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PART II

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Physical And Electronic Audio Calibration

Part II

Norman Varney

This is the last of a ten-part series on the "Ultimate Home Theatre." I have covered everything from how we perceive sound, to how sound propagates in a room, to how it is evaluated both objectively and subjectively, to how to set up and calibrate your own home theatre. I have discussed how important construction materials and methods are to both noise control and sound quality, how materials are characterized and classified in acoustic labs, and how sound has more emotional impact than picture. I have also discussed how much more important set-up, calibration and acoustics are than the electronic equipment. Hopefully, you have learned more about how you might improve your existing system, or have learned the steps required toward building the "Ultimate Home Theatre" that performs beyond your expectations.

In Part 1 of Physical And Electronic Audio Calibration, I discussed how easy it is to evaluate a home theatre in 21 steps using only your eyes and ears, a tape measure, an SPL app, and disc that includes the THX Optimizer. No special training required. A basic set-up and performance evaluation should take less than an hour, and should be done after every installation.

If there is just one thing that you glean from this series on home theatre acoustics, I hope it is that audio drives the believability and the emotions over picture.

This basic audio evaluation should also be included for any home theatre awards—a simple pass/fail score card. Home theatre awards lacking audio performance quality is something that bothers me. I'll see video display calibration results, but nothing for audio and acoustics, other than maybe room layout and possibly some talk about acoustic treatments. Sorry, but that doesn't confirm if it is even hooked up right, let alone if it sounds decent. Information about the audio/acoustic evaluation should be a part of every home theatre award listing!

The previously discussed is just to evaluate objectively, not to calibrate or evaluate subjectively. So far I have talked about objective things that are **observable**. But remember how important acoustics are to the experience? We really need to look at some things that are **measureable**, as well as some things that are a bit **subjective**. For example; what are the reverberation times for the room? What is the noise floor and maximum SPL of the system? Have the delays and SPLs been calibrated to a particular seat? Is the soundstage convincing? Does it sound natural and involving without any buzzes, rattles, etc.?

Remember that this is for the "Ultimate Home Theatre," so much of it may not be applicable to yours. Remember also that we're not able to go into depth with only a few thousand words.

Voicing

Voicing is optimizing the electronic equipment to perform to its maximum potential, and to control the room acoustics from chaos to organized sound. To calibrate the equipment with the environment and optimize the two for performance, I need to confirm or identify what I'm working with. Like most processes, there is a hierarchy to follow when "voicing" a system. I typically arrive asking that the system be pre-wired and basically configured, whether it is a newly installed system, an upgrade, repair, etc. We should be in the ball-park without fine-tuning anything. I shouldn't be spending my time on what integrators can and should have in place. At this point, the system should be working correctly; it just doesn't offer the magic that it is capable of delivering yet.

I. The process starts with a quick investigation of the **shell and electrical**:

Photo 1 *The author installing a constrained-layer damping treatment to an existing noisy HVAC duct.*

1. What are the room dimensions, are they square, are they what they are supposed to be, etc.? If I've done the design and modeling for the room, and find the dimensions are different, they will change where I estimate the loudspeakers/listener footprint will be in the room.

2. I want to check that the door is properly sealed if it is a noise-rated door.

3. I want to listen to the HVAC system for anything unexpected (See photo 1).

4. Confirm that the AC power being delivered is as expected (See Photo 2). This involves using some test instruments to check for:

a. Outlet wiring. I often find outlets wired wrong. Not only can this make the equipment sound bad, but could be dangerous to the equipment and personnel.

b. Line voltage minimum and maximum.
c. Frequency
d. Current
e. Additionally, I may want to check the following:
i. Sags and swells in amps and voltage
ii. THD percent
iii. Harmonics
iv. K-factor
v. Power factor
vi. Transformer load
vii. Ground potential
viii. AC cable dressing

Once I have the above information, I know what my baseline is. I know that it is the best it can be, including the acceptable compromises (there are always compromises), and I can move forward. If I were to continue with say, something wired wrong or interfering, etc., you would never be able to obtain the system's potential. You might even try to make corrections (like adding an unnecessary power line conditioner) to the system that could add some negative side effects to the sound.

Photo 2 *Showing clean AC flowing in the separately derived power system for the author's acoustic lab.*

Photo 3 *Some of the author's tools for voicing a home theatre.*

Each step of the process must be confirmed as optimal (under the conditions) before we can move on. Otherwise, we are going to end up chasing our tail and never experience what is possible. **Each step of the voicing process influences all of the remaining steps.** From here forward, and like steps in video calibration, you often have to go back and forth between steps in order to fine-tune the two associated influences of each before you move on.

Subjective Analysis

A lot of subjective listening takes place when voicing! My ears tell me what is needed. If I am hired to make improvements on an existing system, I take a listen to it at this point, playing material that I am intimately familiar with for evaluation of its performance. If something sounds amiss, I may need to check the signal along the path from the source to the loudspeaker drivers. We have confirmed that the AC is good up to, and including, the wall outlet. There are many possibilities for problems and many tests that can be performed. As mentioned in the previous article, you don't test things that don't require investigation and/or confirmation. However, there are occasions where you might need to investigate an issue, which may involve the following:

1. Controller configuration
2. Signal levels
3. Waveform distortion
4. Signal frequency response
5. Loudspeaker near-field frequency response
6. Loudspeaker impedance from 20 Hz to20 kHz
7. Loudspeaker wiring loop resistance
8. Electrical noise floor
9. System hum
10. Amplifier oscillation

2. Channel Identification

Verify that each channel is correct: left is left, center is center, etc. This is done simply by listening to a DVD/Blu-ray going through the entire audio chain that has spoken identification tracks.

3. Driver Absolute Polarity

Verify that all loudspeaker drivers are in phase with each other. There are exceptions to this where the driver is intentionally reversed per the manufacturer.

4. Channel Phase

Verify that all channels are in phase with each other by listening to a DVD/Blu-ray that allows you to compare phase in channel pair combinations, listening for the phantom image between two loudspeakers. Even if all driver polarities are correct, channels can be out of phase from one another by other means.

At this point, I am confident that the electronics and loudspeakers are providing the correct signals and that I am safe to move to the next step.

5. Loudspeaker/Listener Positions

Room modes and soundstage. I'm betting that my modeling has determined the best locations for the loudspeaker/listener positions from a room mode and soundstage analysis, but I need to subjectively verify and then fine-tune both.

If the room is not actually built to the designed dimensions, adjustments to the locations of the loudspeakers, listeners and acoustic treatments can be made. We want the listener(s) and loudspeakers to be positioned away from the first three axial room-mode pressure peaks. When we know the room dimensions, we know what standing waves exist, how long their wavelengths are, and therefore, approximately where they live in the room (construction materials and methods will have influence). In order to insure proper image and soundstage, it is wise to keep width-of -room sound pressures symmetrical from the listener's perspective. This means we will put the prime seat in the middle of the width of the room. This is an unavoidable sacrifice that must be made because the room is an enclosed space.

The first part of this process is about getting the bass response right. As I have discussed in the series, bass response is generally our first means of judging if the system is to our liking.

a) Primary Seat Location (Bass And Centering)

If I'm setting the system up for the first time, I first need to establish where the primary seat should be for best bass response between the front and rear walls. In other words, where the room modes are least obvious. Remember that the modes can easily swing 30-dB SPL from being cancelled, where you can hardly hear a particular frequency, to so loud that it sounds like one note bass. Either is very annoying. This is done by listening to the bass response with a low-frequency driver positioned in a tri-corner to excite all the room modes. I'm listening for where the bass is most linear across the low frequencies up to about 250 Hz.

Photo 4 *The author laser-aiming a loudspeaker.*

b) Right And Left Mains Position (Bass And Centering)

With the primary seat established, I move next to setting up the front left and right main loudspeakers. Again, you are striving for best bass response moving the loudspeaker different distances from the front wall and the side wall. If this is a subwoofer, this step is a little easier than if it is a full-range loudspeaker. With a full-range loudspeaker, you also must listen for optimal soundstage and tonality.

c) Right And Left Mains (Soundstage, Image And Timbre)

In general, the size of the soundstage will be determined by the geometry between the two front loudspeakers and the listener, and the spatial specificity and timbre will be determined by the amount of toe-in (loudspeaker angle toward the listener's ears). Soundstage, spatial specificity and timbre are a bit subjective, and they are all influenced by this positioning, to the fraction of an inch. This is a critical part of the voicing process and takes the most time and care. This is also where experience and trained ears are very helpful. This phase of voicing is more critical to the entire project than any other part, more critical by far than the quality of the equipment or even the acoustics (with some obvious exceptions). For instance, you can't hear stereo from a stereo boom box unless you are listening to it centered and at the right distance from the loudspeakers (not that you would ever be seen doing that).

A quick way to align the loudspeakers to the convergent spot is using a White noise (uniform energy with frequency) generator, listening for a small, solid center image. Then I use music CDs that I carry with me to tell me about timbre, depth and width of the soundstage and image size.

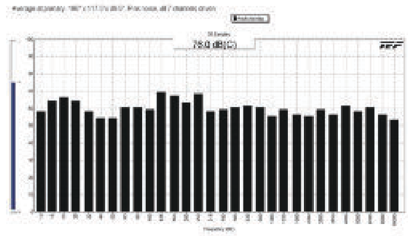
When adjusting loudspeaker/listener positions, you start out making course movements, then graduate to finer adjustments. Use tape to mark positions that sound good, the center of the room, first order reflection points, etc. You will hear things go in and out of focus when you are at extremes. You will hear voices sounding thin or the soundstage sounds separated when loudspeakers are too far apart, or it sounds too bass heavy when the loudspeakers are too close to a wall, or too bright when the loudspeakers are aimed in too much, etc.

d) Physical Time Alignment Of Loudspeakers

Once the mains sound optimal within a fraction of an inch, they are match-aimed with a laser across the room for symmetry (See Photo 4). This includes bubble-leveling them so that the drivers are aligned per the manufacturer. There are some loudspeaker models that allow you to adjust driver distances so that all the drivers converge at the primary seat. Most electrodynamic loudspeaker designs will have a particular distance where all the drivers converge at the same point in time and space. Rarely do you get to design the room around this, and rarely do you get lucky. Ideally, the same loudspeaker model, at the same distance, is calibrated for the primary seat. As you can understand, having fixed-position behind a screen or built-in wall loudspeakers will probably not offer optimum sound. Typically, the best you can do is calibrate the processor electronically for each loudspeaker delay and SPL. Precise confirmation of loudspeaker time-alignment of drivers and/or channels can be confirmed with acoustic test equipment. General SPL balance between channels can be confirmed by ear with a mono source played simultaneously to the two loudspeakers under test. With the main loudspeakers positioned, the remaining loudspeakers are positioned following much the same process.

6. Subwoofer Crossover And Output Level

With a subwoofer system, I may start out playing pink noise using a real time analyzer (RTA) to get me in the ballpark (I have probably computer-modeled the room first to find out where the ballpark is in the room). While making adjustments, I look for a smooth graphical balance between the transition of the subwoofer and the main loudspeakers. Then I make the final adjustments with my ear using various well-recorded acoustic bass, etc., to incrementally fine-tune the position (See graph 1). Optimum height off the floor should also be incorporated.



Graph 1 *Showing an RTA test for adjusting a smooth transition from the subwoofer to the mains.*

Once set, I like to document the subwoofer's peak output and low-frequency extension for the client. It is something they might want to boast about to their friends.

7. Controller Configuration

Now we are ready to configure the processor, or controller. We know that everything is operating properly and physically positioned. Amplifier gains and signal outputs should have already been verified. Now we can tell the electronics what to do without fighting other issues. Every controller has the basic controls and often many more. You want to start out with as little processing as possible. So any filtering, equalization, boundary compensation, "enhancements," etc. should be turned off!

I don't think I need to explain this procedure in detail, as most of the readers are familiar with it. It's just a matter of matching input gain and output signal levels so that they are balanced in sound pressure at the listening zone, and then setting the delays so that all of the loudspeakers converge at the primary seat at the same time. Remember, there is only one point in space where all of the sound can converge together in time, frequency, and energy. Once configured, all settings should be documented and/or secured from being accidently changed.

Once I've got things dialed in, I like to put on some DVDs/Blu-rays that I am familiar with to subjectively evaluate the system at this point. Things to listen for: a) articulation and clarity, b) accurate sound location, c) enveloping and convincing surround sound, d) smooth tonal balance between subs and mids, between the L, C and R, especially with dialogue, between all loudspeakers, e) macro and micro dynamic range.

Know that if it sounds correct at the primary seat, it will be as close to the target as possible at every other seat.

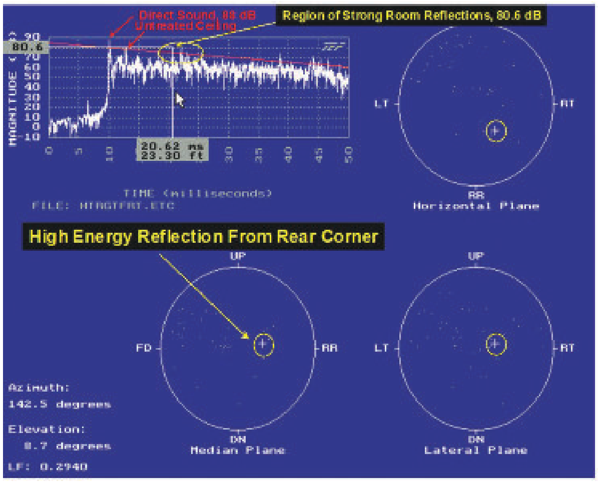
9. Loudspeaker Buzz And Rub Test

Using a tone generator and a loud output, listen to each loudspeaker carefully for noises that should not be there. This can be caused by internal wiring that is vibrating against the cabinet, a driver not tightened down enough, etc.

10. Acoustic Treatment Layout

a) First Order Reflections (Absorption And Diffusion)

Once loudspeaker/listener positions are established, we can verify or locate the first order reflection points of each loudspeaker, on each surface, to apply acoustical treatments. This can be captured with acoustic test equipment (See Graph 2), or with two people and a hand mirror. Have an assistant hold a mirror flat against the surface and move it along until you see the reflection of the loudspeaker's tweeter in question from where you sit. Each loudspeaker will have a reflective area on a minimum of six surfaces; two side walls, front and back walls, floor and ceiling. These areas need to be treated with absorption or diffusion so that the timbre and spatial cues will not be distorted. Repeat for all seat positions.



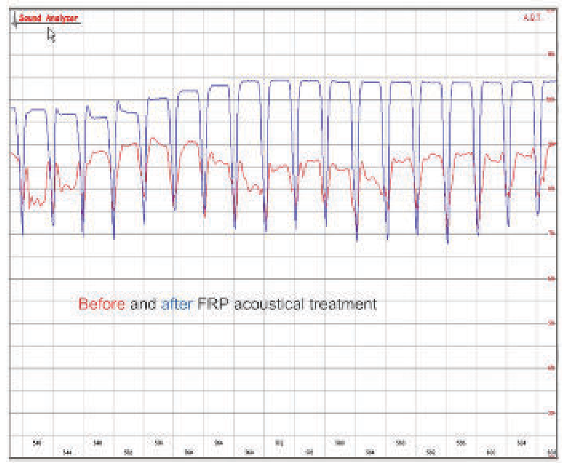
Graph 2 *Results of a Polar ETC plot showing the reflection points (tiny white dots) from a single loudspeaker on all six surfaces of the room.*

As an example, let's say that you are watching a movie where a China dish is smashed against a wall located near the right-hand edge of the screen. To capture this sound, a Foley artist smashed a China dish, which was recorded for editing and mixing later. Now, in the mixing stage, the engineer's job is to accurately place that sound effect in space and time to make it coherent and believable with what you see on the screen. This works well if you hear the direct sound from the loudspeakers predominately, but if you hear the direct sound followed by the sound traveling to the right wall and then to you, the image will spatially shift towards the right because of the perceived delay. This delay will also cause phase anomalies, which changes the timbre and amplitude of the sound. The reflected surface will be selective as to which frequencies it will absorb and which it will reflect and by how much. You may now have a plastic dish sounding like it is breaking to the right of where you see it and slightly behind in time of when you see it. Add the reflections from all the other surfaces and you have quite a mess. Every room and every setup will have its own different mess. While this example may seem subtle, it is only after this level of attention is applied that the movie magic begins.

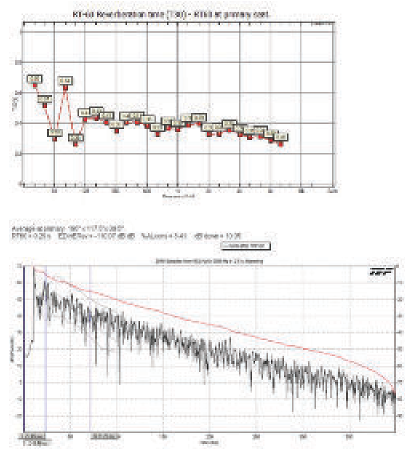
Treating first-order reflections is one aspect of room acoustics that allow you to more closely experience the original signal as the artists intended. Typically, treat the first-order reflection points with absorption for the L, C & R loudspeakers and diffusion for the surrounds, however, sometimes the room may be too dead or too live. For example, if the room is too dead, diffusion might be substituted at the L, C, and R reflection points. This would eliminate the "hot spot" and still maintain longer reverberation times. You really only need to cover about a two-foot square area of the surface because we are only addressing the mid and high frequencies, and their wavelengths are small.

b) Bass Control

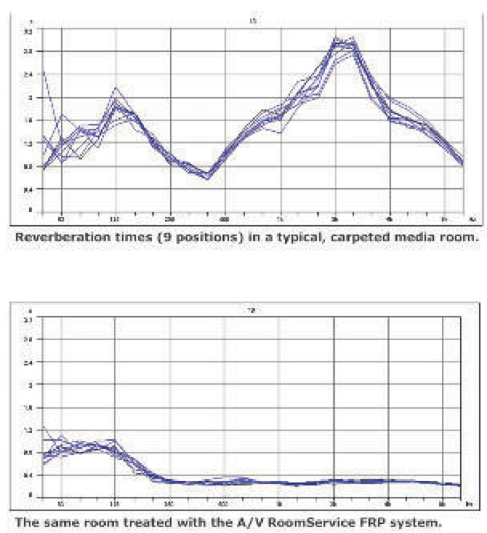
Acoustic treatment for low frequencies is difficult, and there are many types available. Most are not big enough to handle the large wavelengths. Remember, though, that when done right, the shell materials and construction, and the room dimensions, are working for us. Still, additional interior acoustic treatments will be needed. The low frequencies are first handled in the corners where they congregate, then midway between the boundaries,



Graph 3 *Low-frequency articulation before and after acoustic treatments. The gated sweep signal starts and stops quicker and exhibits more energy in the room after treatment.*



Graph 4 *Showing two types of reverberation or RT60 tests. The top shows time versus frequency. Bottom shows amplitude versus time.*



Graph 5 *Showing time versus frequency reverberation results averages from nine seat positions with and without acoustic treatments. Note how the seats' results vary less once acoustically controlled.*

etc. Diaphragmatic absorbers applied as belts or bands around the room work well. When correctly applied, bass articulation is noticeably improved (See Graph 3).

c) Slap echo or Flutter echo

Often there is a small slap echo (one or two echoes) or flutter echo (many echoes) heard somewhere midway between the loudspeakers and the listener that needs to be addressed. It usually only requires a single two-foot-square absorber or diffuser on one side of the wall to eliminate it.

d) Reverberation Times

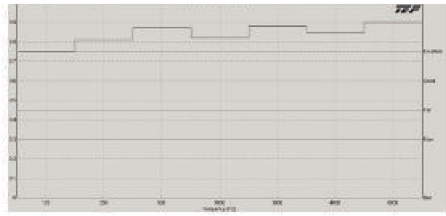
You can't really say that a room has a reverberation time because it has reverberation times. You'll often hear of a single number to describe the reverberation of a room. In actuality, it has many different times, each associated with different frequency bands. An RT60 test is performed to discover how much time it takes for the test signals to decay 60 dB below their original sound-pressure level. In small room acoustics, I typically do an RT30 or RT20. The room is excited with the test signal many times to get an average, and then from many positions in the room for the overall average.

Often rooms that are acoustically treated use too much absorption and become too dead. A room that is too absorbent sounds lifeless. It is not something found naturally in an enclosed space and so it feels strange and uncomfortable. A good home theatre should have an RT60 window between about 0.25 and 0.40 seconds from about 125 Hz on up, with slightly longer decays below 125 Hz. (See graph 4 and 5).

With the right acoustical products, knowledge, and test equipment, you can determine how much of what type of treatment goes where. This is not something you can guess at. It takes good modeling practices, test equipment and acoustic products to achieve a response this precise. The result is a neutral and natural-sounding room.

11. Speech Transmission Index (STI)

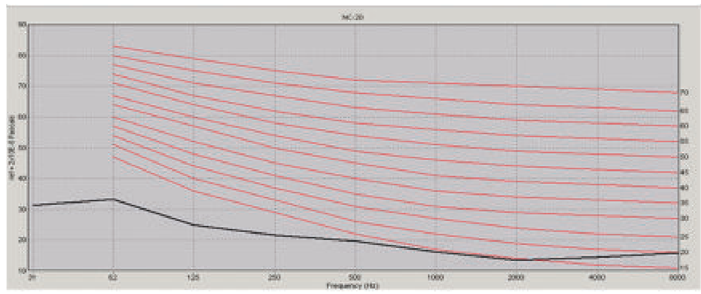
Another important reverberation analysis is the Speech Transmission Index. STI is the analysis for good speech articulation, in particular, consonants following vowels. For example; bath, bad, back, bat, and bag are difficult to distinguish if lingering vowel sounds mask the consonants. STI uses the modulation transfer function derived from the early energy time curve and noise measurements to assign a single number value. The measurements are made in seven octave bands from 125 Hz to 8 kHz. (See Graph 6)



Graph 6 *Showing results of an STI test after interior acoustic treatments.*

12. Noise Criteria

Knowing the noise floor will tell us how much dynamic range we can expect to perceive. Typically, low-level details in soundtracks and dynamic range become limited by such things as HVAC, projector fan noise, or outside noises penetrating through walls, doors, windows and vents. This test is done with everything running; fans, projector, HVAC, etc. (See Graph 7)



Graph 7 *Showing test results of a good-quality HVAC system that will offer low-level information to be heard, wide dynamic range, and no distraction.*

13. Room Buzz And Rattle

Using a tone generator, manually sweep from 0 Hz to about 1 kHz at about 90 dB and listen for buzzes or rattles in the room. Once identified, recommendations can be made to eliminate the source of the problem. It could be as simple as a trinket on a shelf requiring padding or as troublesome as an air duct vibrating against the structure. An occasional noise is a distraction that will pull you right out of the movie and back home to reality.

14. Other Data Captures

Once satisfied with the equipment/room performance, I will document several things for myself and the customer in the form of a report. For example, test results for frequency and phase response, articulation, reverberation times, RTA, STI, NC, etc. I will also take an MLS (maximum length sequence) or possibly a sound leakage test, etc. in order to further analyze an issue to address later on.

Note that I do not recommend electronic equalizing unless necessary. Quality equipment, set-up and calibrated properly, in an acoustically controlled environment should not need equalization. I don't advocate average seat equalization, as it will compromise every seat. I also don't recommend any "room-correction" devices. They don't do much, nor do it well.

In conclusion

Controlling acoustics for accurate playback reproduction involves removing sound that is not in the original signal. This includes removing noises, vibrations and resonances. It also includes controlling the prorogation of sound waves in the room. It means physical setup and calibration of the environment and calibration of the electronics.

I hope that this series on acoustics for the "Ultimate Home Theatre" has been beneficial to those of you who already have a home theatre or to those planning to build one in the future. Acoustics is best considered at the planning stage. Acoustics control the performance outcome of the entire investment and make or break the enjoyment factor. **WSR**