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Sound Quality For Home Theatres

Smoke And Mirrors 101

Norman Varney

What makes for good sound versus bad? What are some of the misconceptions, pitfalls, and tricks surrounding sound quality? We'll cover a few of the most basic ones briefly in this article regarding home theatre acoustics. Acoustics is vast and covers many different scientific disciplines. Home theatre falls under small room acoustics. Different rules apply here, both physically and objectively, than say, large venue or outdoor acoustics, etc. There is a lot of bad information out there that can lead you and your hard-earned cash away from the nirvana you seek and deserve—and that your equipment is capable of delivering. In this article, you will learn that investing in expensive equipment can have little to do with achieving a great experience.

Sound quality can be broken down into many subjective sonic categories. Common terms used to describe room attributes are live (reverberant, not enough absorption), dead (too much absorption), bright, dull, fast, slow, muddy, droning, etc. Sound quality vocabulary of playback systems include dynamics (contrasts between soft and loud sounds), imaging (ability to localize and sense size and space of a particular sound or instrument), resolution (low-level detail), soundstage (how deep, wide, high, and solid the aural presentation is), perspective (perceived distance between listener and soundstage), tonal balance (naturalness), articulation (definition and intelligibility), speed (how fast sounds start and stop), and drive (vitality), etc. These "audiophile" descriptors help us characterize what we like or dislike about playback systems and enable us to focus on how to improve them. They are commonly used by audio equipment reviewers to communicate their opinions.

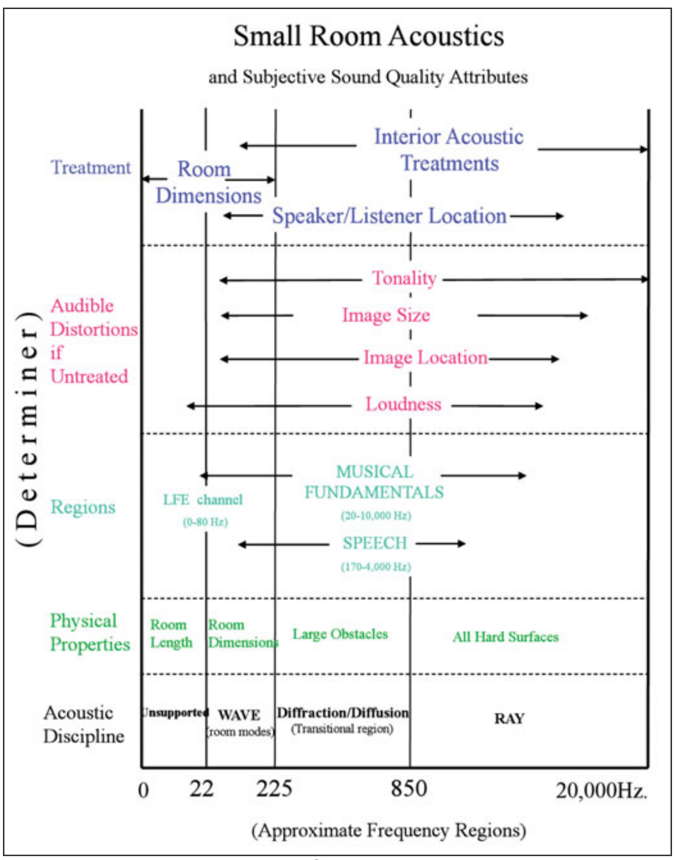

Chart 1

Though I own and appreciate high-end gear, I know that the room itself has more influence on these perceptions than the electronics. I can enjoy good music on a transistor radio, but play it through a good system that is set up right and it can make me cry. It can make my hairs stand on end, make my heart rate increase, and cause me to jump when startled. There are movies so quiet and suspenseful that I'm apprehensive to breathe or swallow for fear of being heard by others. If you have not experienced this kind of emotional involvement with your BDs, DVDs or CDs, then you're missing out!

In the last issue we talked about noise control. Noise control is fundamental and the first step to good sound quality. They go hand-in-hand. You can't have good sound until you control noise. Let's summarize noise control and its relationship to sound quality:

- Noise can distract focus, pulling you out of the movie experience and back to reality.
- Noise can come from a source outside the room such as traffic, an appliance, footfalls from other occupants, etc.
- Noise can come from a source within the room such as HVAC, equipment fans, electrical system, etc.
- Noise can mask dynamics, which are so important in conveying emotion.
- Noise can mask low-level details, which may offer important clues to the story.
- Keeping the noise floor down means not having to turn the volume up to understand dialogue, and then back down during loud passages.
- Noise is anything added or subtracted to the original signal.

You may think that noise control is mainly about isolation and shell construction, but it includes the entire electro-acoustical system. Remember, noise is anything other than the original signal. This means signal integrity through each system of transducers—from the electrical energy of the electronics, to the mechanical motors of the loudspeakers, to the sound waves interacting with the room, to the listener perceiving correctly. I believe you can categorize a hierarchy for good playback performance with the following: setup, calibration, acoustics, and lastly, equipment. Let's briefly explain what these categories are so that you may understand why this order is so important and why it cannot be changed.

1. Setup

Room Dimensions

Setup begins with room dimensions. Ideally, you want a rectangular room. A rectangular room is symmetrical and acoustically predictable. In new construction, optimum room dimensions are first governed by the available space, then by noise control issues (thickness of wall, ceiling, and floor systems) and by budgetary, cosmetic, local building codes and construction practices, maybe even "green" issues, and finally room modes. The primary room modes are axial resonances that occur between parallel boundaries, such as the floor and ceiling, side walls, and front and rear walls. They are troublesome in the bass region below approximately 350 Hz. Without going into much detail, understand that there are also a train of modes (harmonics) following these fundamental modes and that there are also tangential and oblique modes to consider. Low frequencies have long wave lengths (50 Hz = 22.5 feet), and they create high and low pressure points along their wavelengths. Simple math can tell us what the room mode frequencies are, as well as where their associated high and low pressure points live in the room. What we want to accomplish is optimum distribution of the room modes so that they are not so audible. Good modal density and spacing is key to good linear bass response, and we can control them with our room dimensions. For example, if we have equal room dimensions (a box) or dimensions divisible by each other, we will observe some very loud bass regions, and some very soft, because the modes will reinforce themselves.

Remember, I stated that a rectangular room is acoustically predictable. We can estimate, with reasonable accuracy, what modes exist and where. We can control room modes via three design elements: by changing the dimensions of the room (modal density and spacing), with speaker/listener positioning (emphasis or de-emphasis of anti-nodes), and with acoustic treatments (more on this later). What about the popular "splayed walls" technique? There are two reasons people do this: one is to remove the possibility of what is called "flutter echo" (quickly repeated reflections heard between parallel surfaces), and the other is to avoid room modes. It turns out that neither warrants the cost in real estate. Flutter echo can easily be addressed with absorption or diffusion at the right location. This might be genuine acoustic treatments, or even a tapestry, or a large-leafed plant on one of the parallel surfaces. As for room modes, splayed walls may have relevance in larger venues, but in home theatres we are under the disciplines of small room acoustics, and one of those disciplines says the room dimensions are small in relation to the low-frequency wavelengths we are capable of hearing. Therefore, there are

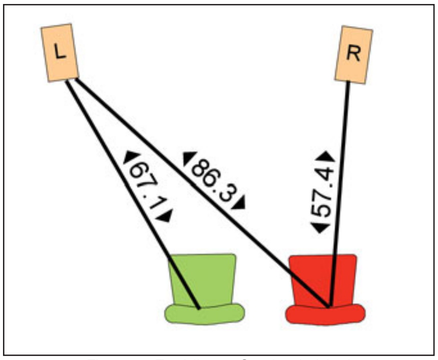

Figure 1. Equidistant Seating is Ideal
Green seat offers equal distance and amplitude from both speakers. Red seat offers different time arrivals and amplitudes from both speakers.

fewer modes, which make them easier to hear. Splaying the walls will not make them go away. They will still be there, only now they may be impossible to predict, test, or treat acoustically because they are skewed about in the room.

Another misconception is that all flutter echoes need to be eliminated. You may have seen someone clap his or her hands to find flutter echoes in the room. The only echoes that are relevant to the playback system are the echoes created by it, which are geometrically related to the loudspeakers, the boundaries, and the listeners. By addressing other non-related echoes, you may end up with an overly dead-sounding room.

Speaker/Listener Locations

Room dimensions dictate three important issues regarding loudspeaker/listener locations: the room's modal response, the loudspeaker/listener relationship, and the boundary effect.

First, we don't want to place the listeners or the loudspeakers in areas where low-frequency room resonances (room modes) will cause nonlinear frequency response. The dimensions of the room call this out because of their relationship to sound wavelengths, and if we don't watch out, we'll end up exasperating the modes, resulting in bass that is too heavy at certain frequencies and/or too light in others. Placing yourself or a loudspeaker in an antinode (constructive crest, maximum pressure) will cause that mode to be louder than the other frequencies. On the other hand, place yourself in a node (destructive trough, minimum pressure) and you may miss the note entirely.

Second, we want the listeners to be placed for optimum soundstage. Let's say you have a stereo boom box. You won't perceive it as stereo unless your head is oriented between the loudspeakers, forming an equidistant triangle. If we have listeners closer to one side, they obviously will hear more sound from the loudspeaker they are closest to, and those sounds will arrive sooner (shorter distance) than sound coming from the further loudspeaker (see Figure 1). This results in distortions of amplitude, phase, and frequency response, which destroys tonality and spatial cues. In addition, any low-level details coming from a far loudspeaker are masked by the closest loudspeaker. No big, solid, three-dimensional, holographic soundstage, no natural timbre, and no belief that the sound is coming from the picture. Add more channels of audio and the relationship between loudspeakers and listener becomes even more critical. Contrary to popular myth, there is only one spot in the room where all the loudspeakers can converge at the same level in amplitude, at the same point in time. You heard right, only one magic seat in the house. Sure, you can calibrate to just about any spot you want, but change from the calibrated spot and frequency, phase, and amplitude also change. That's physics. Here's some more smoke to be cleared—you've probably heard about "averaging" the frequency response measured from several seat locations and then utilizing parametric equalizers or a digital signal processor (DSP) so that all seats have great sound? Think about what that means. It means compromised sound for all seats. Equalizers and DSP have their place, but frequency-response averaging for seats is a misuse of these tools. This practice is not for high-fidelity seekers and is not what the artists intended.

Third, avoid placing people and loudspeakers too close to boundaries, such as walls, which will introduce sound wave reflections, again causing phase and frequency anomalies. Also avoid placing the loudspeaker/listener footprint to one side of the room for the same reasons (see Figure 2). Symmetry is key, especially side-to-side. This is

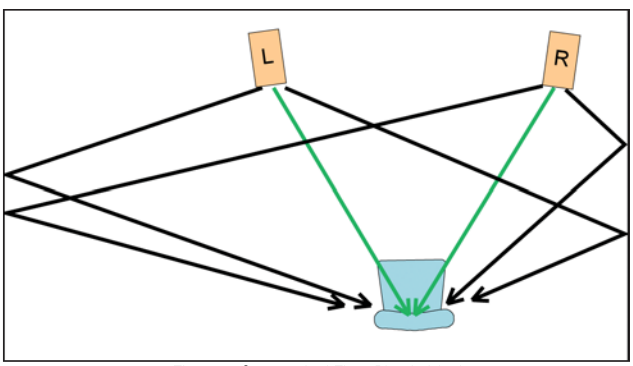

Figure 2. Symmetrical Floor Plan is Ideal
Green lines show direct signal path (shortest distance).
Black lines show side reflections will arrive at later times

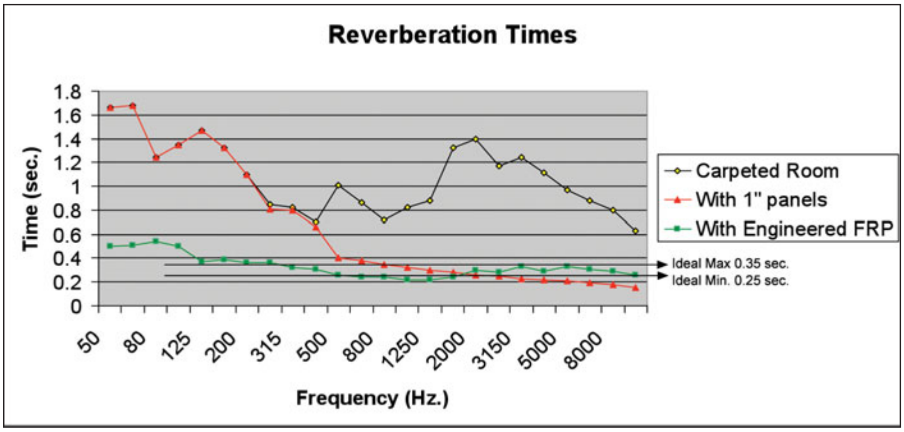

Figure 3. Actual RT60 of a Home Cinema.
The Yellow line represents the room typically furnished. Note the sonic "signature."
The Red line represents optimum 1-inch fiberglass panels. Usually we would see more area treated, resulting in a much steeper dive than shown here. Consequently, this treatment over-damps above 500Hz. and does not address below 500Hz.
The Green line represents application of an engineered, broadband acoustic treatment system.

because of the way our aural and visual systems are designed on our head to correlate and process our environment. Pay attention to proper setup design, and you'll have more seats with better sound and not a bad seat in the house.

Loudspeaker Aiming

Aiming the loudspeakers at the listeners is also a part of calibration. Obviously, if you set up a loudspeaker to fire away from you, it wouldn't sound very good. Different types of loudspeakers propagate sound energy differently, and even the same types can have different dispersion patterns. In general, you want the loudspeaker to be aimed towards the listeners, specifically the primary seat. The higher frequencies are very directional and behave like light beams. This acoustic principal is known as ray acoustics and, dependent on the reverberant characteristics of the room, begins roughly around 1 kHz. Think of the loudspeakers as spotlights. With that said, there are two things to consider: 1) Place the loudspeakers so that they are not blocked by any object along the pathway to the listener's ears. 2) Aim the loudspeakers towards the listener's ears. If you don't aim the loudspeakers properly, no one has a chance to hear a big, accurate soundstage or natural timbre. As you aim all the loudspeakers towards the primary seat, the image becomes intensified and all other seats will have less severe, and more similar compromises. On the other hand, if you don't aim the loudspeakers well, certain seats will be dominated by certain loudspeakers and the entire audio system will fall short of its potential. By the way, consider what high-back seats do for your audio pleasure, they reflect your left, center, and right loudspeakers and block your surrounds.

2. Calibration

Now that we have basic setup in the room under control, we can calibrate. You may be thinking of level and delay settings, but there is a lot we must check out before we can get to those. Calibration of the electro-acoustical system can be broken down into three categories—electronics, loudspeakers/listener relation, and finally interior acoustics.

Electronics—Power Quality

As always, you must start at the beginning of the chain in order to confirm or correct signals that will influence signals further up the chain. We start by checking the AC power. There are many possibilities for the power quality to affect the sound quality of the system from harsh sound, to hum, to thermal shutdown. Check the line voltage, amperage, frequency, THD (total harmonic distortion), current harmonics, power factor, K-factor, circuit loads, and even cable dressing (how power cords, interconnects, and loudspeaker cables are physically laid out in the system to avoid electrical interference). AC can be checked out even before the components are purchased. There are many things that can be included in proper design of the AC system such as isolation, grounding topology, circuit loads, protection, etc. As you can imagine, the topic is vast, and designing, testing, and correcting should be performed by a qualified electrician.

Electronics—Signal Quality

After the electronic components are all carefully hooked up, they must be verified. Don't assume that they are hooked up right or that the manufacturers QC'd their equipment properly either. I find 80 percent of the systems I calibrate are wired wrong somewhere along the chain by either the installer or the manufacturer. Incorrect wiring is an easy fix in the field, requiring at most a soldering iron. Faulty equipment, on the other hand, might need to be replaced. After configuring the processor for general setup of loudspeaker size, bass management, distance, gain, etc., we identify each channel, channel polarity, and individual driver polarity. Problems may involve checking signal gain levels and/or frequency response, driver impedances and/or frequency response, etc.

Processor Settings

Now that we have confirmed that our electronics are hooked up and functioning correctly, and that our loudspeakers are properly aimed, we can adjust our processor for matched signal levels from all loudspeakers. I don't think I need to explain this process here, other than to clarify how to position the SPL microphone. I often hear about positioning the microphone slightly forward to compensate for the way our ears are shaped and oriented on our head. This is a bizarre notion and will give a false reading. We want the signals to match at the primary listening position from all loudspeakers. Position the microphone so that it is aimed straight up at the ceiling. In addition, get yourself out of the pathway so you do not block the sound. This is a simple standard and if we all (mixer and listener) abide by it, we will hear what was intended. If we don't, we are not calibrating to anything.

3. Acoustics

Certainly, noise control and the physical setup we have covered so far involve acoustics. You can even say that the calibration of the electronics has to do with the acoustics because of their interactions. But when you say the word "acoustics," most people think interior acoustic treatments. Actually, most people don't say the word at all, and that's the problem. They don't think about acoustics, even though it is the most important part of the playback system. It has the final and loudest say in regards to your experience. You can have the best gear in the world, but if you don't consider acoustics, it won't matter. A mid-fi system, set up right, will blow away that gear every time. Believe me, an inexpensive system, in an acoustically controlled environment, as described, will offer an experience beyond your dreams. And you don't have to have a golden ear to appreciate it. I have conducted controlled subjective and biofeedback tests and have learned that acoustics can control your emotions by making the experience more believable. It's the difference between "I'm there" versus "I'm trying to watch a movie at home." My mom hushed my daughter in the middle of watching the *American Ballet Theater In Swan Lake*

DVD. She then laughed because she had been temporarily fooled into thinking that she was at the Kennedy Center for the Performing Arts and that people might be disturbed.

Acoustics is the study of sound. The late Richard C. Heyser said, "Sound is what happens when air gets pushed." A loudspeaker converts electrical energy to mechanical energy, which is then converted to sound energy. Once this happens, the sound waves are at the mercy of the physical environment in which they are contained. The propagated sound is reflected, absorbed, and diffused by everything it hits in the container. It hits everything! Therefore, everything is acoustic treatment. Every container has a unique sonic signature (see yellow line in Figure 3). This is not a good thing. The walls resonate, the room reverberates, the curtains absorb, the wood floor reflects, etc. Each of these properties has unique characteristics of absorption, reflection, and diffusion, at different frequencies and different magnitudes. This is chaos in desperate need of being organized.

There are several areas to organize—room mode control, first order reflection control, and reverberation control. Our tools include absorption, reflection, and diffusion. We incorporate computers to do the math by plugging in all the information regarding room dimensions, loudspeaker/listener locations, construction, and furnishings. We evaluate the mess to see how far off we are from our target and in what areas, and begin to apply the correct type of treatments, at the correct locations, in the correct quantities until it is acoustically optimized. "Optimum" must factor in budget, décor, space, architecture, etc. There are many acoustical products available, but the most common are 1-inch fiberglass or foam panels. They are only effective for the mid- and high-frequency ranges from 500 Hz and up. This approach ignores low, mid, and bass regions entirely (see red line in Figure 3). They also tend to cover too much surface area. This results in a room being over-damped in the mids and highs, sounding dull and lifeless, and under-damped below, sounding slow and muddy. Are there any positive attributes with this treatment? Hopefully, first-order reflections were covered, so we have better imaging, but overall, we went from one wrong to a different wrong. The room is still uncomfortable, unnatural, and unbelievable.

Plan Of Attack

First Order Reflections

In a rectangular room, each loudspeaker will have six first-order reflections. One from each of the six boundary surfaces it hits. For a 5.1 system, that's 30 first-order reflection points to address (we're not counting the subwoofer here). If left untreated, each of these reflections will have six more reflections (second order), and so on. Each reflection point is like having an additional loudspeaker playing at you, filtered by the absorption, reflection, and diffusion properties of the material it is reflected by, and arriving later in time from the direct sound of the actual loudspeakers. It destroys tonality, spatial imaging, dynamics, and detail. When you address the reflection points with absorption, you will simultaneously be changing room-reverberation times. A diffuser can eliminate the reflection without lowering the reverberation times because it scatters energy back into the room instead of absorbing it by turning it into heat.

Room Modes

Every room has them—some are worse than others—and every room can be improved. We have discussed room dimensions being optimized for smooth mode dispersion, and we have discussed placing listeners and loudspeakers out of their way. We can also reduce their effects by absorbing their energy with interior acoustic treatments. The best place to begin this treatment is in the tri-corners. This is because all of the axial room modes congregate there. These corners are where the pressure is at a maximum. The modes are laid out like a grid in the room, with sets for the length, width, and height. The most energetic of these should be addressed. We can calculate their locations or sniff them out with an SPL meter, but we can only treat them at their perimeter locations to avoid obstructions in the room. This is best accomplished with diaphragmatic absorbers.

Reverberation Times

When we talk about reverberation times, we are talking about the time it takes different frequencies to decay down to a certain sound level. RT60, for example, is the time it takes sound to die down 60 dB. A common practice is to perform a general test that calls out a single-time number for the room. It may be fine to use such a test for a gymnasium, but for a home cinema, we need to know what frequencies are decaying at what rate, so we can figure out how to treat it to make it sound right. As mentioned earlier, every room has a distinguishable sound of its own. The size of the room, its shape, its construction, and furnishings all control and contribute to the characteristic voice of the room. These contributors result in a unique reverberation signature of the room. We want the room to sonically disappear. We want it to be neutral—to hear only the original soundtrack. We want to hear *James Taylor Live At The Beacon Theater*, not "James at Joe's house." In order to accomplish this, the reverberation signature will need to be flattened out and targeted to stay within a determined time window of about 0.25 to 0.35 seconds from about 100 Hz on up (see green line in Figure 3). To have impact on reducing the overall reverberation times, carpet, cloth-covered sofas, and big pillows will help. Tapestries and bookcases on the walls are also effective. Remember to keep things symmetrical, side to side. The best solution is to find a company that offers "broadband" acoustical treatments with engineering, modeling, and testing to go with it.

Summary

In order to experience deep immersion, emotional connection, and sense of being "in" the movie or "at" the concert, there are rules that must be followed. Many of these rules are simple enough for consumers to follow. More serious issues, as well as precision performance issues, will require help from experts. Every room has compromises to deal with. Hopefully, this article has helped you understand the order of impact to performance (setup, calibration, acoustics, equipment), and that this understanding will help you make more informed decisions regarding your individual compromises. I also hope this article conveyed to you that there is a realm of experience way beyond what you have likely thought possible. Whether you are designing a new system or want to improve your existing system, think about acoustics and put it in the budget. You'll be glad you did. **WSR**

Norman Varney is the owner of A/V RoomService, Ltd, an acoustical firm specializing in sound quality, noise control, power quality and HVAC, offering design, modeling, testing and voicing services and products. Prior to A/V RoomService, Norman was with Owens Corning at the Science & Technology Center where he was a Senior Engineer with the Acoustic Systems Business as the Acoustic Design Center Lead. Prior to Owens Corning, Mr. Varney worked at Music Interface Technologies where he designed critical listening and viewing environments, AC line conditioners, video cables and was Director of the Custom Installation and Home Theater divisions. He was the lead for the development of the 2C3D and 5C3D Certification programs, which recommended structural, electrical and system component set-up parameters for Spectral, Avalon, ASC and MIT. While there, he designed the very innovative and elaborate electrical system for the Scoring Stage of Lucas Film's Skywalker Ranch. Mr. Varney has written many articles for numerous magazines over the years, as well as given seminars and participated on panel discussions regarding acoustics. He became a member of AES in 1981 and has contributed to the Characterization and Measurement of Diffusion Coefficient Standards, and the Recording Academy's Producers & Engineers Wing Recommendations for Surround Sound Production.