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Acoustical Measurement Standards for Stereo Listening Rooms

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This paper presents in-room acoustical measurement standards as well as quantifiers of the environment itself for the purpose of high-performance 2-channel audio reproduction. Context and examples are offered in various metrics ranging from noise, time related elements, frequency response, room size and room construction. The various individual sections are covered each within their own realm and in how they interrelate toward the resulting listening experience.

Introduction

Much has been written about acoustical standards for home theater and professional studio control rooms. Very little, however, has been committed to paper about acoustical standards for high end stereo or two channel music listening rooms. The very practice of locating only two speakers and a single listening location in a room leads to consequences that are too often ignored and certainly poorly understood. In this co-authored white paper Nyal Mellor of Acoustic Frontiers and Jeff Hedback of HdAcoustics aim to explain a basic set of acoustical standards that can be used in the evaluation of existing rooms or the design and post-construction verification of a new room.

Whilst some of the standards for home theater and studios can be seen to have applicability for residential stereo listening rooms many do not. In studios, for example, the 'hot seat' is almost always 'nearfield' due to the location of speakers on top of a mixing console, putting them in a location where the overall sound balance is dominated by the direct energy from the speakers. This is a very different acoustical environment than in a home where reflected sounds from the room are stronger than the direct sound. The other typical studio configuration is for the speakers to be flush or soffit mounted, which significantly changes the way in which the speaker interacts with the room. In a home theater the priorities are different: whilst maintaining spectral balance is an equal priority in both situations digital room correction is often used in a theater. Acoustical design then focuses on minimizing seat-to-seat variability in frequency response through careful study of the number and location of multiple subwoofers. This practice allows subsequent application of equalization. Moreover, a home theater also has surround speakers which make the generation of envelopment and the feeling of being immersed in a three dimensional soundfield significantly easier to achieve than in a two channel environment. It is therefore imperative that we do not just blindly expect well known studio and home theater design concepts to port straight into a two channel environment. We must develop our own set of acoustical standards that take into account the unique aspects of two channel reproduction in the home environment.

With the recent availability of free or low cost 'prosumer' acoustical measurement systems such as Room EQ Wizard, XTZ Room Analyzer and Parts Express Omnimic dedicated enthusiasts can now take a set of measurements that describe the acoustical performance of their existing room. These systems make it easy to take measurements but they do not provide guidance on what a good or bad measurement looks like. This lack of guidance from the software, and the lack of any formal standards from the acoustical practitioner community that are specific to the challenges of two channel reproduction make this white paper sorely needed.

This paper puts forward a set of targets for what the acoustical measurements of a high performance two channel music listening room should look like. We describe what the key measurements are, what an optimal measurement would be and a range of acceptability. Once a room's measurements have been compared with targets the end user can then decide whether to go the path of educating themselves on acoustics, acoustic treatment and acoustic design by reading books and experimenting and/or hire the services of an acoustical designer to correct their room's acoustical deficiencies.

Summary of acoustical standards

Criteria	Measurement	Target	Acceptable Range*
A: Noise Control	RC	RC20	RC30
B: Reflected Sound	Energy Time Curve, 0-40ms	L & R speakers visually identical ~10dB reduction in energy level by 40ms Clear decrease in energy over the 40ms Peaks smooth in pattern and density	
C: Low Frequency Decay Times	Low Frequency Resonance**	Reference chart Figure C.1	Reference chart Figure C.1
D: Midrange Decay Times	T20, T30, T60	T60 between 0.2 and 0.5s T20, T30 deviation <25% across one-third octave bands	
E: Midrange Frequency Response	Midrange Frequency Response	L speaker within +/-3dB at 1/3 rd octave R speaker within +/-3dB at 1/3 rd octave No deviation greater than 3dB between L/R speakers	
F: Low Frequency Response	Low Frequency Response**	Within +/-10dB at 1/24 th octave Within +/-5dB at 1/3 rd octave	
G. Room Size and Construction	Physical dimensions	Size of room 224sq ft to 475 sq ft Volume of room 1,750 cu ft to 4,750 cu ft Dimensions lack common divisors (2x) layers of 5/8" gypsum board Surfaces are constructed using similar methods	

* Not all measurements have a lower level performance target defined.

** All measurements should be carried out for each speaker separately except the low frequency measurements which should be carried out with both speakers playing together. It is important to ensure that the measurement levels are consistent when comparing left and right speakers otherwise erroneous conclusions may be drawn from examination of the data.

A: Noise Control (indicated by Room Criterion – RC rating)

Standard: Noise criterion below RC30 for existing rooms or RC20 for purpose built rooms

High noise levels can cause auditory masking of low level details within recordings that reduce soundstage depth and timbral color by:

- Obscuring the way in which sound decays within a recording venue. Each recording venue has a characteristic acoustic signature that can be lost if noise levels are too high. Listening to classical music, it might be difficult to differentiate a performance in the Disney Hall relative to the Carnegie Hall. Standards for concert halls and recording studios are typically RC15-20 and one could argue that a reproduction environment should have an equal or lower noise floor than the recording venue if the acoustic signature of that venue is to be reproduced faithfully.
- Obscuring the low level harmonics that give each musical instrument its characteristic timbre. One might find it difficult to differentiate a Bosendorfer from a Steinway piano. There is a direct relationship between the noise floor of a space and the ability to perceive the highest levels of audio micro-detail.

The noise in an existing space should not be above RC30. This eliminates most distractions that otherwise interferes with the listening experience. Typical residential spaces will have background noise levels in the RC35-45 range. A rating as low as RC25 should be achievable within common ducted HVAC systems with remediation in areas of internal acoustical linings and acoustically rated grilles/diffusors (as just two examples of the types of changes required). It is important to factor other items like the audio equipment itself or comfort elements such as wine chillers that may contribute to the background noise level of the listening environment. For new dedicated room builds we suggest a target of RC20. Meeting RC20 will require paying attention to noise isolation and using specialized construction techniques.

There are certainly benefits to a rating of RC15 and this paper is in no way discouraging the greater potential of room dynamics and “ultra-black” noise floor. It is agreed for the purposes of this paper that the exponential increases to room construction costs make establishment of RC15 as a standard unrealistic.

B: Reflected Sounds

Standards:

ETC of the L & R speakers should:

- *Be visually identical (with only minor deviations) from 0-40ms*
- *Be down to -10dB by 40ms to prevent breakdown of the precedence effect*
- *Clearly show a decrease in the amplitude of energy over 0-40ms. The decay pattern may or may not be continuous.*
- *Show the consecutive peaks of the highest amplitude reflections viewed across the time axis to be relatively smooth in pattern and density.*
- *The criteria above should be considered in conjunction with the other stated targets for reverberation time and L/R frequency response.*

Before we get started it is useful to understand what an ETC is and how it differs from a frequency response chart. Frequency response, as shown by an FFT of an impulse response, adds up all incident sound within the impulse response (IR) gates to produce the amplitude vs. frequency plot. An ETC is a time domain view into how the spectrum builds up. Each peak on an ETC is a piece of reflected sound that reaches the microphone. The ETC is simply looking at amplitude over time but it gives no insight into the spectrum of that energy.

The key requirement with reflected sounds is to properly mate the speakers intended response at a specific distance and axis to the response as measured at the listening position. Typically this means keeping the spectrum of direct and reflected sounds as consistent as possible.

A popular approach is simply to analyze the level of reflections on an ETC and compare these to the direct sound, setting a target for the reflections to be 10dB or more less than the direct sound. This analysis is not sufficient since ETCs are spectrally blind (i.e. they contain no information as to the spectral content of the reflected sound) and the auditory system is very discerning in its requirements for spectral balance between the direct and reflected sounds in a room.

The key point is that spectral distortion in the reflected sounds interferes with perception of both localization and timbre. Most listeners actually show preference for high levels of reflections that are spectrally similar to the direct sound. They add to timbral richness and give body and fullness to images within the soundstage. Two good quotes will help clarify what is happening. Benade (From Instrument to Ear in a Room, Journal of the Audio Engineering Society, 1985) states:

"The auditory system combines the information contained a set of reduplicated sound sequences (authors note - i.e. the direct sound and its reflections) and hears them as if they were a single entity, provided:

- a) *that these sequences are reasonably similar in their spectral and temporal patterns*
- and*
- b) *that most of them arrive within a time interval of 40ms following the arrival of the first member of the set.*

The singly perceived composite entity represents the accumulated information about the acoustical features (tone color, articulation, etc) shared by the set of signals. It is heard as though all the later arrivals were piled upon the first one without any delay – that is, the perceived time of arrival of the entire set is the physical instant at which the earliest member arrived (authors note – this is known as the precedence effect).

The loudness of the perceived sound is augmented above that of the first arrival by the accumulated contributions from the later arrivals.

The apparent position of the source of the composite sound coincides with the position of the source of the first-arriving member of the set, regardless of the physical direction from which the later arrivals may be coming"

And Wrightson (Psychoacoustic Considerations in the Design of Studio Control Rooms, 1986):

"Normally a sound perceived by the ears is spectrally shaped by the pinna, torso, distance, etc. This aids to the localization of the sound signal. The introduction of a similar signal with different characteristics will alter the perceived localization"

Deviations from the targets above warrant examining one-octave bandpass filtered ETCs at 500Hz, 1kHz, 2kHz and 4kHz. When analyzing these ETCs one should be looking for the following differences:

- Between the L&R loudspeakers in the same band (i.e. between the L&R at 500Hz)
- Between adjacent bands for the same loudspeaker (i.e. between the 500Hz and 1kHz for the L speaker)

Figure B.1: This is the Left / Right speakers of Example Room 1 (see page 26) which meets all standards: similarity, smoothness and decay.

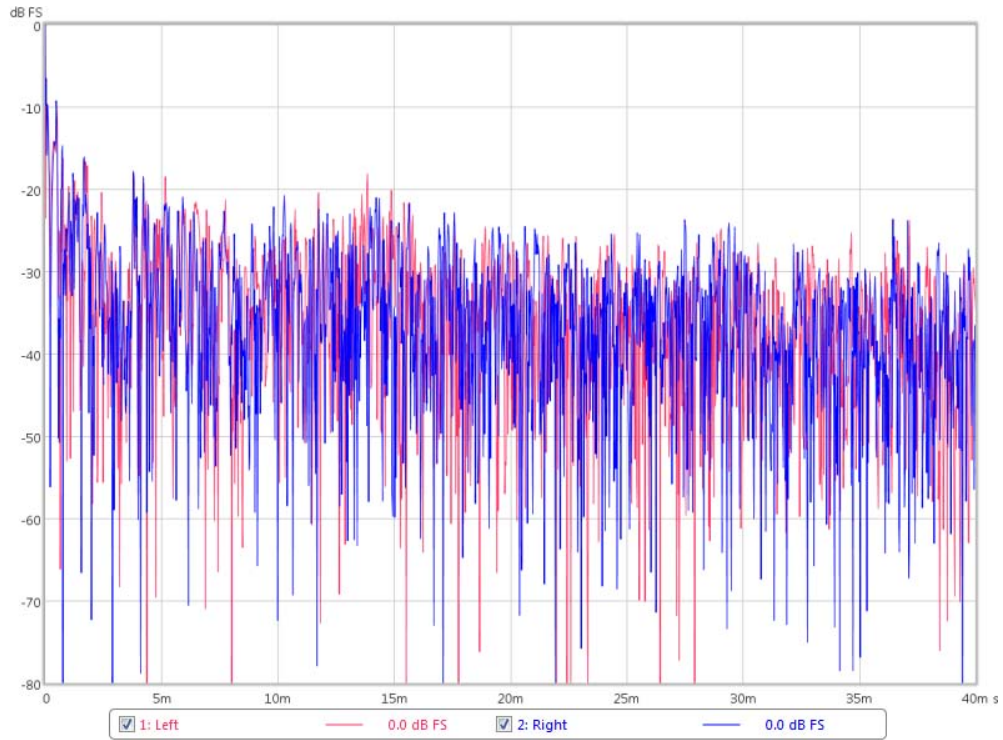


Figure B.2 This room exhibits a ragged appearance to the ETC which warrants further one-octave band studies. Whilst this room does meet the criteria for decay of 10dB over 40ms it does not meet the T60 requirements – midband T60s are over 0.7s. This is actually seen in the general reflection pattern which has no decay (viewed by not focusing solely on peaks).

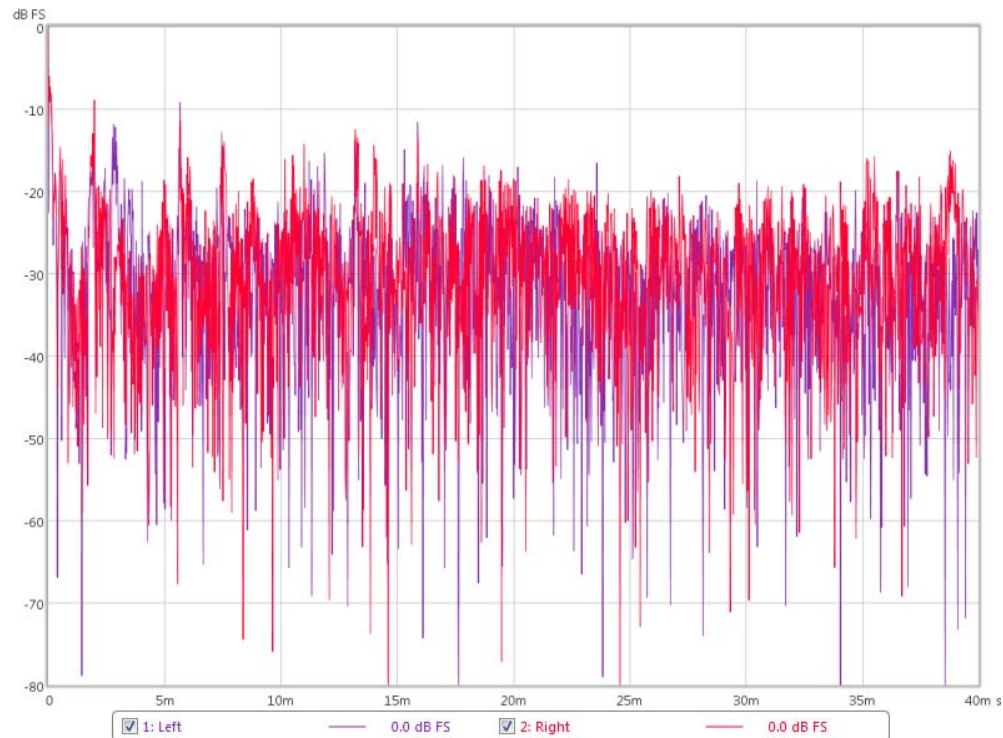


Figure B.3: This ETC measurement, which is from a left loudspeaker, shows a ragged profile worthy of further investigation.

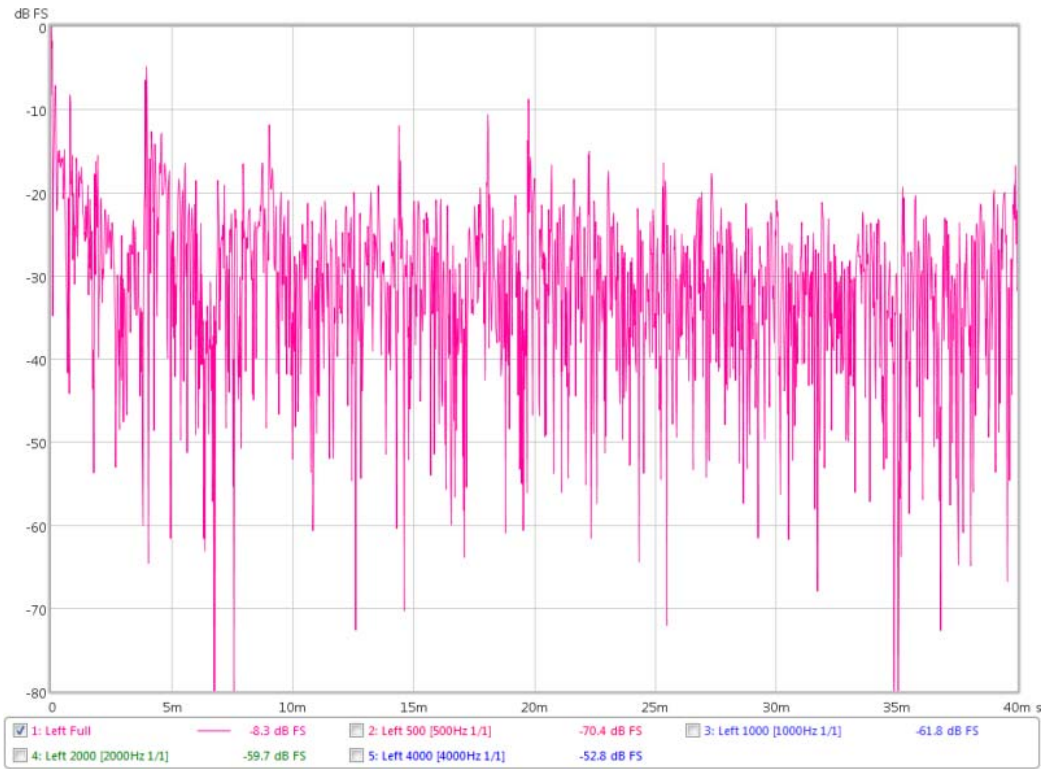


Figure B.4: Further investigation using one-octave filtered ETCs at 500Hz, 1000Hz, 2000Hz and 4000Hz shows distinct differences in the spectral content. These differences are more clearly seen with some ETC smoothing – see Figure B.5

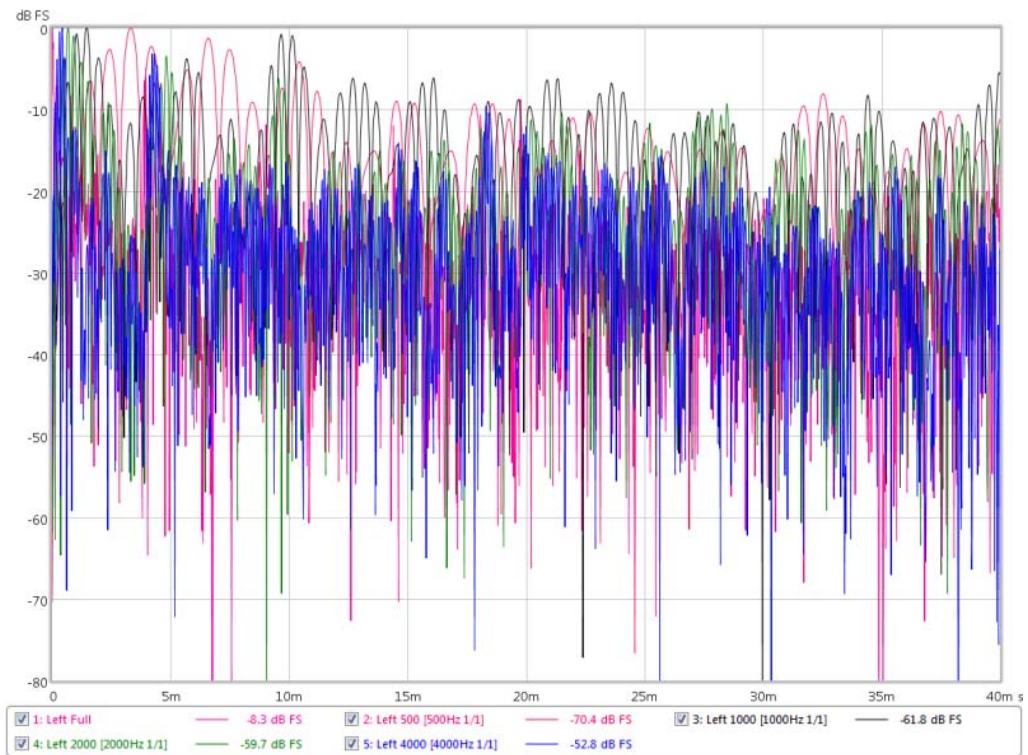
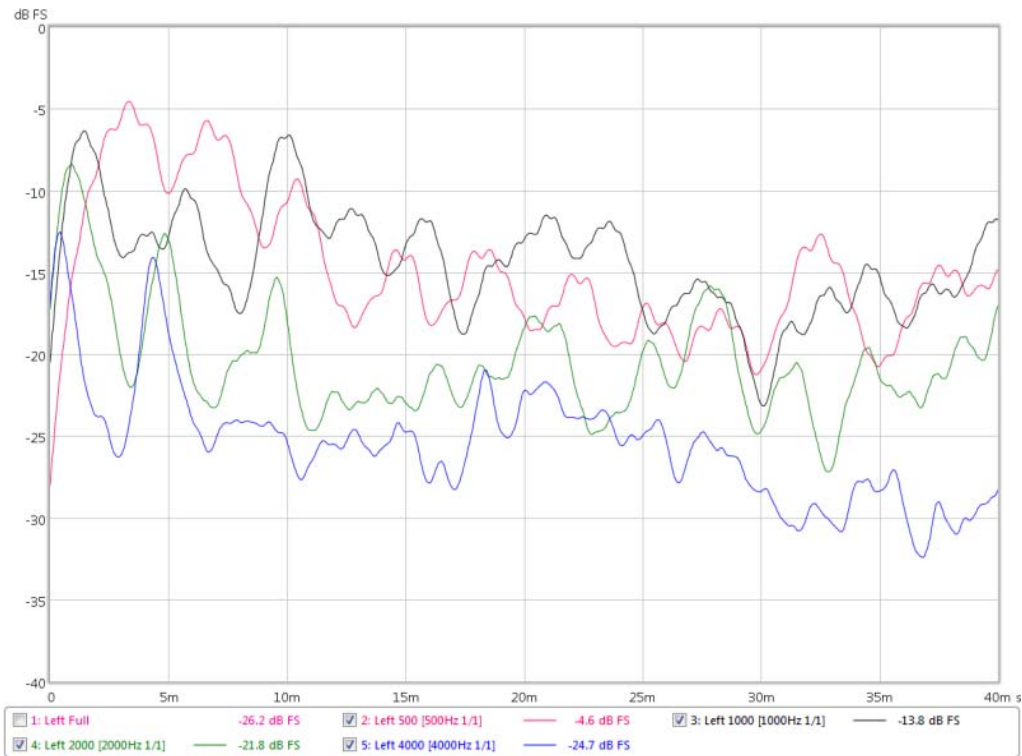


Figure B.5: Smoothed versions of the ETC in Figure B.4 using a 1ms moving average filter and a reduced vertical scale. Whilst 500Hz and 1000Hz track each other very well, clear differences can be seen at 2000Hz and 4000Hz. In this room these differences can be traced to the speakers which have poor off axis performance and the presence of thick, fibrous wallpaper on all walls.

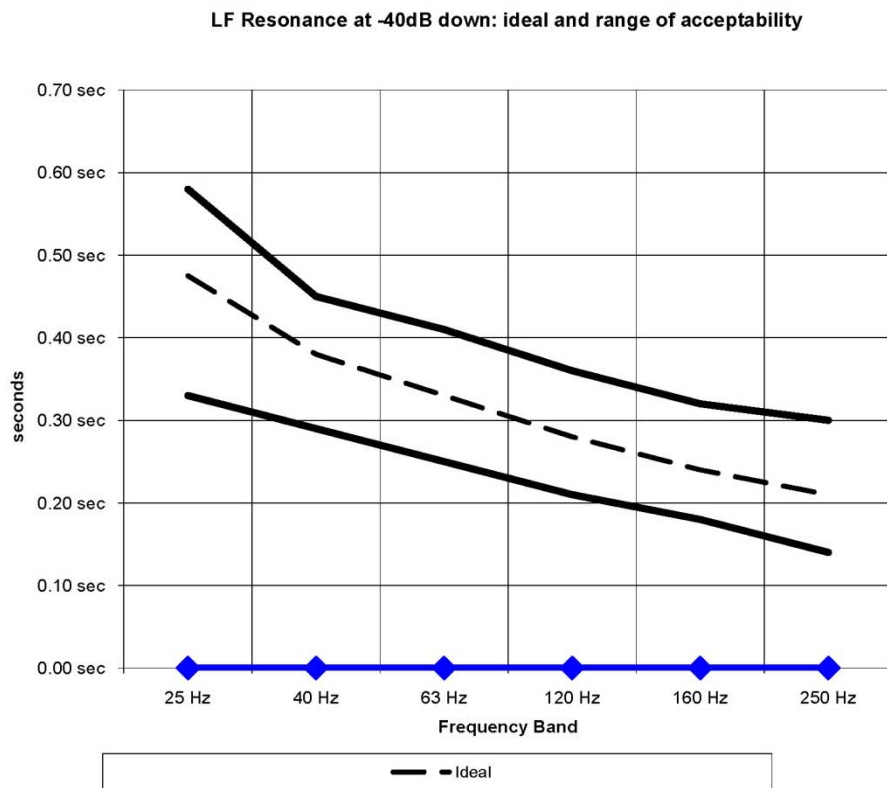


C: Low Frequency Decay Times

Standards:

- **Reference Figure C.1. In particular:**
 - **Resonances from 35Hz-300Hz should not extend beyond 350ms before decaying into the noise floor or reaching a level of -40dB.**
 - **Below 35Hz this standard is relaxed to 450ms.**
- **Room dimensions should be referenced to the standards in Section G of this document. If the dimensions fail, the expectation of resonance control should be lessened.**

Figure C.1: shows the ideal, minimum and acceptable ranges for LF resonance



Resonances due to room modes are clearly and most easily seen on a chart such as a cumulative spectral decay, spectrogram or waterfall that show time on one axis, frequency on another and plots sound pressure levels as the data.

It is important to realize that we hear the frequency response and that below 250Hz the room's behavior is mostly minimum phase meaning that in practice peaks in the frequency response correspond very closely to ringing in the time domain. However looking at a spectrogram clearly and

quickly allows discrimination of the modal resonances and is therefore a useful compliment to the 1/24th octave frequency response measurements.

Resonances should decay into the noise floor or reach -40dB before 350ms otherwise audible issues may occur such as 'one note bass' and 'boominess'. Such excess resonance is actually a distortion of the recorded waveform affecting the attack, decay and timbre of bass range content. In the worst cases a particularly slow decaying resonance can make a system almost unlistenable as musical notes at the resonant frequency seem to come almost omnidirectionally from the room rather than from the speakers. In mild cases one will notice that some notes on instruments such an acoustic double bass will sound louder than others and will decay at a different rate compared to those around them. This uneven decay damages dynamic articulation, particularly on fast paced music, and can lead to a subjective reduction in dynamic impact.

Below 35Hz the target is 450ms; it is much more difficult to control resonances at very low frequencies due to their very long wavelengths. Furthermore at frequencies below 35Hz we are below the fundamental frequencies of nearly all musical instruments. For these two reasons the decay standard is relaxed.

Figure C.2: Example Room 1 Spectrogram. Compare to Figure C.1. IR window is 300ms with a frequency resolution of 3.3Hz.

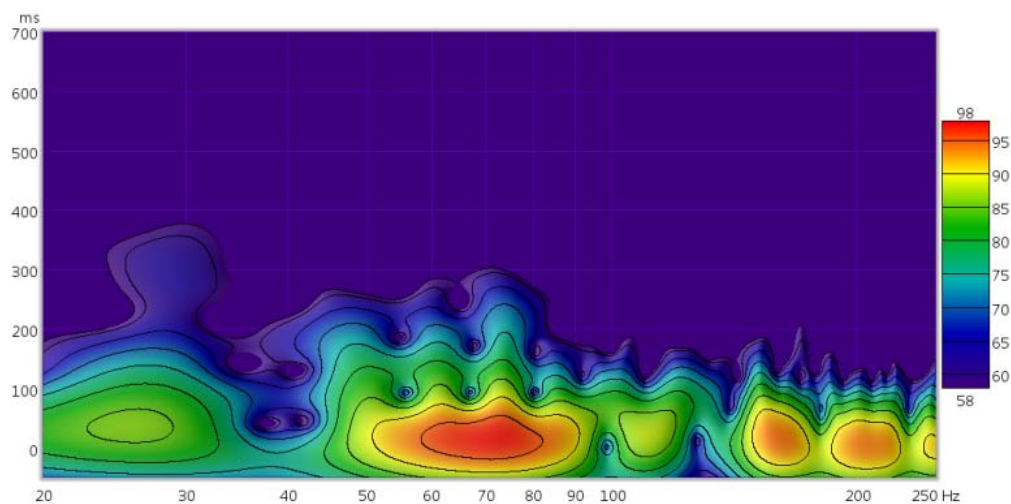
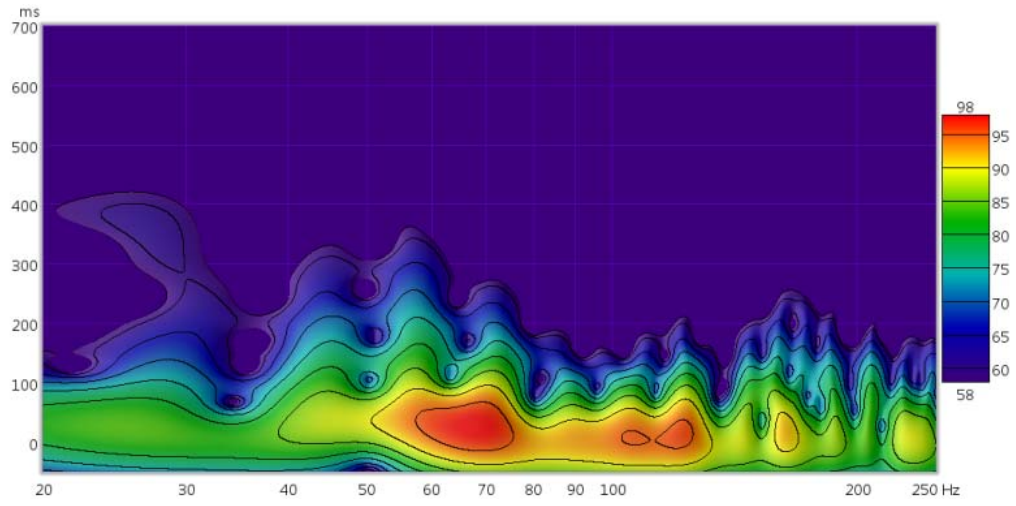


Figure C.3: Example Room 2 Spectrogram (see page 27). IR window is 300ms with a frequency resolution of 3.3Hz.



D: Midrange Decay Times

Standards:

- *Time taken for sound to decay 60dB (T60) should be between 0.2s and 0.5s from 250Hz to 4kHz*
- *T20 and T30 should be +/- 25% across the same frequency band using one third octave smoothed bands.*

Single figure T60 measurements cannot do much more in a small room than tell you whether a room is overly live or overly dead. More useful is to look at how sound decays across the critical midrange frequency bands from 250Hz to 4kHz and to examine whether the speed of this decay is consistent over time. There are four different problems that can exist with decay times – they can be too long, too short, uneven across the frequency spectrum or vary excessively over time.

Overly long decay times can obscure low level detail and the timbre of a voice or instrument in much the same way as a room with a high noise floor. A room with a long decay times also tends to sound harsh and brittle and can be an unpleasant place to listen resulting in rapid fatigue. Overly long decay times are considered those over 0.5s.

Decay times that are too short may not allow a spacious, enveloping soundstage to develop and therefore can be quite boring places to listen. Overly short decay times are considered those under 0.2s. Music does not come to life but rather sounds dry and sterile. Of note is the fact that acoustical diffusors actually yield absorption effects in the process of dispersing energy. This is important as a space with ample use of an appropriate type of diffusor may have a decay time on the lower range but not feel dry/sterile (likely just the opposite!). This is a prime example of the nuanced nature of acoustical control where the “road you take” to a specific measurement result is every bit as important as the end measurement.

A room that exhibits uneven decay characteristics, where the sound decays much faster at some frequencies than others can at worst sound noticeably unbalanced with a ‘dull’ treble or ‘bloated’ bass. Uneven decay is most often caused by furnishings within the room such as thin drapes and carpets that absorb significantly more energy at treble frequencies (above around 1kHz) than they do at midrange frequencies. Providing the energy follows the criteria in Section B of this document, it is actually preferred to retain upper midrange and high frequency energy. Our target here is for T20 and T30 to be within +/-25% across the frequency spectrum. Significant changes in decay time from T20 through T60 are also a good indicator of spectrally unbalanced reflected sounds.

Figure D.1: Example Room 1 is on the lower end of the range which is appropriate for the secondary function of multi-channel audio (as opposed to home theater).

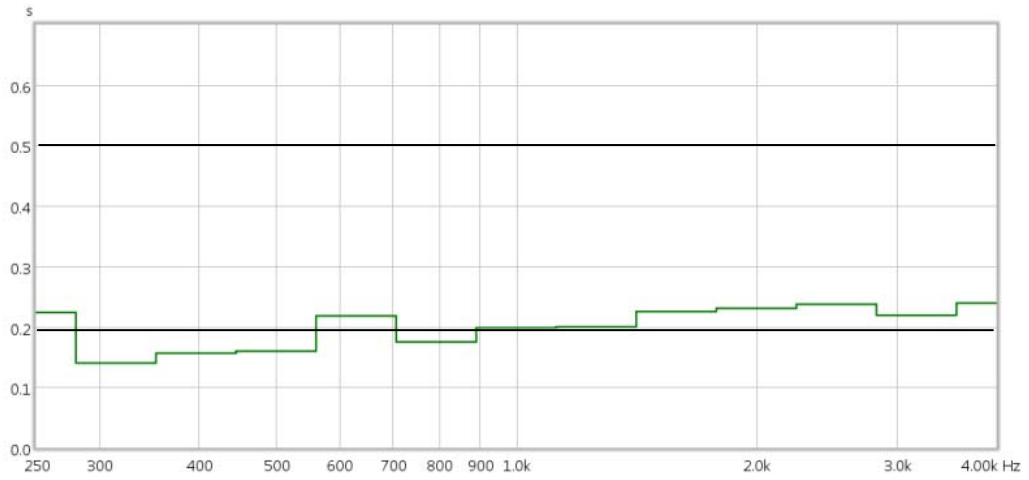


Figure D.2: Example Room 2 is toward the upper end of the accepted range and within deviation targets

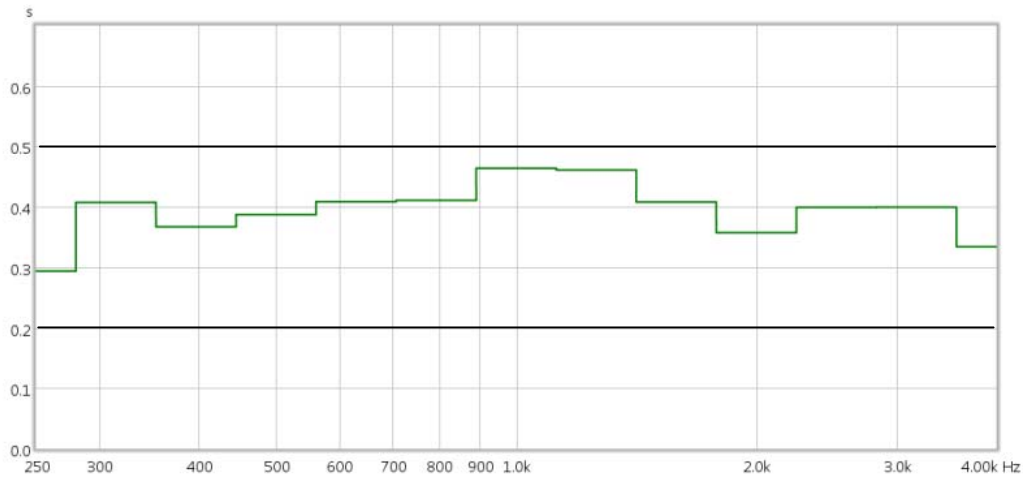


Figure D.3: T20 showing acceptable range of deviation (+/-25%) for Example Room 3 (see page 28).

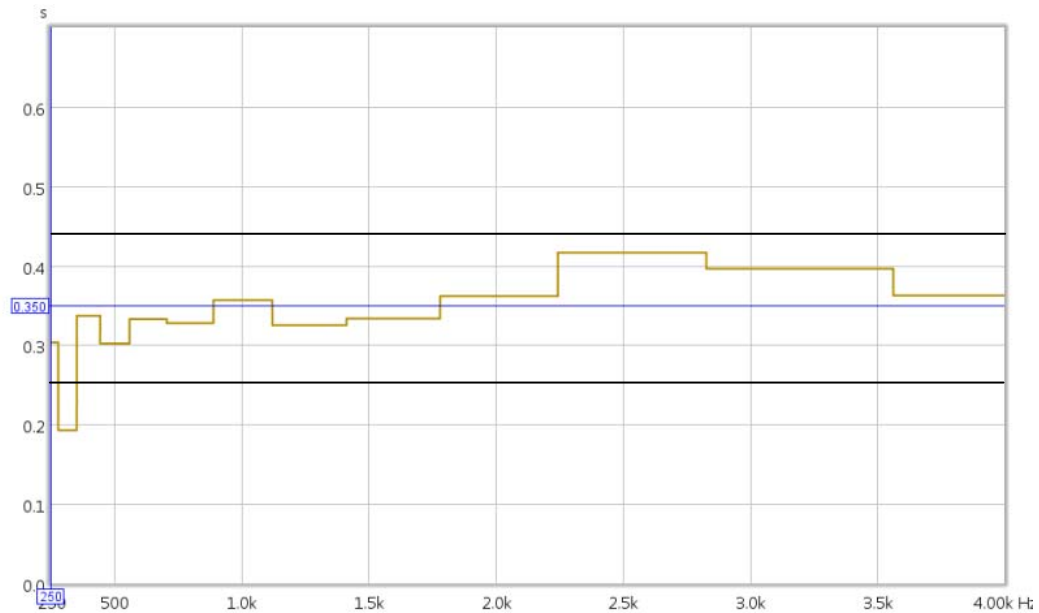
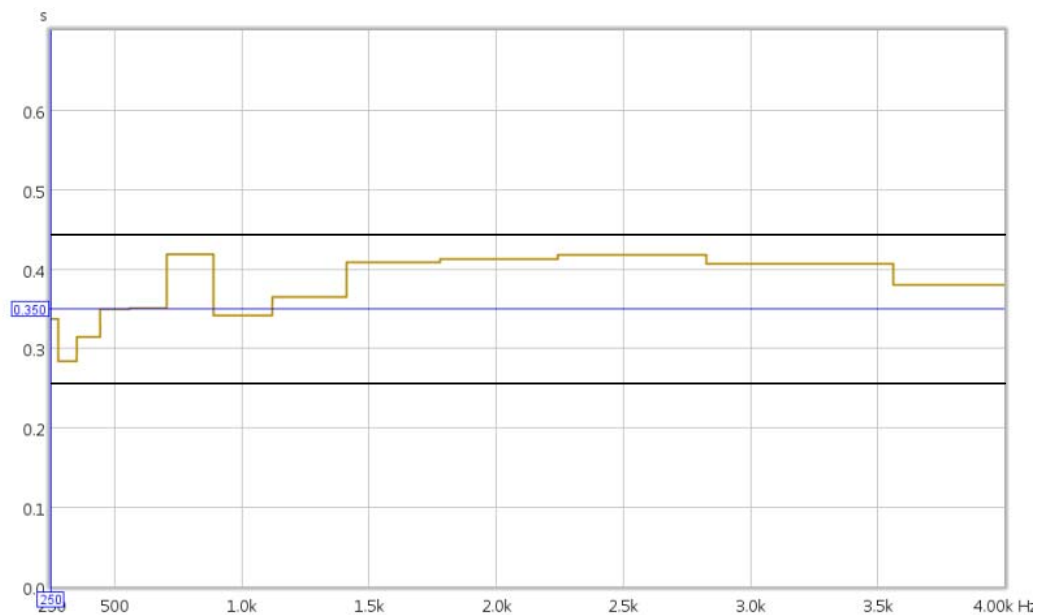


Figure D.4: T30 showing acceptable range of deviation (+/-25%) for Example Room 3.



A further complexity is that room size and musical preference also play into determination of what the decay time should be.

- On the subject of musical preferences - whilst most of us listen to a wide variety of music some individuals nearly exclusively listen to one type of music. In this circumstance it may be worth considering optimizing the reproduction environment so that it better suits that particular

musical style. Of particular interest is the time it takes for sound to decay. Classical music aficionados may be best served with room that is more 'live', with a higher T60 of 0.4 to 0.5s. Those who listen to nearly exclusively to close-miked multi-track recordings should aim for a lower target with a T60 approaching 0.2 to 0.3s.

- On the topic of room volume - generally speaking the larger the cubic volume of the space, the longer the decay time may be.

E: Consistency of Midrange Frequency Response between Left and Right speakers

Standard:

- ***In room one-third octave smoothed frequency response measurement at listening position for each speaker should be within +/- 3dB from 250Hz to 4kHz.***
- ***Each speaker should exhibit a deviation of no greater than 3dB from the other***

Nearly all the fundamental notes produced by musical instruments, including the human voice, occur within a range bounded at the top end by 4kHz. At the low end, fundamentals occur down to 35Hz or even slightly below. One could argue that a high end room should therefore be flat between 35Hz and 4kHz to maintain timbral accuracy and spectrally balanced sound reproduction across the critical midrange. In practice, however, this is very difficult to achieve due to the dominance of modal resonances and boundary effects below 250Hz which cause peaks and dips in the frequency response. A sensible target might therefore be stated as +/- 3dB within the range 250Hz to 4kHz when the frequency response is examined with a one third octave smoothing. In a high end room one might try and get the frequency at which the response breaks the +/-3 dB barrier as low as possible such as 200Hz or even 150Hz.

1/3rd octave smoothing is a very 'traditional' way to smooth a frequency response chart in order to create something that is closer to what we hear. The ear's resolution is actually higher than 1/3rd octave though – recent studies show that the ear loudness summing resembles something closer to a 1/4th or 1/6th filter and even then in-band frequency anomalies affecting timbral resolution can be discriminated. 1/3rd octave is nevertheless useful for identifying general spectral trends.

Frequency response measurements should be conducted for Left and Right speakers individually and the responses compared.

Sometimes differences in placement relative to room boundaries, a lack of left / right symmetry in the room, poor pair matching or acoustically dissimilar surroundings can lead to one speaker having a different response to its partner. This must be avoided since this often causes the soundstage to be pulled towards one speaker consistently or at certain frequency bands. The first effect can be handily countered by using a balance control, assuming that one's equipment still has this functionality. The latter effect must be avoided at all costs since it causes images to waver depending on, for example, which note is being played or sung. The target here is for each speaker to exhibit a deviation of no greater than 3dB from the other. 3dB is a perceived loudness difference of around 20%.

Attention paid to speaker quality, listening room symmetry and appropriate treatment of reflection points is typically enough to meet targets without any further alterations to the room design. Note that very good results can be achieved in slightly asymmetric rooms as long as the above condition is respected - it is not necessary for the speakers to be placed exactly the same distance from the left and right side walls. In fact this approach can often lead to problems since the path length differences from

each speaker to nearby boundaries are the same, causing speaker boundary interference related nulls to coincide.

Figure E.1 Example of frequency response for left and right speaker that is outside tolerance; in this case moderate imaging wavering was observed as well as an overall shift in the central image towards the left speaker

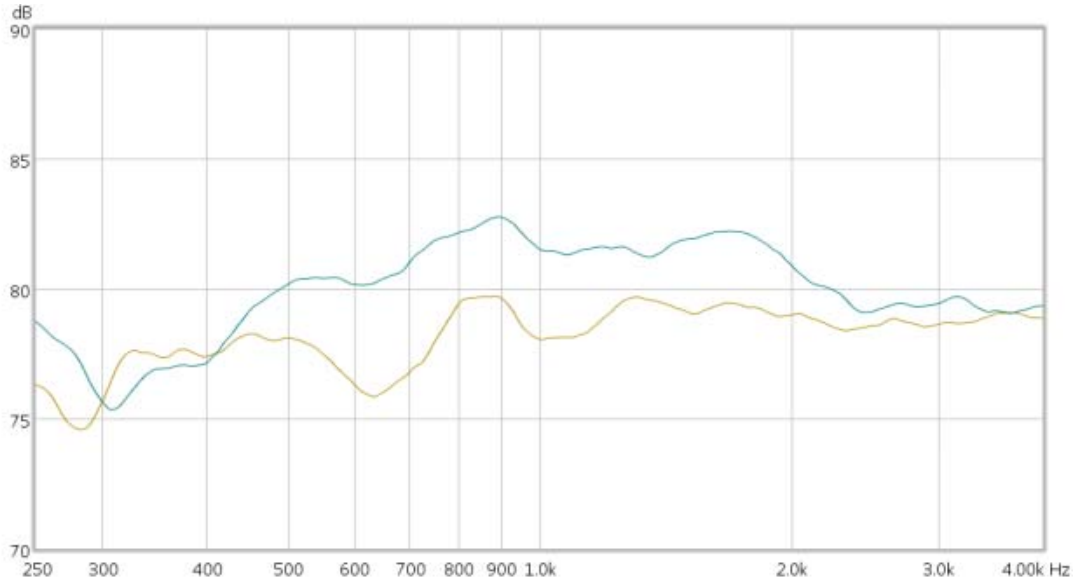
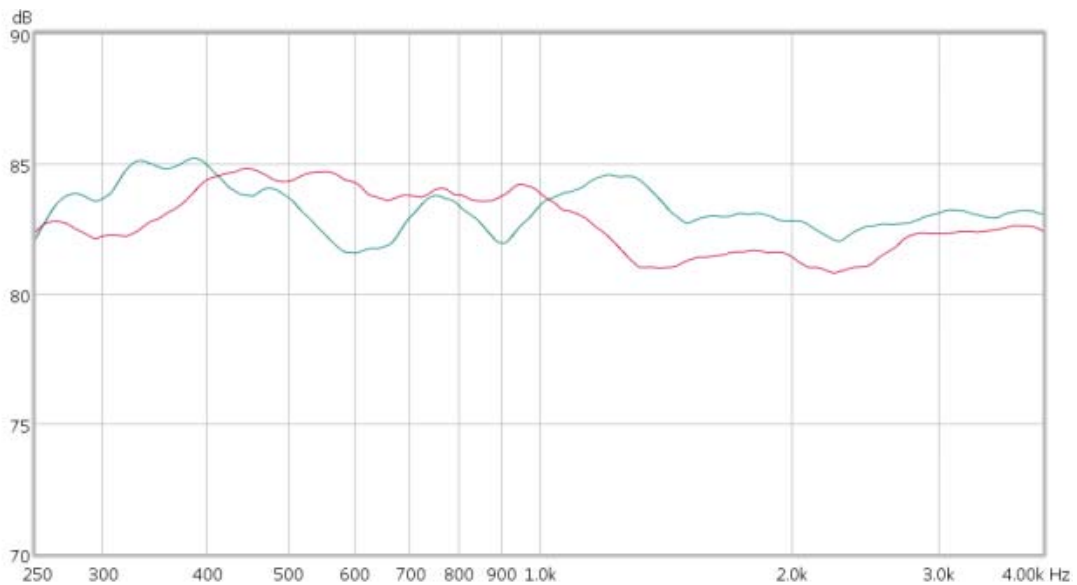


Figure E.2 Example of frequency response for left and right speaker that is within tolerance.



F: Low Range Frequency Response

Standard: In room low frequency (LF) response measurement at listening position should be:

- *Within +/- 10dB at 1/24th octave resolution from 20Hz to 250Hz for both speakers measured together.*
- *Within +/-5dB at 1/3rd octave resolution from 20Hz to 250Hz for both speakers measured together.*

Two measures are required to properly validate the quality of a room's low frequency response. 1/3rd octave studies provide a view into overall spectral trends equating closely to how the human ear perceives loudness whilst 1/24th octave allows discrimination of individual resonances that cause timbral distortion.

The low frequency (LF) response of a stereo pair of speakers in a room is first dictated by the speaker and listener positions and then by the acoustical control that exists within. Boundary interference patterns are created within ~65ms when the LF energy of the speakers makes contact with the room surfaces and recombines with the direct energy. After 65ms the room modes will impart distortions if not properly damped (reference Section D).

To obtain the best possible LF response:

- The speaker and listener initial locations should be carefully selected based on proper study of room dimensions and practicality. The left and right speakers should create a spread of 45 to 60 degrees from the center point of the listening position.
- After a subjective review of the initial response, acoustical measurements should be taken to begin the fine tuning of both speaker and listener locations. These changes would typically involve movements greater than 6".
- The remaining boundary interference issues can be tougher to address. Varying the fixed distances from "speaker to boundary" and "listener to boundary" will reduce strong cancellations. It is a balancing act as one location that may offer a smoother LF response may not provide the optimal midrange and treble response. Note: as speaker distances from the front wall may often be 4'-6', a speaker boundary interference related null is likely to appear between 70Hz to 45Hz respectively. There would also be similar type null based on the relationship of the listening position to the rear wall.
- The frequency response should always be correlated to a resonance study as both are crucial to balance and natural perception of LF transients.
- More evolved levels of analysis would factor single speaker data as well as the phase aspects of the in-room response (excess group delay).

At this point, it is appropriate to look closely at use of parametric EQ or digital room correction options to flatten the LF response. On this topic from Dr. Floyd Toole, *"I try to be careful to say 'at low frequencies (subwoofer region below 80 Hz) small rooms **behave as** minimum phase systems (as it applies to equalizing resonances).'* When pushed I go on to say that this is mostly

true for resonant peaks that stand above the average spectrum level, but as that level recedes below the average spectrum level, we clearly have a "signal to noise" (minimum phase-to-non-minimum phase) problem, because there are obviously non-minimum-phase activities in the region - interference dips being an example. This is relevant because the best evidence of an audible resonance is a highly visible peak, which, if attenuated to the average spectrum level (i.e. flat) results in a severe attenuation of ringing - which is the desired situation."

In the larger sense, everyone desires a "flat" LF response and no modal ringing. Simply, this is a tough achievement. The absurdly large collection of interrelated variables between two fullrange speakers and the room (*speaker design, speaker/listener location, room size/construction and acoustical control within*) makes this so. It is up to the individual to determine what their limits are as regards placement and acoustic treatment.

Figure F.1: Example one twenty fourth octave LF response.

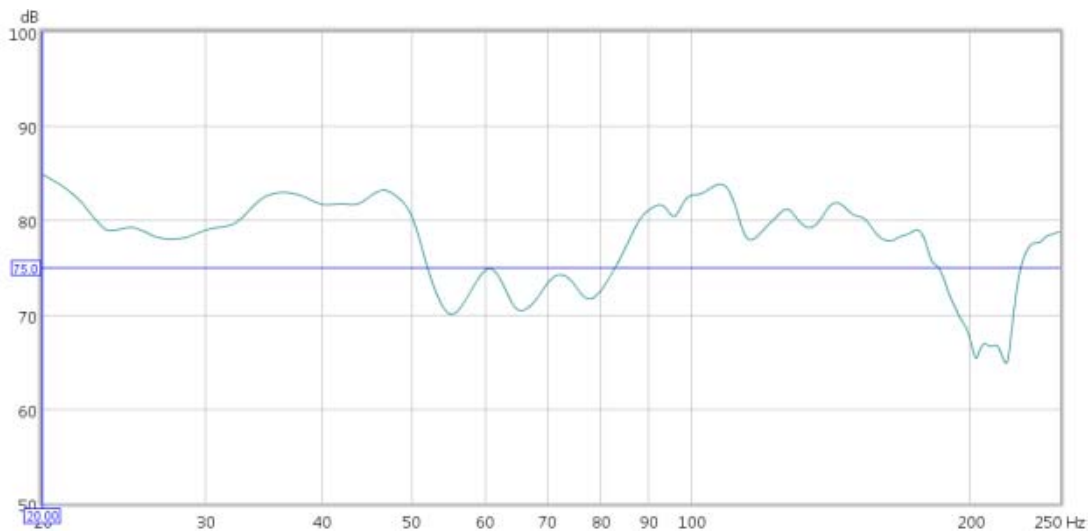


Figure F.2: Example third octave smoothed LF response.

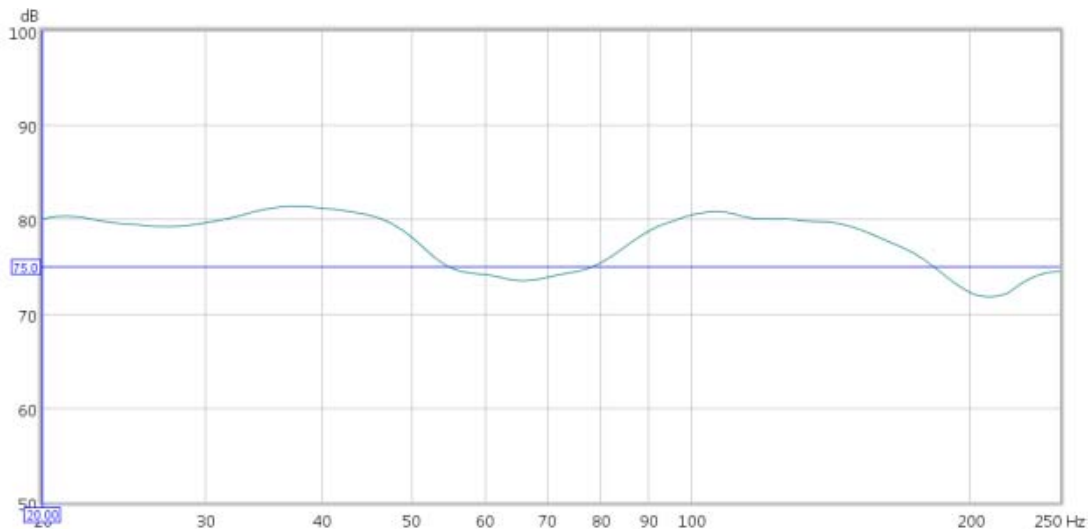


Figure F.3: Example Room 4 (see page 29). The next two images compare an UNSMOOTHED and 3rd-Octave SMOOTHED view of the same data. The UNSMOOTHED actually falls within standards at 1/24th resolution. The interest of showing the UNSMOOTHED graph exists in studying the many narrow valleys while the peaks follow a flat trend (with a slight up tilt below 50Hz that can be pleasing). These valleys are due to heavily sloped ceiling angles and other asymmetrical factors of the room.

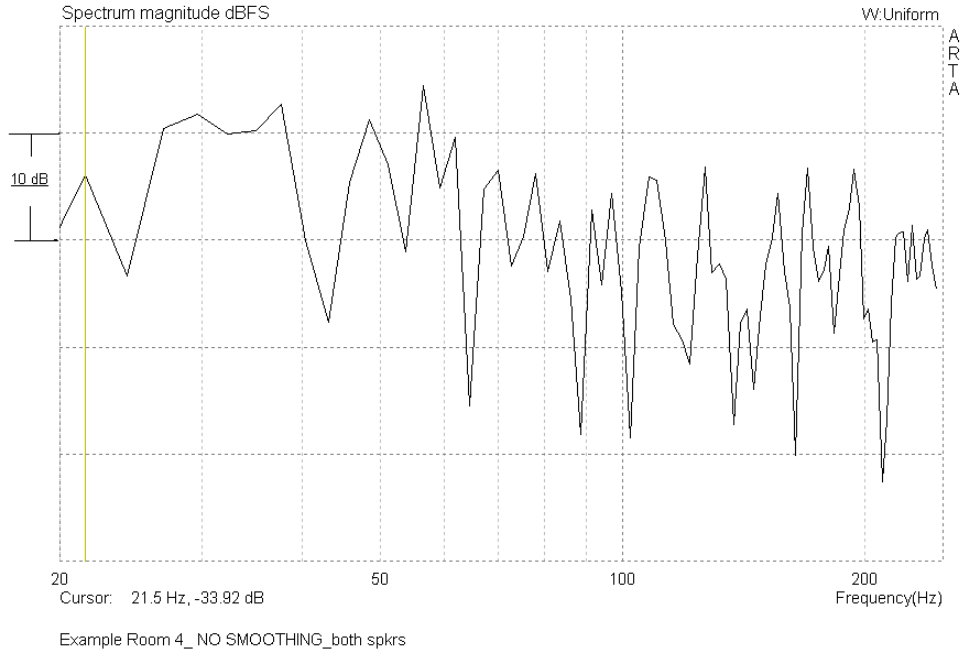
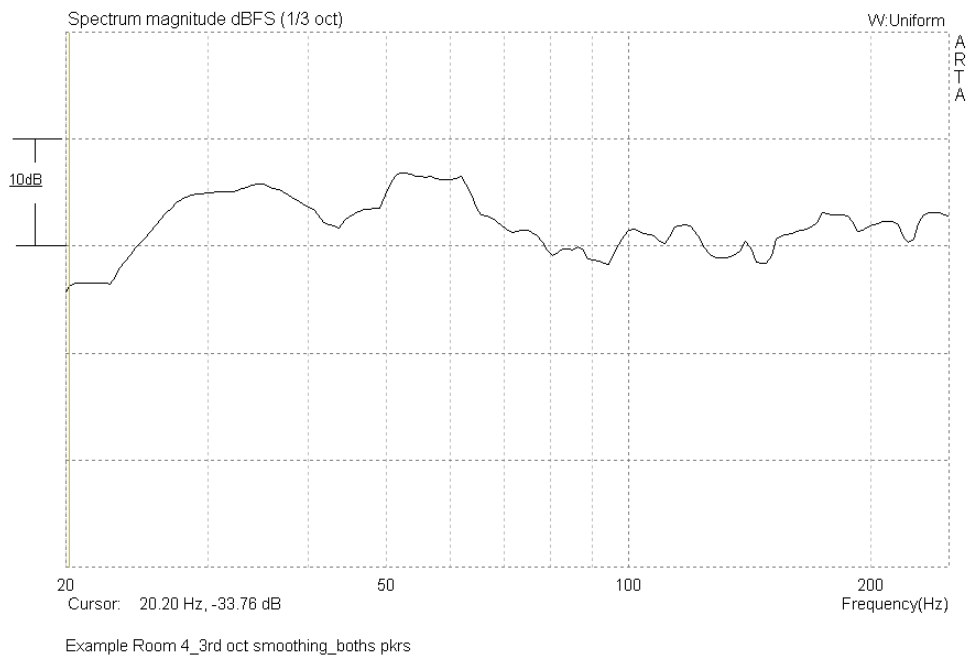


Figure F.4 shows the 3rd-Octave SMOOTHED LF Response of Sample Room 4. It is +/- 3.5 dB (well within standards). The point of interest is how to gain value from various levels of resolution. The narrow nulls of the UNSMOOTHED response are heard as “flat” in this situation.



G: Room Size and Construction

- ***Square footage should be in the range of 224 to 475 sq. ft.***
- ***Room volume 1,750 to 4,750 sq. ft.***
- ***The room dimensions should mathematically have no common divisors and no pair of dimensions should share more than one common divisor***
- ***The use of (2x) layers of 5/8" gypsum board is advised for walls and ceiling***
- ***Irregular shape rooms, rooms with varied construction methods on different surfaces and rooms with adjoining secondary spaces should all be carefully considered for the task of high performance listening.***

Both the Square footage and Room Volume are excellent qualifiers of a performance driven dedicated listening environment. The desired range of square footage should be between 225 and 475 sq ft. The room volume should follow suit with a desired cubic volume of 2,250 to 4,750 cu ft. So then, what should the exact room dimensions be?...well, it depends (sorry, no easy answers exist). However, having at least one dimension between 20' and 25' allows the room's lowest mode to be lower than 30Hz. The ceiling height should be 9.5' to 11' as this places the listener's ears comfortably below the floor to ceiling modal null. Regarding internal room volume, the targeted range yields greater modal density extending down toward 50Hz. Following these guides will offer tangibly smoother and more even bass response and a more pure connection to the speaker's true overall sound.

The ratio of room dimensions (width, height and length) is a foundational aspect of your listening experience. In this regard, your room should be thought of as an instrument. Proper relationships between the room dimensions will yield the smoothest, most consistent bass response, period. Sorry to report though, there are no "factory set" ideal room ratios. There are good starting points such as the Loudon Ratio of 1, 1:4, 1:9. If given a blank page, the room dimensions should mathematically have no common divisors and no pair of dimensions should share more than one common divisor. The goal is to yield an even density and distribution of room modes.

How the walls, floor and ceiling are constructed is a significant part of the sonic signature of a listening room. Massive concrete surfaces retain nearly all "bass" energy while lightweight residential partitions allow nearly similar amounts to pass through to adjoining spaces. Optimal sound quality in this realm is a lot like Goldilocks...not too hot or too cold but just right. Sonically (not factoring isolation needs), "just right" is a double course (2x) of 5/8" gypsum board. This yields enough mass for the low frequency energy to be punchy and focused when desired but not so much that the resonances are overwhelming. Further benefits can be had from use of certain isolation hangers and dampeners as they diminish "after-ring" elements that building materials can exhibit when fully excited by sound vibrations.

Conclusion

The purpose of this paper is to offer clear standards in areas that affect the audiophile two channel listening experience. It is important to realize that no single measurement can tell you what a room will sound like. When considered in combination, however, these standards provide powerful insights into your room's performance. It is our belief that as a result of this article you will be much better placed to determine and prioritize the acoustical areas that need improvement. Further, it is clearly shown that the process of locating two speakers and a single listening position in a room is complex and no speaker in and of itself should be expected to compensate for all possible variables in a given space.

It is not realistic, nor is it crucial, that your room meets all of these targets. But identifying which areas of reproduction are important to you and optimizing your room to meet these goals is an important step towards improving your listening pleasure. Whether you choose to complete this journey yourself, or seek the expert counsel of the authors Nyal Mellor of Acoustic Frontiers or Jeff Hedback of HdAcoustics, you can be sure that the time and money spent on optimizing the acoustics of your listening space is one of the best bang-for-the-buck investments you can make in this hobby.

Acoustical design considerations for different speaker types

Conventional (typical forward radiating box type speakers)

This type of speaker is characterized by an on-axis and off-axis response that varies significantly as the angle off-axis increases. This variance in off axis energy requires more aggressive and muscular acoustical control at lateral and vertical first reflection points. Absorption of the lower mid and midrange frequencies (100Hz-2KHz) is typically a must to experience a dynamic and clean response. In this case: tighter decay times, lower levels of reflected energy and more careful speaker location in terms of modal peaks/nulls are key steps toward sonic excellence. Frequencies below ~300Hz propagate omnidirectionally in these speakers.

Constant Directivity

CD type speakers or Constant Directivity (also called termed controlled dispersion) are characterized by an off-axis response that varies minimally from the on-axis response. It is not uncommon for the off-axis response up to as wide as 40 degrees in the horizontal plane to have essentially the same frequency response. It is also typical that the vertical dispersion is more tightly controlled. In speaker design terms, this is achieved by the use of a horn or waveguide element in conjunction with the high frequency and/or midrange driver. Like conventional speakers, frequencies below ~300Hz propagate omnidirectionally.

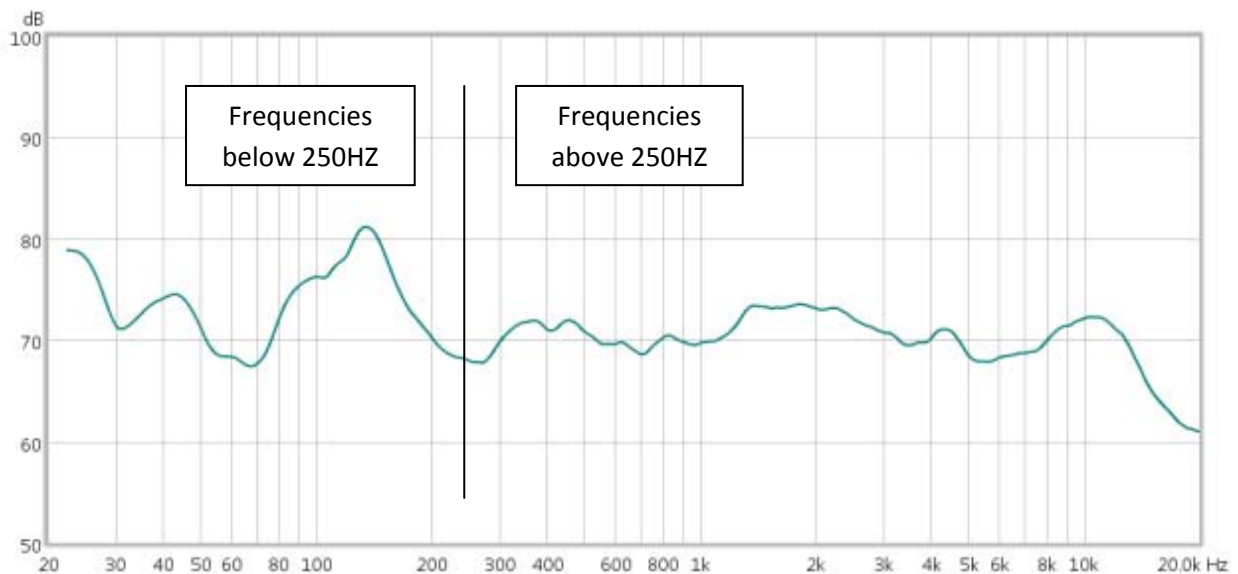
Dipoles

Dipoles are a quite popular type of speaker both in traditional electrostatic / ribbon / planar magnetic configurations and new school cone open baffles. Dipoles have a couple of characteristics that are worth bearing in mind with respect to the acoustical targets defined above and the application of proper acoustic design to realize high end reproduction.

1. Dipoles radiate equally forwards and backwards.
2. Dipoles have cancellation nodes perpendicular to the baffle axis. Due to this they do not excite room modes along this axis and have reduced interaction with the side walls.
3. Dipoles have a lower reverberant field for a given SPL at the listening position (3.8dB less) relative to a monopole due to their increased directivity. The distance to which the direct sound dominates spectral balance is further as a consequence of this; this also means that single figure T60s can be higher for dipoles relative to conventional speakers.
4. Dipoles are velocity rather than pressure sources. This means they couple to room modes differently. A pressure peak is a velocity low and vice versa.
5. Dipoles cannot pressurize a room below the frequency of the lowest modal resonance. This is a consequence of their velocity source nature. In small rooms the lowest modal peak can be in the 30Hz range which makes a subwoofer a consideration. In addition Dipoles have a -6dB per octave cancellation below the so-called dipole peak. This means that very large baffle sizes and displacements are required to reproduce low frequencies at high SPLs.

Explaining the division of the frequency domains

The behavior of a small room in the frequency domain is typically broken down into at least two parts – above the so called ‘transition frequency’ and below it. Below the transition frequency the response is dominated by the effect of room modes. Above 250Hz the response is dominated by the spectrum of the early reflections. This is one of the key reasons why it is important to ensure the spectral balance of reflected sounds are similar to the direct sound. More sophisticated analyses can include a transition zone, say between 150Hz and 350Hz, where the response is neither modally dominated nor early reflection dominated but is a combination of the two. Sometimes the region below around 80Hz is also split out into an area called the ‘sparsely populated modal region’ as this is where room modes are spread further apart. The actual frequencies depend on both room size and the amount of absorption within the room.



Example Rooms

This section contains photographs and short descriptions of some of the rooms from which some of the acoustical measurements in this paper were captured.

Room 1

This is the dedicated audiophile surround room of Ted Brady (moderator of Hi-Rez Circle at Audio Circle). HdAcoustics completed an acoustical renovation of this showcase room in 2010. The SP Tech/Aether Audio Grand Revelations are matched with HdAcoustics custom devices, RealTraps panels (20+) and GIK Acoustics panels.



Room 2

Kevin Jones listening space exemplifies the residential situation with a kitchen off the to the left and other “open plan” connections. HdAcoustics performed remote acoustical analysis to compliment his existing GIK Acoustics materials with those from Ready Acoustics. His Purity Audio Design/Wilson Sasha combination is described by all in terms of great dynamics and being very revealing. The speakers were set by Craig Hampel.



Room 3

This room at a high end dealer in San Francisco was previously 'treated' by hanging thin drapes across 50% of the walls creating an uneven T20 and T30 as frequencies above 1kHz were selectively absorbed. Acoustic Frontiers recommended replacing the drapes with strategically positioned combination absorber / diffuser panels allowing T20 and T30 targets to be met and the spectral balance of direct and reflected sounds maintained.



Room 4

Joe Dalton's "room over the garage" features treatments designed by HdAcoustics: custom sidewall sawtooth absorbers, front wall polycylindrical diffusors and other elements work to yield balance in this architecturally tough space. The sound of the Wilson Sasha's is truly remarkable in this space. The speakers were expertly set by Craig Hampel.



Author Biographies

Nyal Mellor



Nyal is the founder of Acoustic Frontiers LLC, a company specializing in acoustic design, acoustic treatment, room correction and system calibration for high end audio and home theater. Acoustic Frontiers is based in Kentfield, Marin County in Northern California. Nyal was born in England and holds a Bachelor’s degree from Oxford University. In his spare time he enjoys snowboarding and mountain biking.

Jeff Hedback



Is the founder of HdAcoustics (formerly Hedback Designed Acoustics) a full service acoustical design and consultancy firm specializing in unique needs of small room acoustics. Jeff holds a Bachelor of Music Degree from the esteemed Berklee College of Music and began his professional career as a pro bass player with recording credits on major recording labels, national/regional tours, and countless “smelly bar gigs”. HdAcoustics clients include Ozzy Osbourne, Lifehouse and Trevor Horn.

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