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Bass Management PART 2

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Widescreen Review Bass Management **PART 2**

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!!!

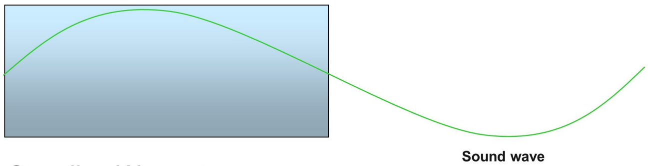
In Part 1 of this series on how get good bass, I showed you an example of errors of up to 30dB in bass frequency response in a pretty standard home cinema. I failed to tell what 30dB really means. Let's get beyond the logarithmic mathematics and just say that the level at some frequencies, from some speaker locations, at some listener locations, can vary from a peak level down to only 3% of that peak level. Yes, that means that you can have a dip of -97% from note to note. If the stock market dipped that much, we would have an international crisis of major proportions. To some, maybe these errors in audio signals aren't that relevant, but to those exacting film sound art fanatics who read this publication, that is plainly and simply an abomination!!

So now that we agree that there are in fact some problems in the proper reproduction of the bass in listening rooms and home cinemas, let's delve into a set of strategies to control this global audio crisis. I think of it as a systematic 7-point strategy that a listening room designer needs to follow for each and every project, and so should you.
The areas to control are shown here in chronological order of the design and installation process:

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)**

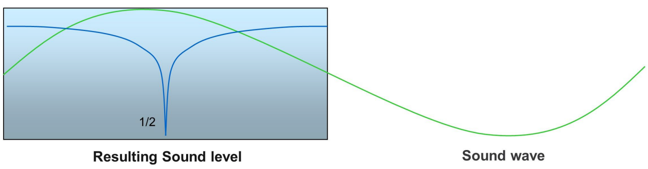
We'll of course start at the beginning, which is optimizing the room dimensions. This is all about controlling bass resonances - also known as standing waves, Eigen tones, modal response, or simply bass boom.

Whatever you choose to call this resonance issue, it is physically a standing wave. It is the result of the relationship between a sound's wavelength at a particular frequency and the distance between the reflection surfaces. A standing wave resonance is set up when half a wavelength fits between two walls.



Standing Waves Resonance
Wavelength of 1st Harmonic

At the frequency that corresponds to that wavelength, the wave that bounces back and forth between the boundaries is correlated at both ends. It is so "happy" to fit nicely there that it wants to stay - and stay it does. Sometimes it can ring with a sustain that is even longer than the mythical guitar in the movie Spinal Tap. At that resonance frequency, there is a resulting gain of sound pressure level at the walls and, tragically, also a null of sound at the mid-point between the two walls.



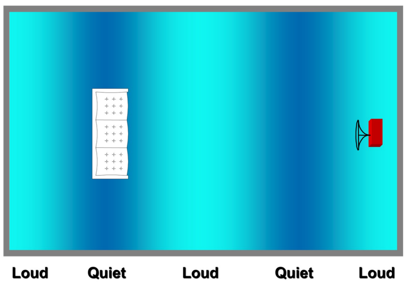
Standing Waves
Sound Pressure Representation for 1st Harmonic

So, at various places in the room, the note stays a long time, is louder, or is severely attenuated. What a mess!

This type of standing wave is called "axial" because it forms on the axis between two room surfaces. Bottom line: If you have walls, ceiling and floor around your home cinema, there will be standing waves, and they will affect bass quality. Up to 97% of bass quality even!

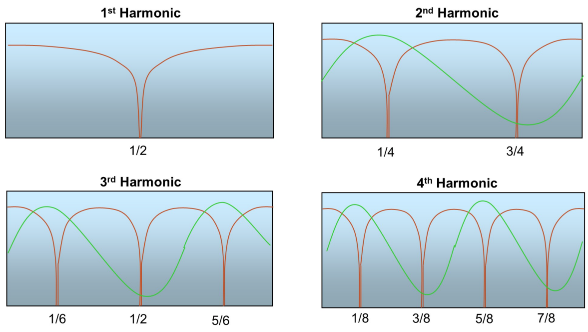
But wait, there's more. There will also be a resonance at double that 1st frequency, when the wavelength is the same as the distance between the two surfaces. This is known as the 2nd harmonic.

There will be a gain in sound pressure level at the surface boundaries, as well as at the mid-distance between the boundaries. There will be nulls at ¼ and at ¾ of the boundary distances. This gets even messier!



Standing Waves
A Second Harmonic Length Axial Standing Wave

Moreover (!), there will be a resonance when 1.5 wavelengths fit inside the room, called the 3rd harmonic. And yet another one when 2 wavelengths fit inside the room, called the 4th harmonic. And yet another one when 2.5 wavelengths, 3 wavelengths, etc. fit inside the room.



Standing Waves
Pressure Representation for 1st, 2nd, 3rd, 4th Harmonics
Green: Sound Wave   Red: Resulting Sound Pressure

It is generally accepted that resonances beyond the 4th harmonic aren't very audible. They aren't typically in the lower bass frequency range we are talking about here, so we'll just ignore them. There are also Tangential and Oblique standing waves, which set up between four boundaries and six boundaries respectively, but they are much less audible than the axial standing waves, so we won't get into them, either. We are to worry about the resonances from the 1st to the 4th harmonic for the length axis, the width axis, and the height axis.

So now what? Let's start at the beginning of our list.

1. Room Dimensional Ratios

Understand that you can't really get rid of standing waves unless you get rid of the walls; then you no longer have a home cinema, but an outdoor cinema! If you wrap a room around your speaker system, you will have standing wave resonances along the three main axes. But the worst room resonance conditions will be if the length, width, and height dimensions are all identical. That's because you would have a triple whammy from all three axes, and the resonances would be worsened. It's better to have an even distribution of the resonance frequencies so that they don't pile up. A common rule is to have dimensional ratios that result in at least 5% separation between resonance frequencies, and to arrange them so that the number of resonances evenly increases with each octave band (doubling of frequency). You go about this during the design phase of the room, adjusting the sizing of the room. You have to look at the interrelationship between the various axial resonances of the length, width, and height and figure out how to do adjustments so that there are the least number of resonance overlaps along the three directions.

You can calculate the theoretical standing wave frequencies by applying this equation:

F = **n**1130/2**D** (in ft)
F = **n**345/2**D** (in m)
Where **F** is frequency
n is the harmonic
D is the distance between walls

You then build a grid for the four harmonic frequencies along the three axes and look for similarities in frequency points. Remember to keep overlaps more than 5% away from each other.

Let's look at two examples. A room that is 20x16x8 feet, and another that is 21x16x9. We will compare the harmonics across the grid, looking for any pair that is closer than 5%.

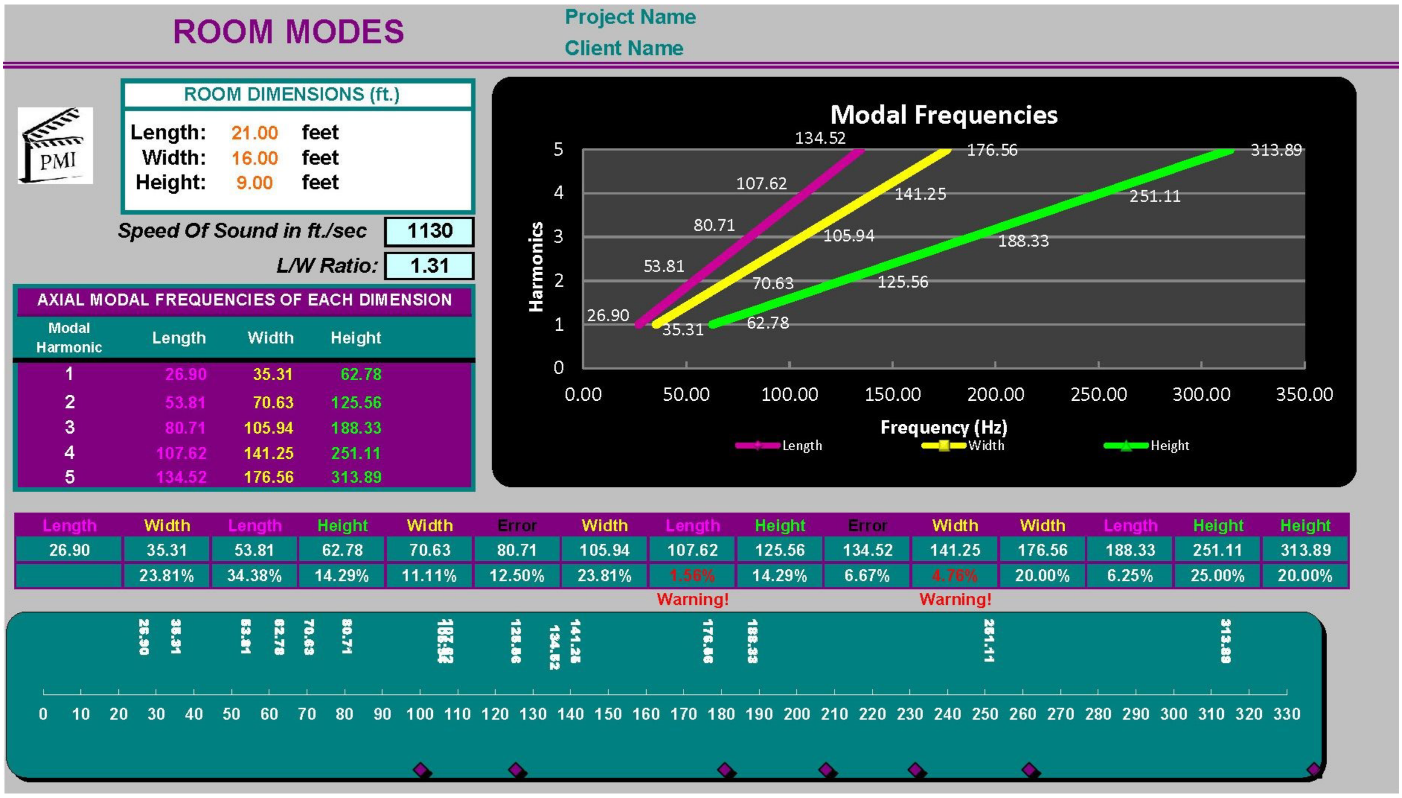
Note that W2 (2nd harmonic of the width) and H1 (1st harmonic of the height) are the same 70.63Hz, and that L5, W4, and H2 are the same 141.25Hz.

20x16x8' AXIAL MODAL FREQUENCIES OF EACH DIMENSION			
Modal Harmonic	Length	Width	Height
1	28.25	35.31	70.63
2	56.50	70.63	141.25
3	84.75	105.94	211.88
4	113.00	141.25	282.50
5	141.25	176.56	353.13

21x16x9' AXIAL MODAL FREQUENCIES OF EACH DIMENSION			
Modal Harmonic	Length	Width	Height
1	26.90	35.31	62.78
2	53.81	70.63	125.56
3	80.71	105.94	188.33
4	107.62	141.25	251.11
5	134.52	176.56	313.89

Note that L4 and H3 are pretty close around 106Hz, but all other resonances are reasonably different. We can deal with one overlap condition using solutions outlined later in this article series.

When I do room resonance calculations, I use a proprietary spreadsheet that looks like this. I can see the resonances, the overlap frequencies, and the progression density, all in one view.

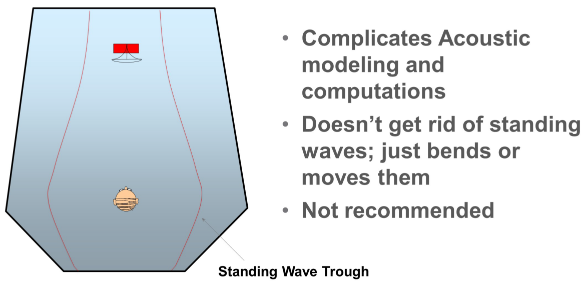


One important caveat is that this prediction only really applies to rooms with infinitely stiff walls - as in 12" of concrete all the way around, with one heavy and stiff door and no windows. In today's modern construction, the majority of walls are sheetrock on wood studs, and they don't behave like the simple mathematical model. In fact, a lot has been written in the scientific literature about how to model rooms with real-life conditions, and you should factor that into your design and engineering work. For one, the resonance frequencies of non-stiff walls will be a little lower than predicted. For two, the wall structures will flex enough at the lowest frequencies to absorb and/or re-radiate the sound pressure to the adjacent spaces - therefore not really supporting a standing wave resonance. This usually happens below 40Hz. For three, standing waves above 150Hz aren't really worth considering in the room sizes we are here to talk about. So, while you may see some resonances up in the 160 to 200Hz region, you should just ignore them for now. They tend to decay rapidly, and you can easily treat them with moderately deep absorptive modules.

Yes, figuring this all out gets quite complex, and it can cost upwards of $5,000 for advanced computerized analysis and modeling to get you close to real-world results. However, you have to draw the line somewhere. Make sure your room dimensional ratios aren't theoretically horrible, and go from there. Otherwise, you could spend all your time and money without moving from this one spot.

If the room is already built, you can measure its standing wave character by placing one subwoofer in one corner and measuring at both the main listening position and at the opposite corner of the room. I suggest using Room EQ Wizard (REW) with a basic USB test microphone such as the ones you can get from Parts Express. Measure with the "Impulse Response" process, and you will be able to see the variations in frequency response, as well as the waterfall decay in the time domain. If you see strong and long ridges - and these are not just ambient noise - you will get some clues on the standing wave decay time of the room.

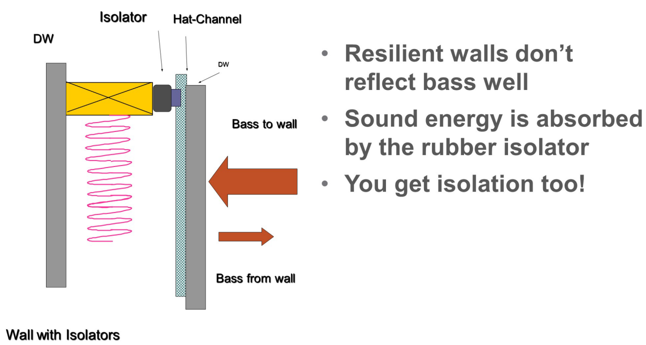
All of the above discussion of room ratios applies initially to rectangular rooms with flat ceilings. What happens is the walls aren't parallel? What if the ceiling is vaulted? What about the legend that rooms with splayed walls and truncated corners eliminate standing waves? Well, it exactly that: a legend. The standing wave resonances don't go away, they just change; the lines of nulls and peaks snake around and get almost impossible to predict. I have been in many rooms with odd shapes and ratios in which the bass resonances were just as bad as in rectangular spaces. The solutions are the same as what is to follow here.



Standing Waves
What about non-rectangular shapes?

2. Bass Damping

I mentioned that non-stiff walls aren't good at sustaining acoustical standing waves, and we can actually use that to our advantage. In fact, a light-weight wall made of ½" sheetrock on 2x4 studs spaced on 24" centers is going to damp bass sound reflections - and, therefore, standing waves. The problem is that this type of wall is going to transmit a lot of sound energy to the space next door. If that space is a garage, no worries. If that space is a bedroom, you aren't going to be able to watch action movies at night! A better option is to build up a suspended wall structure using one of the sound isolation rubber bushings readily available on the market. Pac International and Kinetics Noise Control are two suppliers of these isolators, and there are others. The inner layer of sheetrock is mounted on a metal channel which is installed on the isolator. That assembly is fastened to the studs, and you get a flexible wall with 10 to 15dB better isolation than a regular stud-and-sheetrock wall - along with the useful damping of bass resonances.

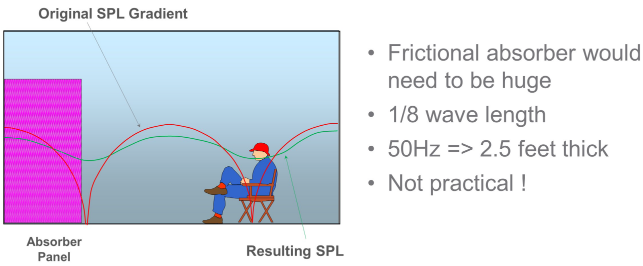


Damping of Standing Waves - Resilient Walls

Another form of bass damping is specially-made bass absorbers, aka "bass traps." These come in all forms and shapes from several vendors, but they generally work in the 100Hz region. This won't do much good at the main resonance frequencies we are dealing with in home cinemas. I hadn't mentioned this yet, but the worst issues we deal with are in the 40 to 90Hz region, given room sizes between 300 and 600 square feet. The vendors of these bass traps don't generally give you any useful or honest data on the absorption efficacy of their modules at these frequencies, often because it is hard to measure and even harder to quantify them as related to standing waves. A few notable research papers presented at the Audio Engineering Society conferences by Dirk Noy suggest a method and metric for bass damping, but the acoustical product vendors haven't adopted his scheme.

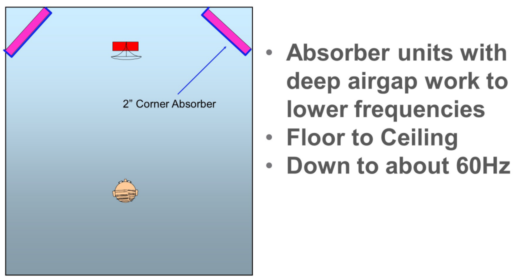
FRICTIONAL ABSORBERS

Frictional absorbers act as "sandpaper" for sound waves, converting the moving air particles into heat through friction. If you were to use frictional absorption to control your bass waves, the modules would have to be at least 3' deep. That's because they need to be at least of the wavelength you want to control. A 50Hz signal would need 30" (76cm) thick panels! These are simply not practical...



Solutions to Standing Waves
Frictional Absorption – Don't even try

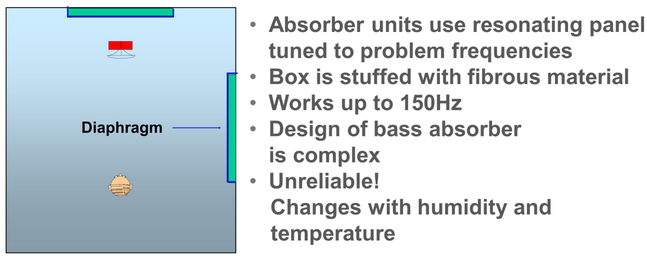
However, you can place 2" thick absorber panels at the corners of the room, bisecting the corner to create a deep air gap behind the panel. That will get you effectiveness down much lower than the 500Hz cutoff 2" panel would regularly give you. However, don't expect much effectiveness below 60Hz, and you would need to go pretty much floor-to-ceiling.



Solutions to Standing Waves
Corner Frictional Absorbers

DIAPHRAGMATIC ABSORBERS

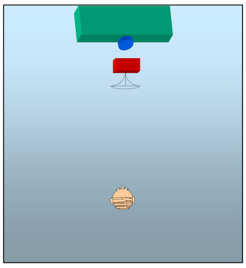
You will commonly see these suggested as bass traps in books, magazines, and forums. They work on a different principle from frictional devices. They are essentially large drum-like enclosures in which the main face is made of some flexible material. It is fastened over a box of the right depth so as to resonate at a standing wave frequency of the room. At the resonance frequency of the face, the device flexes, and no longer "returns" the incoming waves the way a stiff wall would. You would probably need a number of these to treat the various standing wave frequencies and to provide enough surface for effectiveness. A huge problem with these devices is that the face resonance frequency varies with humidity and temperature. One day they will work well, and your bass performance will be outstanding; the next day they will drift to a different set of frequencies, and your bass standing waves will be back. Bummer!



Solutions to Standing Waves
Diaphragmatic Absorption – Unreliable!

HELMHOLTZ ABSORBERS

Named after the German physicist Hermann Von Helmholtz (https://en.wikipedia.org/wiki/Hermann_von_Helmholtz), these devices look like large vats, and they resonate at a frequency that depends on the ratio between the port size and the enclosure size. They are a bit hard to design, but they are accurate. The problem is that they pretty much only act at the surface area of the port, so you need a lot of them before you get a significant effect on the standing wave energy of the room. Also, you would need one size per standing wave frequency you want to treat. Yes, this, too, gets complicated.

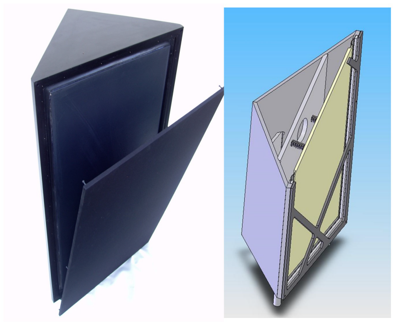


- Helmholtz units are tuned to problem frequency
- Absorption in box widens resonance peak
- Design of Helmholtz absorber is complex
- Inefficient – Absorbs over the surface area of the port only

Solutions to Standing Waves
Helmholtz Absorption – Low Efficiency

COMBINATION ABSORBERS

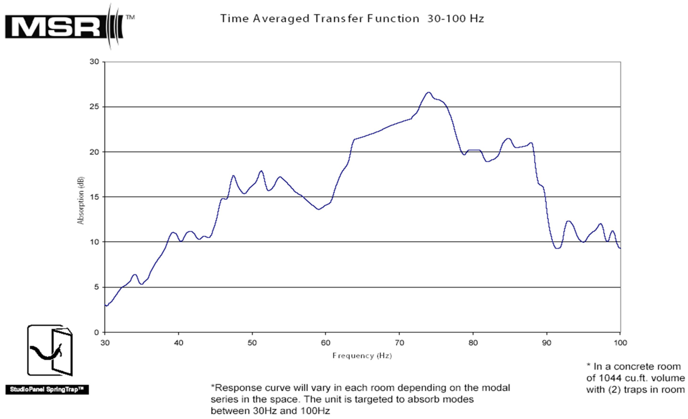
There are a few devices on the market that combine several different absorption schemes. They sometimes use membranes adhered to thick panels of fibrous materials, and are, therefore, damped bass absorbers. They work well overall, but are relatively inefficient. Inspired by the work of Dirk Noy mentioned above, I developed and patented a brand new system that combines pistonic and Helmholtz resonator schemes. I then produced a novel and effective product called the SpringTrap. Unfortunately, as of this writing, its production is on hold due to rising costs. This complex device uses a membrane suspended on six precision springs, which pressurizes three volumes tuned with a Helmholtz port to three overlapping frequencies in order to cover from 35Hz to 90Hz.



- Combination Pistonic diaphragm and Helmholtz
- Triple ported enclosure

Solutions to Standing Waves
SpringTrap Absorber

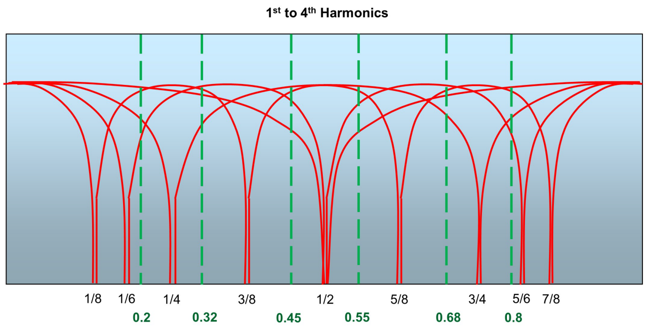
Here is a novel way to represent the efficacy of a bass absorber. An impulse response measurement is conducted in a concrete room with strong standing waves. The room is first measured empty, then with the unit under test. The source and microphone are opposite trihedral corners, and the bass absorber is placed in another corner. Compare the decay times of the two measurements, and express them in reduction of energy in dB. Here is how the SpringTrap fared: up to 25dB reduction of staining wave errors at around 70Hz. That's good!



3. Seating Locations

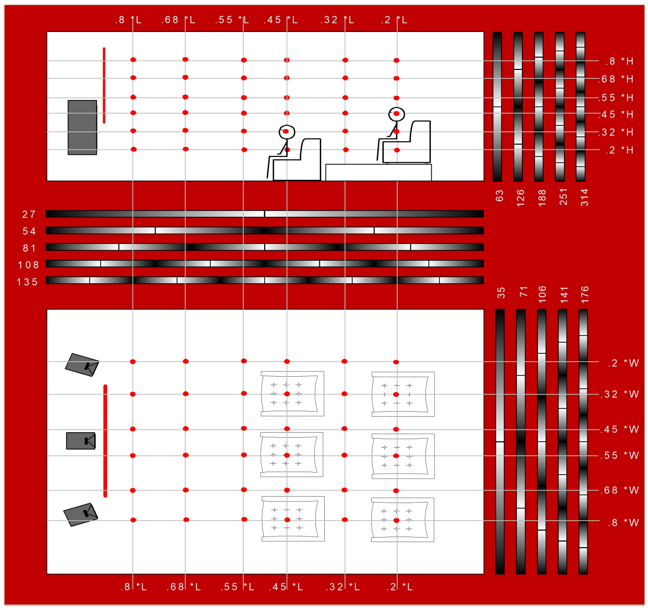
This may be a bit of a Zen question, but if a standing wave results in a peaks and troughs of sound pressure at places in the room, and no one is seated there to hear it, is there still a standing wave? The answer is yes there absolutely is a resonance, but you may be seated at a place where it doesn't matter so much. That's good news!

At first, this all seems pretty simple. Just don't sit at a peak or trough...but where is that? You can look at the resonance trough for a harmonic and avoid that location. But you also have to avoid peaks. The diagram here shows the peaks and troughs for the 1st through the 4th harmonics along a dimension of the room - remember that series from earlier on? – and if you sit at the locations shown in the green dotted lines, you are neither at a strong peak nor trough. The "Seating Magic Ratios" of the dimension are 0.2, 0.32, 0.45, 0.55, 0.68, and 0.8. There may, of course, also be other good locations in the room, but this is a great start.



Standing Waves
Pressure Representation for 1st, 2nd, 3rd, 4th Harmonics
Red: Sound Pressure Gradient   Green: Target Seat Locations

Like they say in TV commercials, "But wait, there's more!" This first diagram shows locations only along one axis of the room, but you need to consider all three axes. Apply those Seating Magic Ratios to the length, width, and height of the room, and you may just end up with decent bass response there. This diagram shows dots for target seating placement along the three axes for a room that is 21x16x9 feet, along with a shading representation of the sound pressure for five harmonics in each axis. Try to place seats on these dots. By the way, this room size happens to be the IEC standard listening room, as described in IEC268-13.



You will notice that, in an effort to avoid sitting where there is a width trough for the 1st, 3rd, and 5th harmonics, the seating is not centered in the room. Yes, that is sometimes what you need to do to get the right bass. That may mean that you need to offset the front speakers to the left or to the right a bit, or you can use time alignment from the distance/delay settings in your surround decoder to correct the imaging error. But that's a whole other story, maybe for another article...

Let's Summarize

In this second 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!**

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