Originally written for

Widescreen REVIEW & Custom Home Theatre Design

Bass Management

PART 3

November 11, 2022

Anthony Grimani

GrimaniSYSTEMS

SPELLBINDING HOME ENTERTAINMENT

Widescreen Review Bass Management
PART 3

I said it once, and I will say it again:
Bass is good!
Good bass is even better!!
Really good bass is hard to get!!!

In Part 1 of this series on how to get good bass, I showed you how inconsistent and underwhelming bass can be in a home cinema. Being a big fan of check lists, I think of the process of getting to good bass as a systematic 7-point strategy:

1. **Room Dimensional Ratios**
2. **Bass Damping**
3. **Seating Locations**
4. **Subwoofer and Speaker Locations**
5. **Subwoofer and Speaker Selection**
6. **Subwoofer Crossover Settings**
7. **Tuning (Time Optimization, EQ, Levels)**

In Part 2 of the series, I went through steps 1, 2, and 3 which are essential if you want a chance at getting decent bass.

After these first two parts of the journey, we get to the fun part. The part in which most people usually start: Picking the right subwoofer, and placing it in the room. However, we're going to do this the other way around. We'll work on target positioning for speakers and subwoofers, then pick the gear that will support these targets. Once again, it is all about the acoustical interface between the speakers and your ear, which is the room. We need to always think of that link in the chain first! You may notice that I include the speakers in this discussion of bass, and that's because a part of the bass region is covered by the speakers. As a reminder the origin of name "Subwoofer" was meant to mean a device that reproduces the notes below what the limit of a typical Woofer from speakers in the 1980s. That would be around 40Hz. There really isn't much musical energy down there, unless you listen to a lot of organ music, or EDM. However, there is plenty of signal content below 40Hz in movie soundtracks, as sound designers and mixers use that bottom octave to give audiences a tactile and impactful sense to the experience.
Over time, the crossover frequency climbed up

from 40 Hz up to 80, 100, 120, or even 180 Hz for some of the systems with really small loudspeakers. This type of bass device could hardly be called a subwoofer anymore at those higher frequencies, but marketing and practicality got a major vote. Also, standing wave resonance ranges in most residential rooms go up into the 100 Hz range, and it can be very beneficial to cross over from the loudspeakers to the "subwoofer" at a frequency that is well above the bottom limit of the loudspeaker in use. More on this a bit later... For now, let's talk about how high a crossover frequency you can get away with using. Research by Juhani Borenius of the Finish Broadcasting Company, way back in 1985 (AES Paper 2290) showed that humans typically can't detect the position of subwoofers displaced from the main loudspeakers if there is a high order (steep slope) crossover at 120 Hz and a subwoofer with low distortion and no rattles. I know; that's pretty high up! In this body of research, two standard deviations down from the statistical mean of detectability is 80 Hz. If you want to make sure no one in your group of friends is bothered by a subwoofer placed away from the front loudspeakers, target a crossover at 80 Hz with 4th order low-pass (24 dB/octave). Note that all the way up at 180 Hz, the majority of folks can finally hear that the subwoofer is separated from the loudspeakers if it is 90 degrees off axis, so you have plenty of tolerance as long as you use a decent subwoofer that doesn't chuff, rattle, buzz, or produce unwanted distortion.

STANDING WAVE REGION

Let's first figure out the range of frequencies where we need to worry about standing wave resonances. There are two prevailing thoughts. One is that resonances past the fourth harmonic aren't very audible. Another view is there is a frequency sometimes called the "Schroeder frequency" or "transition frequency" up to which you will hear significant resonances.

Time to do some math.

You can calculate the transition frequency with the followingequation (US or metric):
11,250 x ffIRT60 / V (ft.)
1900 x ffIRT60 / V (m)

Did that scare you? It's not that hard. Let's take the example of a room that is 21x16x9 feet. Multiply these three together and you get:
21x16x9 = 3,024

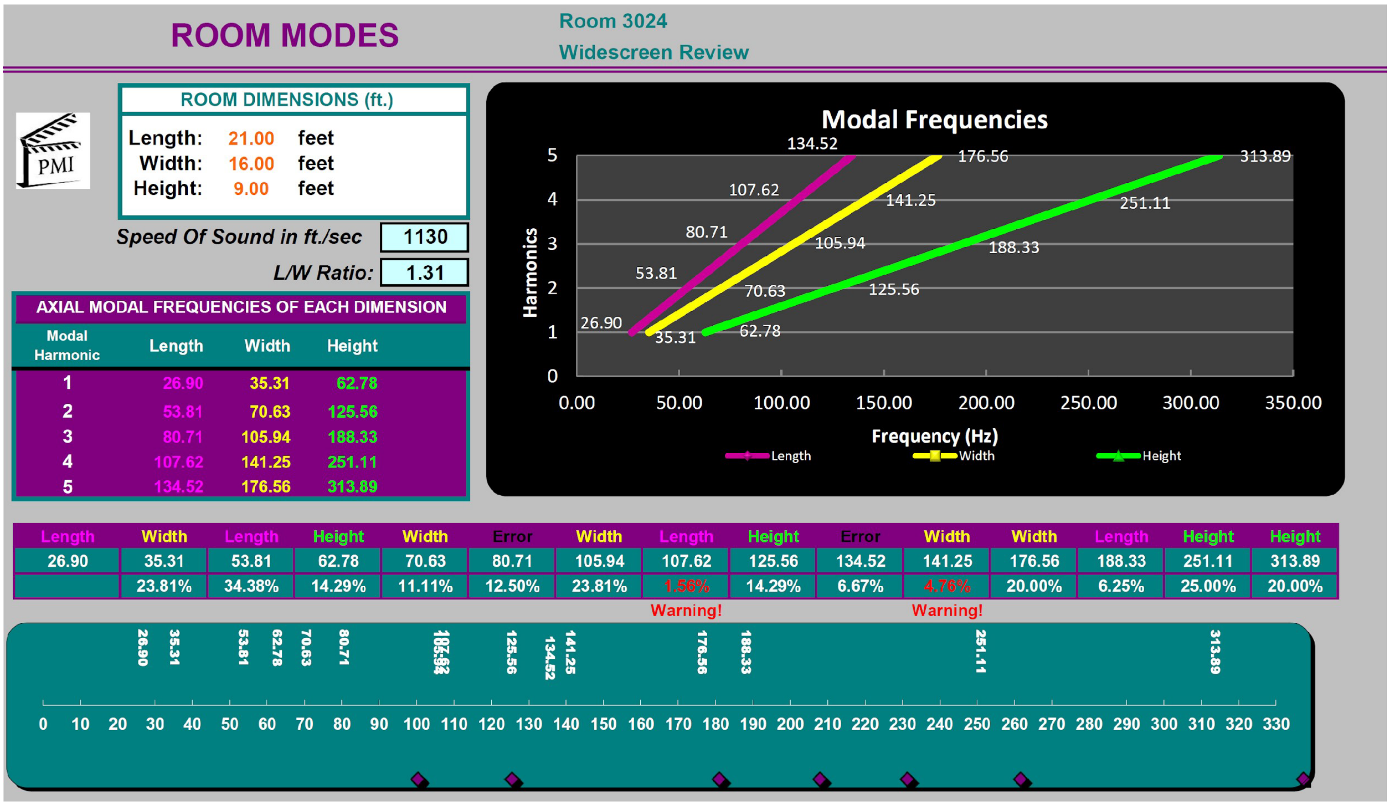
A room of this volume should typically have about 0.3 seconds of RT60 reflection decay time.
So let's go on:
0.3/3024 = 0.000099

Take the square root of that:
ffI0.000099 = 0.00995

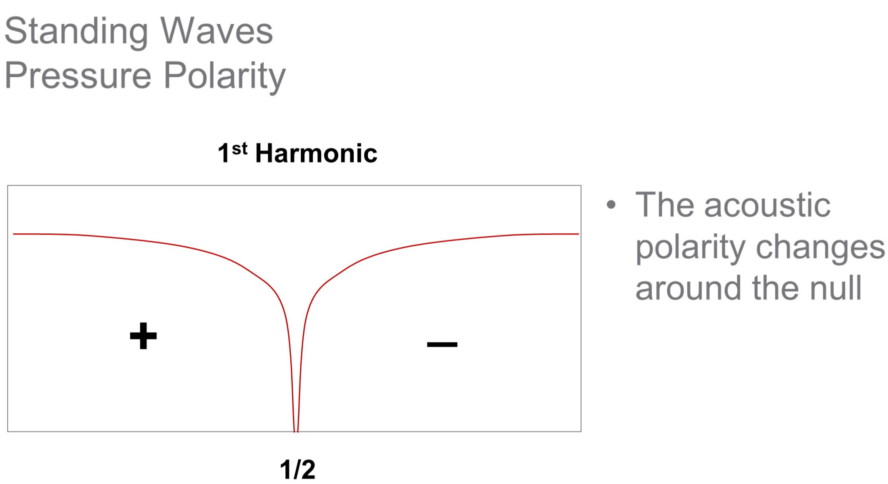
Now multiply by 11,250
11,250 x 0.00315 = **112Hz**

This predicts that the room will have significantly audible standing wave resonances up to **112Hz**!

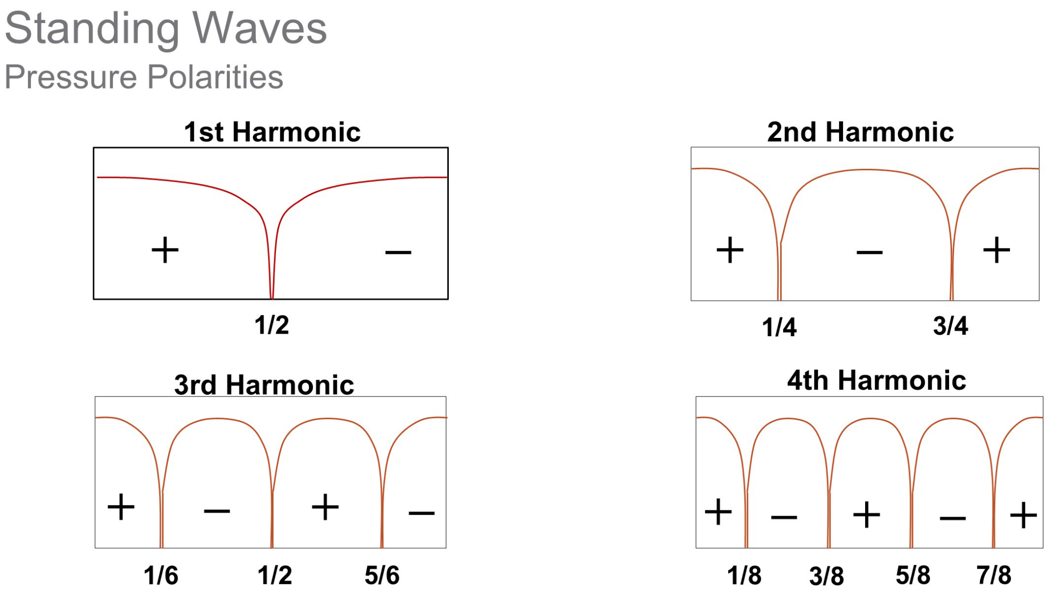
Let's look at a prediction of standing wave resonance frequencies for this room size:



As you can see, the resonances for the fourth harmonic in the Length direction go up to 107Hz, and the width direction up to 141Hz. So, it makes sense we should be cautious up to at least 120Hz. What does cautious mean? We should be cautious about where we put speakers and subwoofers! How so? Well, here's a very cool little trick: The acoustical polarity of a standing wave's sound pressure flips at the null location. For a 1st harmonic, it would look like this:



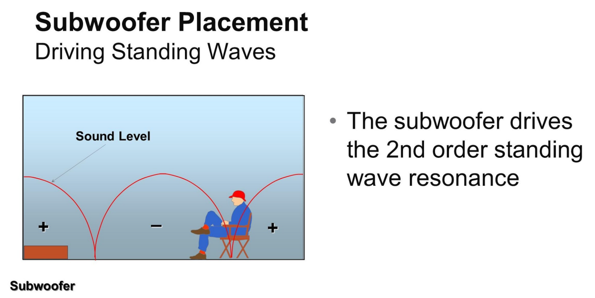
For the four first harmonics it would look like this:



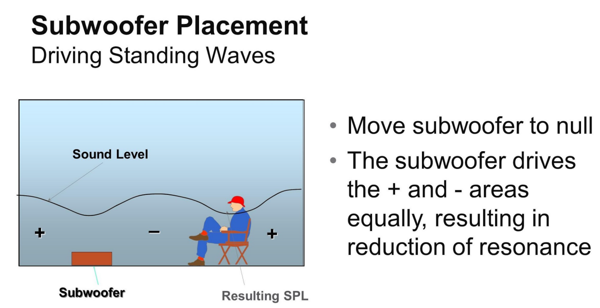
You can actually hear the polarity flip if you stand at the null, and turn your head so that each ear is on either side of the null. You will get a sense, similar to a head cold, when listening to speakers that are out of polarity. Now, if you place a subwoofer, or a speaker right at the null point, it will try to drive both sides of the null in phase, while the standing wave wants them to be out of polarity. As a result, you get a reduced standing wave resonance. Pretty cool! You can hunt after standing waves and knock them on the head, or the null to be more exact.

KNOCKING DOWN STANDING WAVES

If you place a subwoofer at the front wall of a room playing the second harmonic of the length (54Hz for our 21 ft room), you would get this unfortunate event: No sound at a seating position ¾ of the way back in the room:



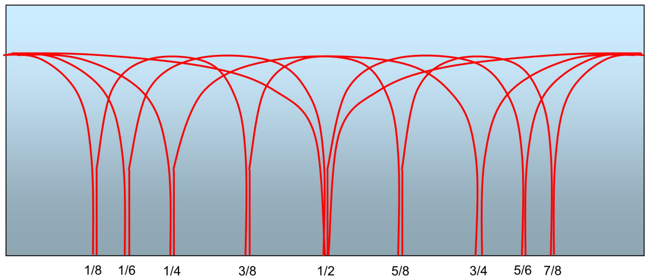
If you move the subwoofer ¼ of the way back in the room, and make it contradict the standing wave polarity inversion at that 54Hz frequency, you would get this type of sound pressure gradient. Less of a null at the seating, and also less peaks at other seat positions.



We are going to make use of this useful feature for placing both subwoofers and speakers, at frequencies up to about 112 Hz at least.

Now, remember this chart that shows the various standing wave nulls:

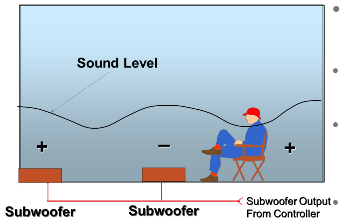
1st to 4th Harmonics



Standing Waves - Where does the subwoofer go?
Pressure Representation for 1st, 2nd, 3rd, 4th Harmonics
Red: Sound Pressure Gradient

So where do you put that one subwoofer? At the 1/4 point, the 1/6 point, the 1/8, or other? You may get to a point where you resolve one bad standing wave condition, but end up with another unaffected resonance at another frequency. This could get very frustrating! There too, there are some cool tricks. Imagine that rather than place the subwoofer at a null in order to drive it in a contradictive way, you put two subwoofers on either side of the standing wave null, playing the same signal, as shown here. The two subs can be smaller since they work together, and you can hide them easier. You can see that you may be able to knock down the 2nd, 3rd, and 4th harmonic of the length axial standing wave resonance.

Subwoofer Placement
Driving Standing Waves

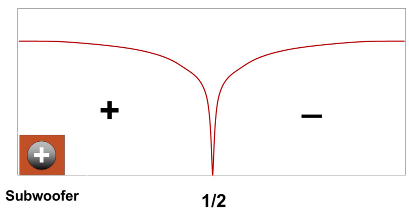


- Improving a 2nd order standing wave
- Connect the 2 subwoofers together as "in-phase"
- The 2 subwoofers drive the + and - areas equally, resulting in reduction of resonance
- Experiment a lot

Let's look into this a bit further so that we really get the concept. Starting with a frequency that is the first axial harmonic standing wave with one subwoofer at one end of the room. The sound pressure gradient would look like this – a deep null in the middle of the room, and gain at the walls:

Standing Waves - Using Single Subwoofer

1st Harmonic

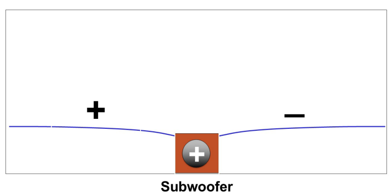


- The subwoofer drives the standing wave

If we move the subwoofer to the middle of the room, the sound pressure gradient would look like this – Reduced null at the middle, and less gain at the boundaries:

Standing Waves - Using Single Subwoofer at Null

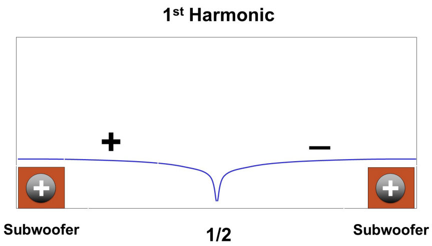
1st Harmonic



- The subwoofer drives the pressure minimum
- Less resonance

If we use two subwoofers at the ends of the room, the sound pressure gradient would look like this – Reduced null at the middle, and less gain at the boundaries:

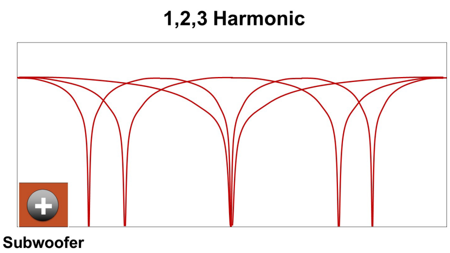
Standing Waves - Using Dual Subwoofers



- The 2 subwoofers drive the + and - areas equally, resulting in reduction of resonance

That's all good for just the first harmonic standing wave frequency. What about the other harmonics?. Starting with the three frequencies that is the first three axial harmonic standing waves with one subwoofer at one end of the room. The sound pressure gradient would look like this – deep nulls at 1/6, 1/4, and 1/2 of the room, and gain at the walls:

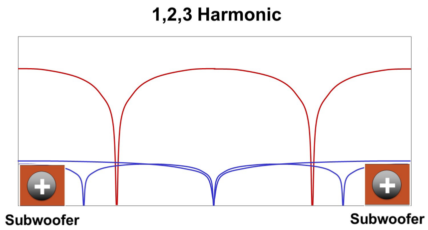
Standing Waves - Using Single Subwoofer



- The subwoofer drives all the standing waves

If we use two subwoofers at the ends of the room, the sound pressure gradients of the first three standing wave harmonics would look like this – Reduced null at the middle, and less gain at the boundaries for the first and third harmonics only:

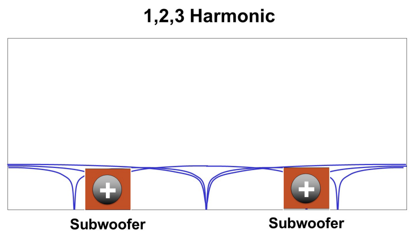
Standing Waves - Using Dual Subwoofers



- These two subwoofers reduce the odd order standing wave harmonics

But check this out. If we use two subwoofers at 1/4 and 3/4 of the room, the sound pressure gradients of the first three standing wave harmonics would look like this – Reduced nulls and less gain at the boundaries for all three harmonics!:

Standing Waves - Using Dual Subwoofers

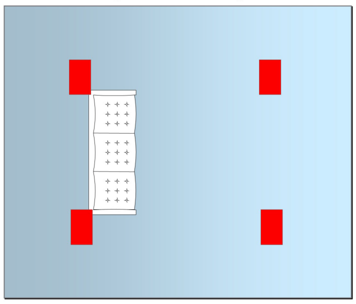


- These two subwoofers reduce the three first three standing wave harmonics

I don't know about you, but I think that's pretty cool. Can we generalize this to the width dimension too? If you expand the thinking out to four smaller subwoofers, and place them at the four quarter points of the room, you can great, even, tight bass in the room.

Subwoofer Placement

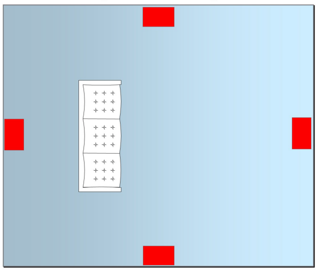
Reducing Standing Waves – A Good Solution



- 4 subwoofers
- Not very practical
- Todd Welti et al.

Except that it's not very practical in terms of placement! It turns out that if you put the subwoofers at mid-points of the room, you will also knock down the standing wave resonances for the Length and Width up to the fourth harmonic at least.

Subwoofer Placement
Reducing Standing Waves – A More Practical Solution

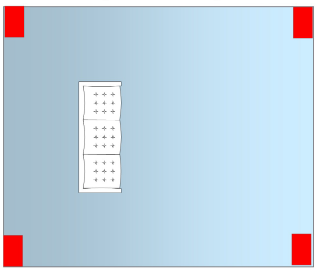


- 4 subwoofers
- They can be small and hidden
- It's the latest research findings
- Todd Welti et al.

I will give credit to Todd Welti, from the research group at Harman International for modeling this out as part of an Audio Engineering Society paper he published back in 2003. That's a little while back, but sometimes good ideas take a while to propagate!

In his seminal research paper, Todd Welti also pointed out that this next layout works almost as well, while providing significantly higher room gain, which is useful when it comes to bass headroom (you never have enough bass SPL!)

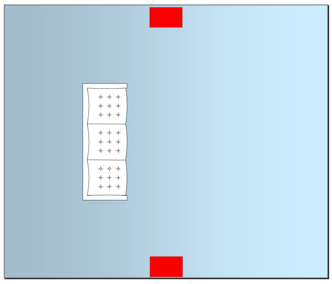
Subwoofer Placement
Reducing Standing Waves – Another Good Solution



- 4 subwoofers
- More room gain
- They can be small and hidden
- It's the latest research findings
- Todd Welti et al.

If you can't go up to four subwoofers, you can also do some good with just two if you place them mid-point of the side walls, or mid-point of the front/back walls.

Subwoofer Placement
Reducing Standing Waves – Another Good Solution

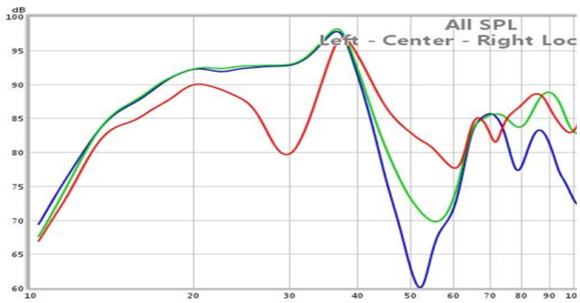


- 2 subwoofers
- More standing waves

You may think I'm kidding with all this business of 4 subwoofers. I'm always the first to say "prove it to me!"

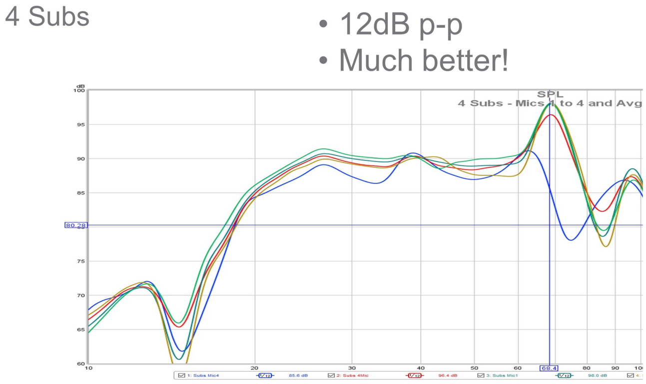
You may remember the nasty bass response I showed you in Part 1 of this series, from three different subwoofer locations. It looked like this, with Errors up to 38dB!

1 Sub at L/C/R Locations
- 20Hz to 200Hz
- All Bad!

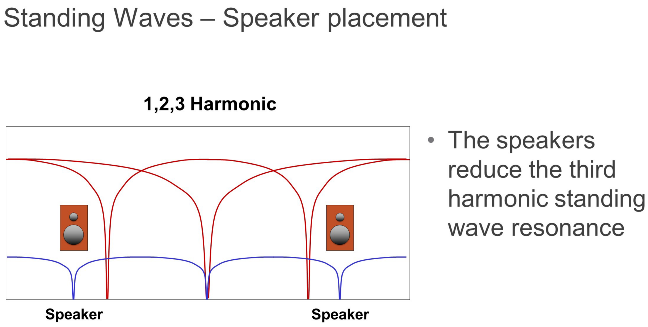


And now, here is the same room with the same type of subwoofers, but four of them in the four corners. Much, much better!! The bad errors around 52Hz are gone, and there are now some

some deviations in 68Hz region at the original mic location, but only 12dB worth. I also show a few other mic locations, and we see some seat-to seat variations in that same 68Hz region. We will talk about how to deal with that during the tuning optimization phase later on.



All this business of knocking down standing waves by selective driver placement of course also applies to speakers. Audiophiles have been tuning rooms for years by moving speakers around to dial in the bass. In our case, we will also attempt to place speakers so that they null out the standing wave effects at the frequencies in which the speakers operate, as in, above the subwoofer crossover. There is of course less latitude since you also need to keep the speakers anchored to the screen orientation and location. One good tool is to see if you can get rid of a width standing wave by placing the Left and Right speakers at those nulls. For example in the 21x17x9 room we discussed earlier, there was a standing wave overlap of the fourth harmonic of the length (aka H4) and third harmonic of the width (aka W3) around 106Hz. If you place the Left speaker at 1/6 of the width from the left wall, and the Right speaker at 1/6 of the width from the right wall, they will both land at nulls of the width third harmonic standing wave, and therefore reduce the resonance. In this case the speakers would subtend about 43 degrees from a seat placed at 0.68 of the length of the room, which is within a good target range of separation. That's all good!

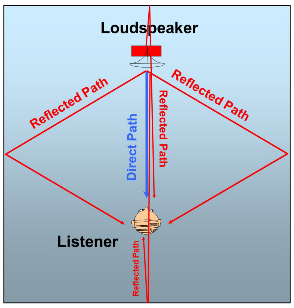


BOUNDARY CONDITIONS

Standing waves aren't the only cause for bass errors in rooms. There are also individual reflections from boundaries that can result in cancellations between the direct and reflected sounds arriving at your ears. These are grouped together in a study called Speaker-Boundary Interference Response (SBIR). This takes quite a bit of math, so I won't go there right now. Suffice it to say that the worst thing that could happen is to have cancellations from multiple boundaries that end up at similar frequencies, because that ends up sounding really bad.

A few examples of reflected paths are shown here. They could be the left wall, the right wall, the front wall, or the back wall.

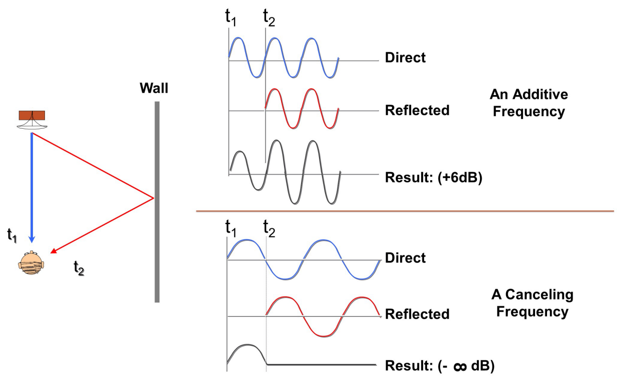
Room Reflections



- Reflections cause
  - Blurring of image
  - Spectral errors by comb filtering

A reflected path is longer than the direct path, and at a frequency where the added path length is half of the wavelength, there will be a cancellation effect when the direct and reflected signals meet at the listener's head. See the effect below for a full wavelength of delay (additive condition) and a half wavelength of delay (cancelling condition).

Room Reflections - Comb Filter Effect (Part 1)



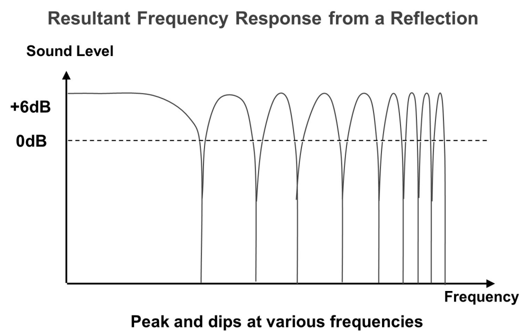
If you really want to know, the wavelength is:
L=Propagation speed of Sound/Frequency.

As an example, for 100Hz, the wavelength is 1130/100 = 11.3ft.
So if a reflected pathlength is half of that, 5.65ft, there will be a cancellation at 100Hz.

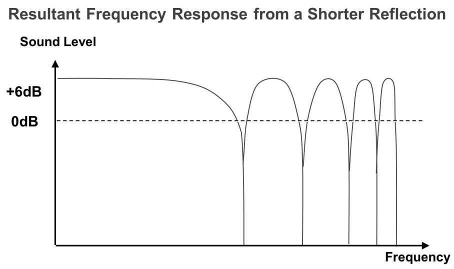
That could happen if a speaker is 2.82 feet from the front wall, or if the listener is 2.82 feet from the back wall. Worse yet, if both conditions apply at the same time, there will be a deeper null at 100Hz. And what if the speaker is a distance from the left wall such that the combination of the extra distance to the wall plus the bounce from the wall to the listener add up to 5.65, you have an even worse condition at 100Hz.

Note that the half wavelength cancellation isn't the only error condition. There will also be one at 1.5 wavelengths, at 2.5 wavelengths, 3.5 wavelengths, etc. The total effect of all these notches and peaks is referred as a "Comb Filter" because it looks like the teeth of a comb. To be fair there probably will be some loss of energy at the bounce point, so the cancellation will not be perfect, but the multiple whammy condition is to be avoided at all cost. For the sake of basic simplicity and since we are mostly interested in the bass region here, we will stick to the condition of the first cancellation, that's the frequency where the reflected path length is a half wavelength longer than the direct sound.

Room Reflections - Comb Filter Effect (Part 2)

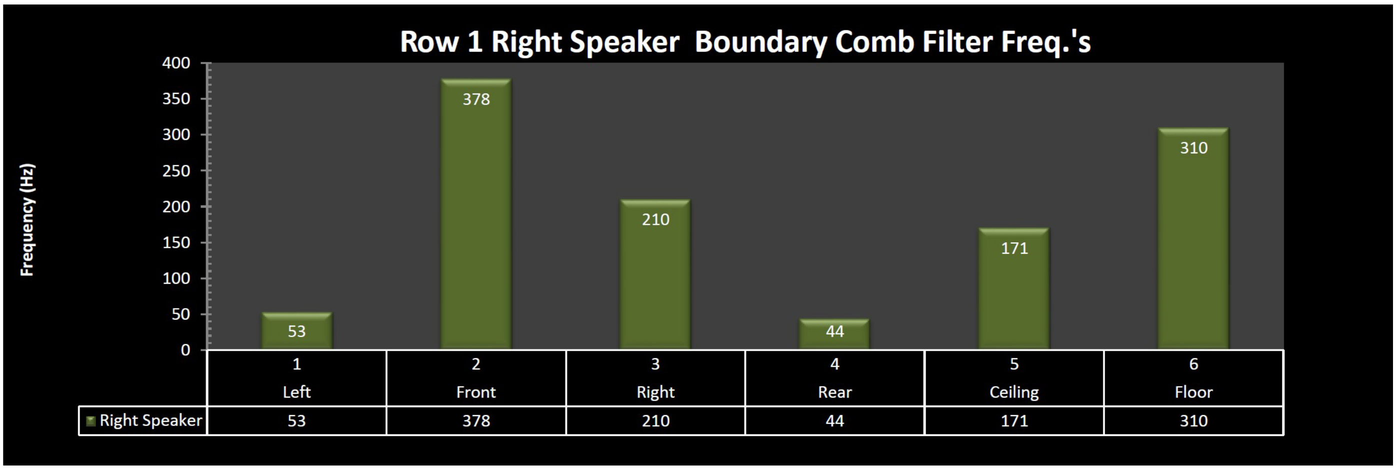


Room Reflections - Comb Filter Effect (Part 2)



Peak and dips at higher frequencies than previous example

As I mentioned above, the predictive math for all this is pretty complex. So much so that we ended up creating a custom calculation module to help us decipher it. We try placing the Left, Center, and Right speakers in some target locations that tie well to the screen, and look at the frequencies for the first cancellation from the six room boundaries around each speaker. For the case of the 21x16x9ft room, with 10" deep front speakers placed on the wall, spaced 10.7 feet from each other, and a main seat at 14.3 feet from the front wall, we get the following SBIR pattern for the Left speaker. We look for two things. Are there any cancellation frequencies that are with 10% from each other, and what would it take to damp out the reflected energy. For the first issue, we see 44 and 53 Hz, but these are in the subwoofer range, so no worries. All other cancellation frequencies are significantly different to each other. If there were significant overlaps, we would move the speakers around a bit, being aware that we may break something else in the process, such as the standing wave null effect. For the damping options here, the Front wall 378Hz round trip reflected signal could easily be absorbed by about 4 inches of fibrous material, such as dense fiberglass or Rockwool. The Ceiling and Right wall would benefit from 6" thick absorbers, located at the strategic bounce point. And the floor; well it would take much more than a simple rug to damp down that 310Hz wavefront. Wherever possible, we try to get an "Absorption Pit" at the bounce point off the floor, but that's a battle we don't always win!



OK, so let's first decide how far down we need the main speakers to play for our room, and pick speakers appropriately. That frequency is sometimes called the "Schroeder Frequency" or "Transition Frequency."

Let's Summarize

In this third part of the article series, we went over the room-related issues of standing wave resonances, bass absorption, and seating locations in our quest for impressive bass response. I know that it got pretty technical, but that's the only way to explain the interrelating issues. In the next part, we'll get into speaker and subwoofer selections and locations. Until then, **enjoy the ride!**

Anthony Grimani is a CEDIA Fellow, and is president of PMI Engineering (pmiltd.com)
and of MSR Acoustics (msr-inc.com and sonitususa.com)
and co-founder of GrimaniSystems (grimanisystems.com).
Chase Walton Contributed to this article.

+1 (415) 883-1476

info@grimanisystems.com

grimanisystems.com

GrimaniSYSTEMS

SPELLBINDING HOME ENTERTAINMENT