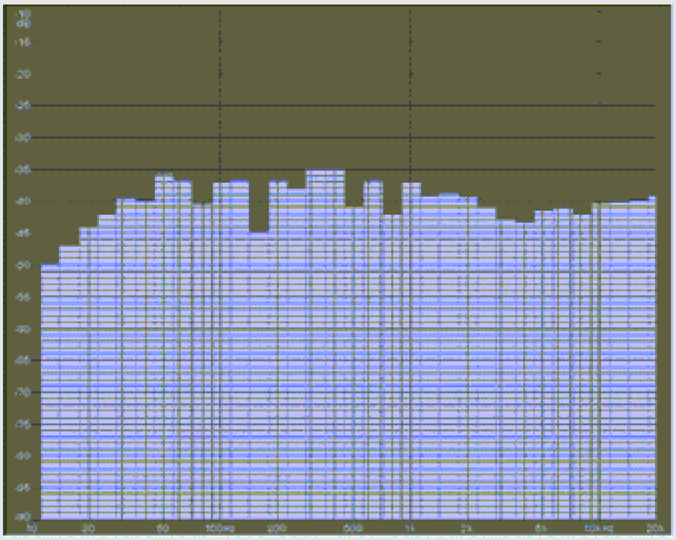
They clearly show the advantages of optimum room treatment and the major improvements at low frequencies due to dipole bass speakers.



Room response of a typical small, floor standing 2 way d'Appollito style speaker. The lower bass driver is 0.45m from floor level

Note the excess bass response due to room gain and the flat HF response even though a 19mm dome tweeter is used which probably has good HF dispersion.

Listening tests confirm that this speaker has excessive bass.



Room response of the MCAudio Segovia / Trueno system. 4 way system with dipole bass, lower mid, midrange and ribbon tweeter.

Variable room correction is provided with this product to help optimize the response of the ribbon tweeter.

The main conclusion is that unless you are prepared to equalize out the above responses to a flat HF response, diffusers are the correct choice over absorbers for recordings with no naturally recorded ambiance. They have much less effect on the HF response.

Much depends on the characteristics of your speakers therefore we recommend simple testing using our **Low Cost Test kit.**

ALTERNATIVE TECHNOLOGIES TO MINIMISE ROOM EFFECTS	
1	Ribbon / Membrane drivers exhibit far less HF roll off in absorptive rooms.
2	Dipole bass speakers exhibit less excitation of room resonances and offer a workable solution to this difficult problem.
3	Near field speaker arrays, using multiple moving coil or ribbon drivers, put the listener in the near field of the sound source over most of the audio range (200Hz to 20kHz) and at a normal listening distance. This automatically reduces room effects and potentially offers an alternative solution for critical room listening especially if combined with dipole bass subwoofers.
4	Use headphones especially with natural binaural recordings. This can be very effective and convincing for stereo using open headset designs.