It's All In The *Acoustic* Details

Part III: Bass Resonance

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In the last two segments we discussed noise control, and a little regarding how we hear, and how critical system set-up is to our experience. In this segment we will talk more about room design and set-up and how it relates to sound quality. We will begin by covering some of the primary issues of theatre design, which happen to affect low-frequency reproduction, room shape, size, dimensions, construction, damping, and subwoofer and listener locations, etc.

If we boil all of the above topics down, we discover that each is about low-frequency resonances. Let me explain some terms for clarification. Acoustical resonances are the propensity of a surface to vibrate when impinged upon by an external force, and which continue to vibrate after the driving force has stopped. Resonators are air enclosures that allow sound waves to press against them. They act as passive amplifiers of sound energy. Harmonics are whole-number multiples of the natural, or fundamental mode frequency. Sound energy sets objects vibrating, and resonances are sympathetic vibrations excited by the sound waves, which results in the amplification of certain frequencies and damping of others, depending on the object's mass, compliance, size, shape, and friction. Nearly everything we strike, rub, pluck, or blow through is heard and altered because of resonances. If it were not for resonators, most of the sounds we make would not be loud enough to be communicative.

Room modes are resonances that are excited by sound energy, with wavelengths that are divisible by the room's length, width, and height dimensions. The longer the dimensional distance between parallel walls, the lower the resonant frequency. For example, let's say the room is 11 feet 3 inches high, 17 feet wide, and 19 feet long, the fundamental axial room modes will be 100, 66.5, and 59.5 Hz respectively. When the diaphragm of a loudspeaker moves forward, it compresses the air particles in front of it, increasing the air pressure above the atmospheric pressure, as it travels across the room at approximately 1,130 feet per second. When the loudspeaker diaphragm moves back, the air particles are rarefied and pressure decreases. Like the loudspeaker, the air particles only move back and forth, but the sound waves continue to travel forward until they encounter an obstacle. In this case, it is a parallel wall on the opposite side of the room. As the sound impinges on the wall, some of the energy is absorbed by the wall and some is reflected back, which interferes with the oncoming waves. This constructive and destructive process, in turn, produces a new complex waveform, which was not in the original recording.

Think of an open guitar string plucked and vibrating back and forth, at say, 100 Hz. If you hold down the string midway down the guitar neck, it will vibrate at 200 Hz; a third of the way, 300 Hz; one quarter, 400 Hz; etc. Pluck the open string again and you can easily hear the fundamental (resonant) frequency, and also the harmonics of the fundamental at 100, 200, 300, 400 Hz, etc. They are not as loud because they have less energy, but they are there. In addition, there are overtones, which are modes of higher resonances that are not whole number multiples of the fundamental. Most musical instruments produce as many as 20 such resonances. All of these resonances are part of the unique sound characteristics of each instrument, and is why a sustained 440 Hz A note heard from a violin sounds different from the same note heard from an oboe. Each has a distinctive overtone signature. The harmonics typically (though not always) decrease in loudness as they increase in pitch.

Room modes are similar (See Figure 1) in that there is a train of modes for the three axes of the room, which can cause distortion to the recording. When a frequency is introduced into the room of long enough duration to travel from one end to the other and then reflect back, an interaction between the opposing waves cause a stable condition. This "standing wave" means high-pressure crests in certain areas of the room, and low-pressure troughs in others. When this occurs, which it does in all home theatres, it is perceived as non-linear bass response. Some frequencies will sound louder than others (positive pressure crests), and some softer (negative pressure troughs). Such notes stand out and draw attention to themselves. Smaller rooms have fewer modes, which means they tend to be more audible. Modes in rectangular rooms are fairly predictable, and it is good practice to design a room whose dimensions distribute the modes evenly. I'm

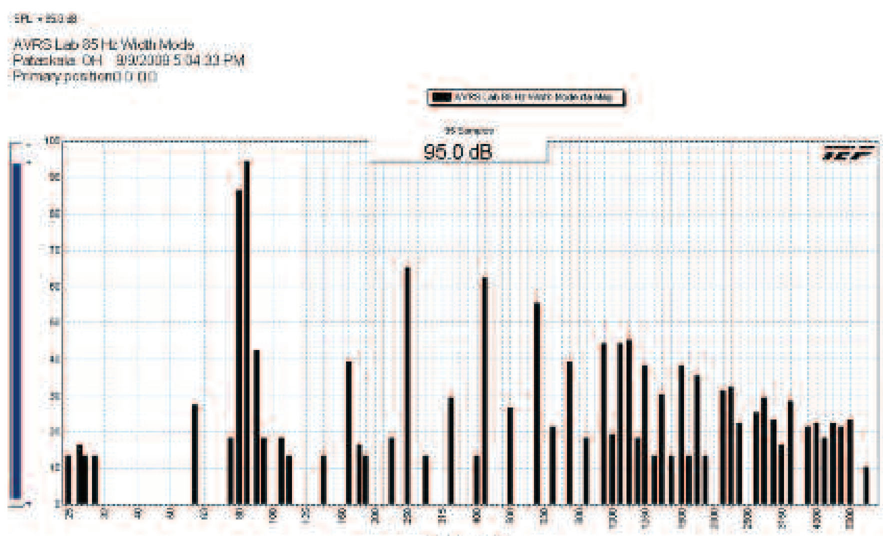

Figure 1. Room Mode Harmonics

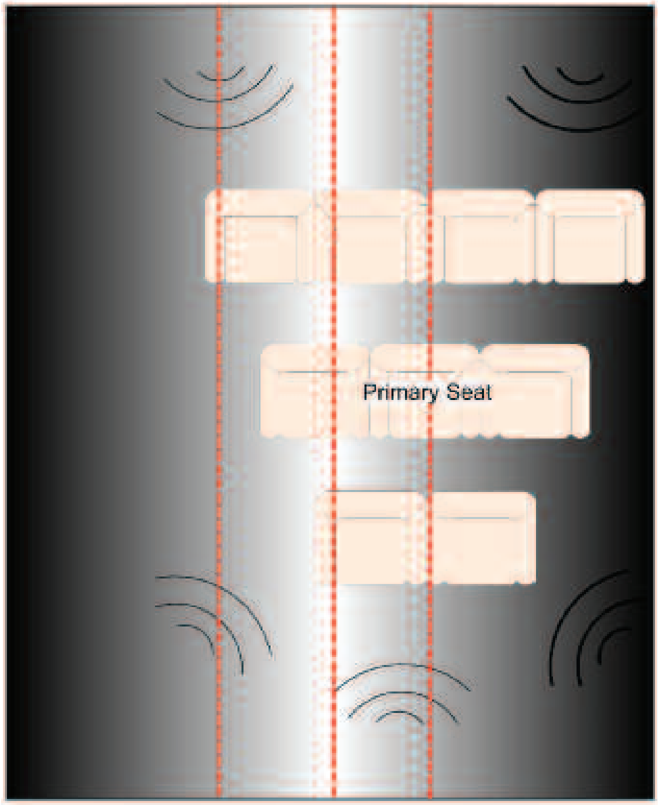

Figure 2. Approximation of bass response of shifting loudspeakers/listeners off-center a few feet to avoid the fundamental width mode. Actual bass response would be even heavier to the left ear, due to the loudspeaker/room coupling on that side. There is not a good seat in the room. Black gradient represent (f1) 38 Hz width mode. Darker areas = higher pressure. Red lines represent (f3) 113 Hz width mode high-pressure peaks.

oversimplifying here, but at least avoid dimensions that are divisible by another. A box would be disastrous. There are many room-mode calculator programs available, even some free on the Internet—you get what you pay for. Something is better than nothing, but if you really want to optimize your room, it's best to hire an acoustical engineer who knows his stuff. There is more to it than simple math.

Experiment #1 *(requires a tone generator)*

Play a tone generator through your system and you can hear this phenomenon. Find a resonant frequency below 100 Hz at the listening position that is loud, then move several feet away, and it appears to smooth out. Move a few feet further and it may nearly cancel itself. By the same token, you can slowly sweep a low-frequency generator and hear the standing waves move about the room. As it excites different modes, you'll hear your unique constructive and destructive interferences. If you have a sound-pressure level meter, you may even observe differences of around 25 dB. It should be noted here that these anti-nodes (high-pressure wave peaks) also cause ringing in the time domain, another form of distortion, which sounds like a droning or muddying of the bass.

Experiment #2

All the room resonances have peaks at the walls, floor, and ceiling, and they sum their energies in the corners. Sit in a tri-corner and you'll hear lots of bass. Similarly, place a subwoofer in a tri-corner and you will excite all the primary modes. This is one reason why you don't want to place yourself or subwoofers in these areas. Poor room dimensions and/or poor listener/loudspeaker locations result in slow, muddy, non-linear bass response.

After doing the math, we must apply human perception to the equation. Many factors come into play and, again, I must be brief, so I'll list some things I look at when hired to design optimal room dimensions, and not go much into why or any specifics.

First, a few points:

- Room modes are problematic at low frequencies because of audible energy gaps and/or overlapping. Smaller rooms are more troublesome because of fewer modes and greater separations.
- Higher-frequency room modes, above about 200 Hz, become so closely spaced that they are difficult to detect. These fall essentially in the upper half of a piano.
- The first three modes for each axis are the most important because they contain the most energy and are, therefore, the most prominent. Tangential and oblique modes are typically not problematic.
- Frequencies below 35 Hz are rare in musical scores, but frequencies below 25 Hz are common in action movie soundtracks.
- A good home theatre will incorporate acoustical treatments to help smooth out the existing modes by lowering their Q (widening their bandwidth and lowering their amplitude).
- Every seat location will offer a different bass response.

Total number of axial modes

High density and even distribution of modes helps to smooth out bass response. A good home theatre will have 20 or more modes below 300 Hz.

Average mode spacing

When the average spacing between modes is too far apart or too close together, they tend to stand out from the other frequencies because of their dominance.

Number of fundamental (1st harmonic) modality issues

Room mode issues are modes where one or more fundamental axial modes are too close or too far apart from an adjacent mode.

Number of 2nd and 3rd harmonic mode issues

The same as above holds true for the second order harmonics, and third, to a lesser degree, due to their energy levels.

Total number of modality issues

Every room has them, but the fewer issues, the better.

Another type of low-frequency resonance that plagues almost every home theatre is the wall, floor, and ceiling cavity resonances. These resonances are also predictable. The shell building materials and their construction methods are basically other mass-air-mass resonators in the room. For example, a typical American interior home wall is constructed of gypsum on both sides of an 8-foot-high 2x4 wood frame without insulation that resonates at around 70 Hz.

Experiment #3

Go hit your wall between studs and hear it play like a drum. Now realize that every time that note is reproduced by your woofer, your walls sing sympathetically, only they do it later in time and are slow to stop. These cavities act like capacitors that store energy and release it later in time. This also makes the room sound slow and muddy.

In Part I (Issue 142, September 2009) we discussed noise control

Photo 1. Seat cushion with springs that resonated at 90 Hz

and how the shell designs should be system approaches with the appropriate applications of blocking, isolating, absorbing and/or breaking sound energy. With sound quality we must introduce a delicate balancing act. We want to contain just the right amount of bass energy. Too much containment and we drown in bass, too little and we thirst for more. The typical shell construction resonates loudly, does a poor job of controlling noise, and does a poor job of containing bass energy. Too often only mass, and too much of it, is selected as the solution to keep the noise from escaping or entering without understanding its detriment to sound quality. Something so inflexible results in bad sound because too much energy is contained and reflected inside the room. Mid- and high-frequencies might be addressable with common interior acoustic treatments, but not low frequencies. Low-frequency wavelengths are much longer and can set whole wall, floor, and ceiling assemblies into motion. The shell construction must be designed to help absorb and control some of this energy. Constrained-layer damping is helpful in reducing sound transmission, cavity resonances, and low-frequency reverberation times. Again, acoustical engineering should be employed to obtain the desired noise control and sound-quality goals. Good shell design results in a fast, articulate, accurate-sounding room.

Windows can be problematic, not only for viewing video, but for listening as well. Obviously noise control can be an issue, but also resonances and low-frequency containment. Low frequencies travel right through windows, as if they aren't even there. They can also act as tympanic absorbers, further reducing bass energy.

Door location can be critical. Typical door constructions do very little to control the transmission of low-frequency noise through them. Positioning a door in the corner might be good in a room that otherwise has too much bass energy build up. On the other hand, it may cause asymmetry and distort imaging. There are often many combo noise control/sound quality issues that should be analyzed and considered when designing the listening space.

Photo 2. Seat cushion remedy

Risers are big bass resonators if not engineered properly. When the right frequencies energize the cavities, the vibrations can be transferred to the body, which is very annoying and distracting. Seats can even resonate (see photos 1 and 2).

Resonances may also cause vibrations that can rattle the structure, furnishings, or equipment. A slow, loud frequency sweep can reveal buzzes and rattles in the structure, or from trinkets, fixtures, loudspeakers, etc. Clapping the hands can reveal ringing from equipment cooling fans, screen housings, HVAC grills, etc. Most of these vibrations, once identified, are easy and cheap to eliminate via damping materials, padding, securing, etc., and can dramatically clean up the overall sound.

There are, of course, many levels of acoustical resonances that can cause distortions, from room modes, all the way down to electronic circuit parts. It is always wise to prioritize and begin to mitigate the major issues first. It is also wise to be practical. For example, it makes more sense to try to move your source component away from a key room antinode (pressure maxima), than it is to buy some expensive anti-vibration platform they may not be up to the task.

When looking at a new space to design, we need to know how much space we have to work within, how many seats are desired, the function of the room, etc. Often the space is a room within a room, primarily for noise control concerns. Noise factors may also call out the shell design and, therefore, its thicknesses. Once this is established, we can establish the best room dimensions for mode distribution, which will accommodate the desired number of seats. As the number of seats increase, so must the room dimensions, much like blowing up a balloon.

Let's say that we have built our ideal room, which is rectangular and has been engineered for good mode distribution, and shell construction that is well damped for fast, articulate bass and isolation from noise, we now must focus on where we place ourselves and the loudspeakers within the space. If we are not careful, we will excite the existing room modes and still end up with non-linear bass response. The loudspeakers and listeners must remain away from the boundaries for many sound reasons. This article is focusing on bass resonances, so we will again look at room modes and how to avoid them, but this time from a different angle.

As mentioned, the axial room modes in a rectangular room are predictable using simple math. It becomes more complicated with non-symmetrical rooms or when incorporating construction materials and methods. Since room modes are dictated by room dimensions, we can calculate what frequencies will live where in the room. We want to avoid coupling the woofers and listeners with the existing first, second, and third-order modes whenever possible. A pair of subwoofers is beneficial for this, and many other reasons, which we'll get into in another segment. Avoid placing woofers in antinodes, and listeners in both nodes *and* antinodes. Placing loudspeakers in an antinode will excite it, resulting in that frequency (and its harmonics) sounding louder than they should. Placing a loudspeaker in a node (null) will attenuate that mode and others, which at times can be useful. Placing a listener in an antinode results in the mode sounding too loud. Placing a listener in a node results in the mode sounding too soft. There is always an optimum position for the loudspeakers/listeners in a room to deliver the best soundstage *and* bass response.

Rant: *Placing the loudspeakers/listeners off center in the room to avoid the fundamental width mode.*

If you haven't already noticed, symmetry is important in audio. Recently the notion has popped up that it's good practice to move the entire auditory scene closer to one side of the room to avoid the first axial width mode. Nice notion, but not good practice. Here are few reasons why:

1. The fundamental mode wavelengths are too large to move away from.

a. By doing so, you'll just end up in another mode.

b. By doing so, you'll end up too close to the side wall, which will cause phase and energy differences between your left and right ears, resulting in severe spatial and timbre skewing.

2. We must settle for the rare louder bass note, over distorting all frequencies, all of the time.

If we took an instantaneous time snapshot of the first-order (f1) width mode in a room 15 feet wide (38 Hz), we could see a positive pressure point to our left, and null in the middle of the room, and a negative pressure point to our right. At the same instant, the second-order (f2) mode (75 Hz), which is half the length of the first, would show a positive peak followed by a null (located about 3.75 feet from the left wall) on our left, a positive peak in the middle of the room, and a null (located 3.75 feet from the right wall), followed by a positive peak to our right. We want to avoid the third-order (f3) mode as well (113 Hz). You would have to move 3 to 4 feet to one side before you would notice any appreciable frequency smoothing of the first-order mode, which moves us into to the f3 antinode at 113 Hz. This frequency is contained in nearly all music and dialogue recordings. Not a good move (see Figure 2).

Summary

There are many resonances in and out of the room that can muddy up the sound quality. Room dimensions, construction design, and loudspeaker/listener locations are key factors to bass reproduction, good or bad.

I hope this brief article provided you with a bit more knowledge and awareness regarding the various low-frequency resonances that commonly plague home theatres, and that they can and should be avoided. In the next installment we will go into more sound quality issues regarding set-up and how to achieve the elusive emotional connections we so covet. **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.