It's All In The *Acoustic* Details

Part IV: Audio Imaging

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We are continuing with information on how to achieve good audio performance. We have discussed how our ear/brain system functions, the significance of noise control, and we introduced the relationship of sound quality to video calibration in Part I. In Part II we continued with relating sound quality to video calibrations and the importance of setup. In Part III we discussed low-frequency issues, such as different forms of resonances, loudspeaker/listener placement, etc. In this segment, we will focus on audio imaging. This descriptor is being used to combine both soundstage and tonality. Though we can view a two-dimensional image of the Grand Canyon, it does not have the same impact as the real thing. With sound, however, when controlled properly, we can realistically re-create a three-dimensional sound image of a thunderstorm in the Grand Canyon, or being trapped in the confinement of a casket, or even swimming under water.

Soundstage, as it relates to the perceived size of the sound space.

Does your audio system appear to have sound coming physically from beyond the loudspeaker's location in both width and depth, or does it seem to only come directly from the loudspeakers? How wide, deep, and solid is the soundstage? Is there a sense of physical space between sounds or instruments, and is it accurately portrayed? Do the French horns sound like they are about 10 feet behind your left loudspeaker and in front of the percussion section?

Tonality, or timbre, as it relates to how the system conveys the space in the recording.

For example, if you're watching a movie taking place in a cathedral, does it sound as big as it looks, which is, of course, much larger than the room you're actually listening in? On the other hand, if the scene takes place in a closet, does it sound like a room that is much smaller than your room? Noise control, reverberation control, and low-level detail are critical in achieving space size cues. Another factor, if the concert is taking place at Boston Symphony Hall, do you hear the Hall, or do you hear your room playing along too? Often the playback room's reverberation characteristics overpower the recorded reverberation, in time and/or levels, to the extent of their being lost.

Tonality also has to do with the size of the sound.

For example, when listening to a rock band on a set of small loudspeakers, the band sounds physically small in size. Our brain knows that a miniature band doesn't really exist, and we can still recognize instruments for what they are, even though we are missing a lot of frequency bandwidth and loudness information. The full-bodied sound of a quality cello being played well is rich and beautiful in real life. You can feel it connect with you physically and emotionally. Listening to an orchestra featuring Rostropovich will place his cello in front of the other musicians and just to the left of the conductor. The same performance re-created by a stereo system can convey the size and locations of the individual instruments on the stage, as well as the specific size of the hall, as in real life. A poor system setup will cause the recording to sound congested and ill defined. A poor system setup (or recording) can make images sound larger or smaller than life.

Audio imaging has more to do with connecting us to the story or the music than any other facet of our movie or music experience—more than the visuals. Think of a place you'd like to go. It might be a ball game, deep sea diving, hiking, whatever. Place yourself there with eyes, but no ears. Now only think of what that place sounds like. Which transports you there best? Sound captures our attention and triggers our emotions more than sight. Think of how well the old radio days worked before television was invented. Even silent films were very unconvincing, awkward, and even boring unless accompanied by live music. Without sound you might be confused whether to laugh or cry.

Good imaging requires the fine details of each of these areas being optimized and combined together. It's what happens when the picture suddenly comes into focus and none of the puzzle pieces are missing. You get all the information. The sound is holographic [holosonic®—Editor] and wraps around you. Individual sounds are isolated in individual spaces, rather than a single conglomerated sound. The loudness, the size, and the location of the sounds are authentic. Most everyone is missing this experience, even those who have spent serious money. Most everyone can at least get more of an experience out of their existing equipment, regardless of what their equipment cost, if they follow any of the guidelines mentioned in this series. Let's go further into system layout.

I believe in the following performance hierarchy for the electro-acoustical playback system: system layout (room/loudspeaker /listeners), system calibration (physical and electronic), room acoustics (noise control and sound quality), and finally, equipment quality.

We previously covered some basics regarding room dimensions and how they affect bass response. We also went over how placing loudspeakers and listeners near the walls is bad regarding bass response. Let's go over why placing loudspeaker and listeners near walls is also bad for mid-range and high frequencies, and how it relates to imaging.

Reflections are acoustical interferences to the original waveform. We want to hear the original sound without sounds being added or taken away. Of course, you can hear the recording without room reflections using headphones, but headphones are not my preference, especially with a group watching a movie. We don't want the room too dead sounding, with absorption everywhere, the room needs to breath a little or it feels unnatural. We do, however, want to remove the first order reflections. Each loudspeaker has a first order reflection point on each surface, and if we don't eliminate those, they will continue with second and third order reflections, etc. In a six-sided room, the left front loudspeaker has six first order reflections: one on the left wall, one on the front wall, the right wall, the rear wall, the floor, and the ceiling. There's a total of 30 first order reflection points for a 5.1 system.

Imagine hearing the sound of a trumpet making a low murmur for two seconds out of the front right channel loudspeaker in a reflective room approximately 15 feet x 19 feet x 8 feet. You initially hear the direct sound at, say, 70 dB. About 4 ms later, you hear the reflection of the front wall arrive to your ear about 2 dB softer. However, it does add onto the still-playing direct sound. This causes the original sound to move slightly to the inside right of the loudspeaker, as if there were a phantom loudspeaker located between the actual loudspeaker and the wall. Just behind this reflection is one from the floor. It's a wood floor, which has different absorption and reflection properties than the drywall has, changing the original timbre yet again, as well as shifting the location diagonally towards the floor. Next in line is a reflection from the right side wall, around 5 ms behind the direct and 3 dB down, causing another change in sound quality and image shift towards the right wall, then the ceiling reflection about 6 ms behind. Next in line is the left sidewall reflection. This one is about 12 ms behind the direct sound and about 6 dB down. Lastly, we have the rear wall reflection, about 17 ms later and about 8 dB down. That creates quite a mess for one loudspeaker (note the subjective audibility is relative to level vs. delay). Now multiply that by four more loudspeakers and you can imagine that the summed image (soundstage and timbre) heard is very different from what was intended. If you don't treat the first reflection, you will have a second, a third, etc. Get the picture? (See Figure1)

Comb filtering is what happens when the direct sound interferes with the reflected sound. Some frequencies will add to others and make them louder, and some will subtract to make them softer. Yes, just as we discussed with room modes for low frequencies, only these are much smaller wavelengths. Imagine two-dimensional water waves in a bucket and how they propagate after dropping a pebble in the water. Ripples start to spread out in growing circles from the point of entry in all directions. Finally the wave hits a boundary and reflects back. When the reflected waves collide with the direct waves, they cause the original waves to become deformed. Constructive and destructive anomalies not only alter the characteristic qualities of the tones, but can even change position in the soundstage, regardless of frequency.

Reverberations

We discussed how timbre is the richness in a tone that distinguishes the sound of the same note played on different instruments. It is the unique voice of the sound, which consists of resonances that vary in loudness, attacks, and decays. Resonant frequency bands are called formants. A clarinet's main formants contain louder soundwaves between 1.5 to 1.7 kHz and 3.7 to 4.3 kHz, while a trombone has only one formant from 600 to 800 Hz. The attack of a guitar string is faster than that of a bassoon. The decay from a piano can sustain for what seems almost indefinitely. Timbre is important to expression. There is majesty in the sound of a French horn, gentleness in the harp, melancholy in the oboe, and fun in the banjo. Finer details in timbre tell us who is blowing the saxophone, what brand sax it is, and what type reed is being used. These finer details are easily covered up by delayed sounds reflecting around the room and colliding with each other. The reflections cause a train of delayed sounds, which give us the sound effect we call reverberation. These delayed sounds also collide with one another, causing constructive and destructive distortions to the signal, which cause tonal colorations to the original sound.

Loudspeaker/Listener Placement

Before we tackle how to find the reflection points, let's talk again about loudspeaker/listener positioning in the room. Remember, symmetry is important, especially left to right symmetry. Position yourself and the loudspeakers away from large surface areas, and center yourself between your loudspeakers. These two basic rules will help reduce timbre and soundstage distortions. Whether you do it yourself, or go for the best and hire an acoustical engineer, the same rules and hierarchy apply:

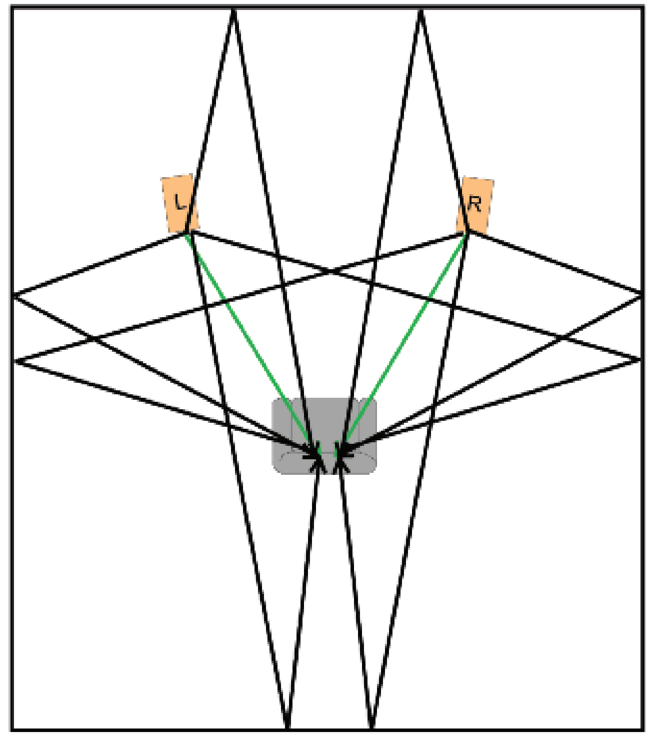

Figure 1. Shows first order reflections for two loudspeakers, on the walls only. If we don't treat these first reflections, we would have second, third, etc. Green lines indicate direct sound.

1. **The room dimensions dictate where the listeners and loudspeakers will live best** in the room, in order to avoid room modes and offer the best imaging (soundstage and tonality). Ideally, we have a rectangular room with the primary seat halfway between the left and right walls and a bit more than halfway between the front and rear walls. The center channel is directly in front of you at 0 degrees, the L & R loudspeakers at about 30 degrees, and the surrounds are between 135 to 150 degrees. All loudspeakers are the same distance away front the primary seat. All loudspeakers are the same model, or at least the same brand, driven by the same amplification. All loudspeaker tweeters are about ear height and aimed at the primary seat. Remember, this is ideal, not necessarily possible.
2. **The loudspeaker/listener positions dictate where the screen should go** and what size it should be. Ideally, the center channel is directly in front of you and slightly behind the L & R, because of the arc the equidistance creates. The screen should be located where the CC is so that the sound and picture are cohesive. This would place the screen so that the bottom of the picture is about eye height, which happens to be the most comfortable, and should offer excellent picture fidelity. A 16:9 (1.78:1) picture will fit between floorstanding loudspeakers without obstruction, and offer a big picture at a smaller price than the same field of view from a larger screen placed further away on the front wall. This author does not condone wide screens that force loudspeakers to the sides, sacrificing the audio by skewing timbre and soundstage.
3. **The loudspeaker/listener positions dictate where the first order reflections are.**

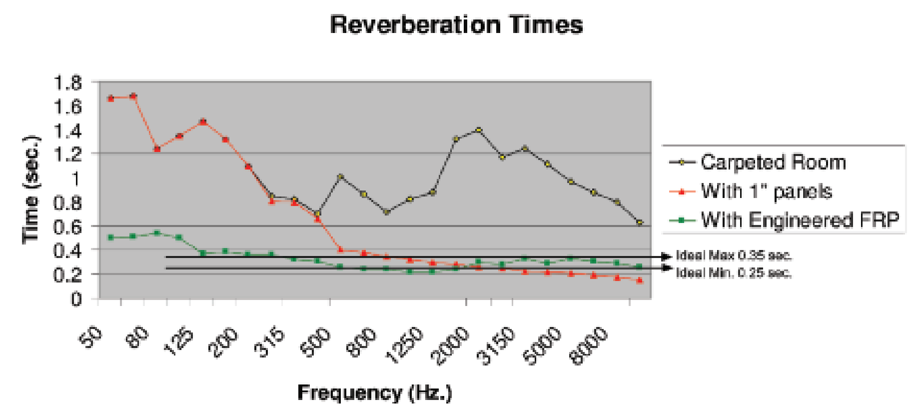

Figure 2. Actual RT60 of a Home Cinema.
The yellow line represents the room typically furnished. Note the sonic "signature."
The red line represents optimum 1-inch fiberglass panels. Usually we would see more area treated, resulting in a yet steeper dive than shown here. Consequently, this treatment over-damps above 500 Hz. and does not address below 500 Hz.

***Rant:** Splaying the walls does not remove room modes in small rooms.*

I often see unparallel walls incorporated with the notion that it will remove standing waves. Of course, canting the walls does not remove modes, and the modes become skewed about in the room to the extent that they are nearly impossible to control with any treatment, and we lose symmetry.

Treating First Order Reflection Points

This is where people typically change the sound from one bad to another. Often designers understand the need to control first order reflections, but don't go about it properly. Most interior acoustical treatments are 1 to 2-inch fiberglass or foam products, which only absorb frequencies from about 500 Hz and up. Designers usually cover the entire wall with it. This makes the room change from too live to too dead, but only in the mids and highs. The low frequencies are still bouncing all around the room. You want to control first order reflections, but without destroying sound quality. You can address those reflection points with absorption and/or diffusion without over-damping the whole room.

To find your first order reflections:

a) Sit down in your primary listening spot. Have an assistant hold a large hand mirror flat against the left sidewall and move it along until you see the reflection of the Left loudspeaker tweeter. Mark this spot on the wall with a piece of masking tape. Moving back towards the rear wall, mark the reflections of the Center channel (if applicable) and the Right loudspeaker. Repeat this process on the right wall.

b) Repeat for the floor if uncarpeted.

c) Repeat for the ceiling.

d) Repeat for the front wall looking for what would be the back of the tweeter.

e) Repeat for the rear wall, with your head facing the rear wall, at the same position.

When modeling an acoustic treatment layout, I typically start out absorbing the first order reflections of the L C & R and diffuse the first order reflections of the surrounds. Then I look at the reverberation times of the room to see what else needs to be done for the reverberation times and/or room modes. If the room is already too dead, diffusers can replace absorption up front. This will eliminate the reflections without reducing the reverberation. A first order reflection point for a single listener would be at minimum a 2-foot square, which would be large enough to cover wavelengths of 500 Hz and higher. Of course, acoustic treatments that cover a broader range of frequencies are desirable and available, but are not commonly known (see red line in Figure 2).

If you have an undedicated room, or are renting, or don't have the budget for the "real deal," there are several things you can do to help remove these reflections that are non-permanent and don't look like acoustical treatments. For example, staggered books or CDs in a bookcase, large leafed plants, tapestries hung 1 to 2 inches out from the wall, throw rugs for the floor, etc. There are also custom acoustical panels with personal photographs or poster art drum-scanned onto acoustical fabric, with acoustic panels behind.

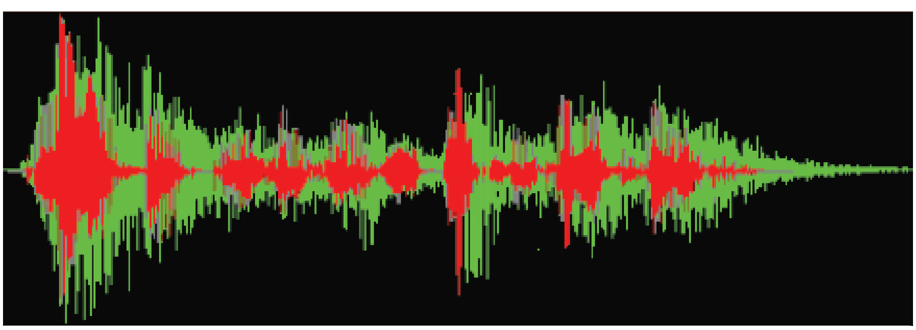

Figure 3. Pulse Response. Red represents a few spoken words without reverberation. Green represents the same recorded words played back in a typically reverberant room. Note how the green reverberation "fills in" the red gaps between words. Poor reverberation control makes for poor speech intelligibility, low-level detail, and dynamics.

Reverberation Times

When addressing first order reflections with absorption or diffusion, you are simultaneously lowering reverberation times. Again, this can be a good thing or a bad thing. We need a little reverberation in the room to be comfortable. A room that is too dead feels congested and tight, like standing inside a closet stuffed with clothes. On the other hand, a room that is too live, which most media rooms are, offers poor articulation and masks low-level details. It is difficult to hold a conversation in a racquetball court because the spoken words keep bouncing around the room. The vowels become dominant, and the consonants get buried by them. It's hard to know if the loudspeaker said bath, bad, bat, or for that matter path, pad, pat, pan because the sound doesn't stop between the words (see Figure 3).

To go one level deeper into human perception of reverberation, you might be interested to know that we perceive delays differently, depending on delay time and loudness, compared to the original signal. If the delay time is too short and/or too soft, we may not detect it. As it becomes delayed longer and/or becomes louder, we first perceive spaciousness to the sound, and then a broadening of the image, and finally a discrete echo, all with tonal colorations. It is because of this phenomenon that acoustic treatments, which reduce the first order reflections by at least 10 dB, are recommended (see Figure 5).

Reverberation time is usually a single number. For example: RT60 = 0.75 sec. This means that the sound takes ¾ of a second to decay down to 60 dB below the original signal. It does not indicate what frequency—it might be 500 Hz, it might be 2 kHz. Ideally, we want to have our reverberation times rather evenly controlled across the entire audio bandwidth. Every room has its own unique reverberation signature. This is because each room has different dimensions, construction materials, and methods, and is filled with different furnishings. This is not good for the artist, the equipment manufacturer, or the consumer. As in video, if we all abide by the same rules, we stand a good chance of experiencing what the artist intended. The lowest frequencies are hard to control with typical acoustic treatments, and some allowance for a bit of "bass hang" is a good thing (See green line in Figure 2). It turns out that if our eyes see the room, we expect to hear it to some extent, and if we don't, we are uncomfortable. I have known people to feel ill stepping into a fully anechoic (non-reflective) room. It's a psychoacoustic thing.

Reverberation and Drive

There are tunes that seem to have a drive in the rhythm that not only makes you tap your foot, but even seems to be driven by itself. Paul Simon's title track to *Graceland* comes to mind. Listening to the instruments with a good playback system, it seems they are all moving forward together on a ride, driven by some external force. There is urgency to the pace, as if it were a locomotive at top cruising speed that could keep on coasting for a long time if the engine was suddenly cut. This sense of drive cannot be conveyed without good equipment in a good acoustical environment. Typical room reverberation times cause drag on the rhythm. Even though the meter is the same, it seems sluggish because the silences that fall between the sounds have been filled and are smeared in time. The intricate temporal patterns of the bass line, for example, are lost, and we are robbed of an entire emotional dimension.

As we talk about "ideal" setups, understand that every room and every system has many compromises, each with associated decisions that must be weighed. It is the duty of the acoustician to identify them and help you understand what those compromise-to-performance values will mean to you, so that you can make informed decisions.

In the next segment we will continue the quest for audio nirvana, with more information about setup and some of the physical and electronic calibrations that people don't do, but should. **WSR**

About The Author
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 many acoustical 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. He continues to study and develop the science of subjective acoustic value-to-performance relationships. Norman can be contacted at www.avroomservice.com, or normanvarney@avroomservice.com.