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Bass Management
PART 4

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SPELLBINDING HOME ENTERTAINMENT

Widescreen Review Bass Management **PART 4**

I said it three times already,
and I will say it again:
Bass is good!
Good bass is even better!!
Really good bass is hard to get!!!
And I'm now going to talk to you about items that seem even harder to figure out.

Before we dive into all this, let's review our 7-step strategy check list, and see how far along we got:

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 are now in Part 4 of the series on Bass Management! I bet you never thought it took this much effort to get good clean bass. Neither did I when I started down this rabbit hole about 25 years ago! With a lot of experimenting, reading scientific journals and a pile of books, and talking to several experts in the field of acoustics and speakers, I am starting to get a picture of the solutions; just starting! In this part we are going to talk about picking the right speakers and subwoofers for your use and for the room, then about setting up the right crossover frequency, slope, and filter type in order to get the smoothest bass transition.

In Parts 1, 2, and 3 of the article series, I went through steps 1-4, and we can now get down to steps 4 through 6; picking the right speakers and subwoofers, and setting their crossover filters. 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. I mentioned this before; the term "subwoofer" was initially coined to describe a device that reproduces the notes **below** the bass extension limit of a typical **woofer** from speakers in the 1970s and 1980s. That would have been around 40 Hz. These days, subwoofers are commonly used up to 80Hz in the vast majority of upscale home cinemas, and much higher than that in low-cost schemes. That's in order to allow the use of smaller speakers that can only get down to 80Hz or 120Hz. It makes sense to make them smaller when you have many speakers in an immersive audio system so as to not take over the whole room with the gear. And, as I clearly showed you in parts 1, 2, and 3 of this series, it is also beneficial to use correctly located subwoofers to help combat bass standing wave resonances. So, think as subwoofers as devices that play the lower bass sounds, and also as devices that help you produce clean deep bass by giving you the ability to place them correctly in the room for optimal bass interface without changing the imaging and spatial character of the sound played by your main speakers.

As we discussed in part 3, standing wave resonances in most residential rooms go up into the 100 Hz range, and it can be very beneficial to cross over from the speakers to the subwoofers up that high, even though it is above the bass extension limit of your speakers. Just remember that you can actually go up to 120Hz, if you have steep crossover filters and if you have good low-distortion subwoofers, without noticing that the speakers and subwoofers are in different places.

CHOOSING YOUR SUBWOOFER

Picking the right subwoofer for your system seems simple at first but takes some careful consideration. Here is a set of bullets, in no particular order:

- **Bandwidth.** How high and how low in frequency does it go? And how low does it go at high output levels? Ideally it should play down to 20 Hz at least, but it doesn't need to have flat frequency response all the way down. Rooms have 12dB/Octave bass gain typically bellow 30Hz, as shown by Louis Fielder of Dolby Labs. (Journal of Audio Eng. Soc., vol. 36, no. 6, 1988 June.) So, you just really need a subwoofer that plays down to 30Hz, tapers down by 12dB/Octave, then cuts off at whatever limit below 20Hz the driver, cabinet and amplifier could handle. This should all be shown by the manufacturer in frequency response charts in their specification sheets. And it should not just be at low output levels, where it is easy to put out deep bass. It should also be shown at the stated maximum output level. Now, go find products that clearly disclose this info, and pick from those. You may have to call the manufacturer to get the info from their engineering department, since their marketing people, who make the brochures and specification sheets, don't usually include it. I'm working with a CEDIA technical committee to encourage the dissemination of this data to fine people like you, who want to know what their gear can do. Be on the lookout for it!

Two other things to consider are if you want "infrasonic" capability, and the high-fre quency cutoff. The infrasonic issue is getting a lot attention these days, since some folks have found that there is signal content all the way down to 15Hz or lower. It is still not clear if those infrasonic signals were intended to be heard or if they are a bi-product of the production process and were not actually noticed in the mix stage of the film post-production studio. If you want to cover all bases, you may as well extend the cutoff down to these infrasonic frequencies just in case there is more of that in the future. Interestingly, since the room standing wave issues tend to disappear below 30Hz, you can get away with a single large infrasonic unit, along with four smaller "main" subwoofers that only need to play down to 30 or 40Hz. Now there's a new thought!

On the high-frequency side, the subwoofer needs to reach up to the target crossover frequency and at least one octave above that (double the frequency). You'd think that shouldn't be a problem since even the largest drivers can play up to 500Hz, but there are some "bandpass" subwoofer designs out there that cut off around 80Hz. That could become a problem if you need to stitch the crossover region at 100Hz because you have small speakers or if you have standing wave issues between 80 and 100Hz.

- **Cabinet type.** There are many cabinet and driver configurations in the world of subwoofers. There are lots of predictive equations to aid in the proper design of these devices, including the now-famous Thiele-Small parameters.

  The most common is a large front-firing driver in a sealed cabinet. These are simple, straight-ahead designs, with decent performance and no notable side-effects. The driver needs to be large enough to play to lower frequencies at high SPL, and the cabinet needs to be large enough to allow the driver to play low into the bass range. A variant of the sealed box design is one in which the driver is pointed down to the floor in order to enhance its loading character. There are also several products with a vent port which's role is to extend the bass response and increase the overall efficiency of the subwoofer. Some of these designs work well, and some of them exhibit significant "chuffing" noise at high sound pressure level. A variant of the vented subwoofer is one with a secondary mass-loaded passive radiator that resonates at a target frequency close to the natural roll-off frequency of the main driver+cabinet scheme. This extends the low frequency capacity of the overall subwoofer. Another design is known as a bandpass scheme where the driver(s) vent into a port that naturally filters the low and high frequency range. These are even more efficient, but are sometimes perceived as resonant or lacking of impact. But wait, there's more; but we can't go over every variant here! I have generally found that you can get high-enough SPL out of good-quality sealed subwoofers, especially if you use four of them in the corners of the room; maybe start with that approach unless you can be convinced that going with ported designs or other trickier schemes is right for you.

- **Maximum Output Level.** This one is a big deal, and hard to get real data on. The target is that your subwoofer scheme should be able to produce at least 110dB SPL long-term, and 115dB SPL bursts at your seat position in the two bottom octaves (20 to 80Hz) before it overloads, limits, or otherwise goes on strike for unfair labor practices. How do you know it will get there? If you could get accurate data of the long-term a burst-condition maxima of your candidates, you could do this. You may need to reach out to the engineering departments of your favorite brands, or look forward to the CEDIA Performance Facts data sheets. The maximum level data is typically measured at 1 meter from the subwoofer under anechoic conditions, so you will need to figure out how that translates to the sound pressure in your listening area. Once you know the 1-meter anechoic numbers, for a 3,000ft^3 room, subtract 7dB from the stated maxima. For a 6,000ft^3 room, subtract 10dB. For a 9,000ft^3 room, subtract 13dB. For a 12,000ft^3 room, subtract 16dB. For larger rooms, call me ☺! What if you use two subwoofers, or four subwoofers? For two subwoofers, add 4.5dB to the maxima of one subwoofer. With four subwoofers, add 9dB to the maxima from one subwoofer. HOWEVER, know that different room construction will absorb more or less bass in the wall, floor, or ceiling structures, so actual numbers may vary. Of course, if you have an open floor plan, where the bass waves billow out into larger volumes, it gets really hard to figure out what you will get. Note that if you are using passive subwoofers, you will need to know the sensitivity for 2.8Vrms (that would be one watt into an eight ohm load), along with the maximum input voltage. You would then need to get power amplifiers that produce that output voltage into the stated impedance load (see below). Here again, these numbers can be hard to get from manufacturer's data sheets.

- **Impedance.** It would be useful to know the load impedance that the subwoofer(s) present back to the power amplifier so as to make sure the two can get along. Usually, anything less than four ohms tends to cause some overload issues. Note that while impedance is usually stated as just one number, it really varies between a maximum and minimum value, and these can have quite a swing-like from 3 ohms to 20 ohms over the range of the operation!

- **Overload Character.** Either way you figure it, at some point in a very loud movie with lots of action the subwoofer will reach its limit, and it is good to know what happens when it exceeds the limit point. The better-designed product will simply not play louder, and will behave without any alarming noises. The more rudimentary products will produce loud banging sounds, or other unwanted effects, and will distract you from the movie action because you are now worried that you irreversibly damaged your expensive acquisition. One way to find this limit side effect is to play low-frequency band-limited pink noise into the subwoofer(s), and turn it up until you get to the maximum value as measured on your SPL meter. If you can get up to 115dB there without any audible strain, you should be good. Either way, turn it up until it won't go any further and listen for the behavior. It should just limit out without any noticeable overload sounds.

- **Dimensions.** So, this may be obvious, but make sure you have room to locate these subwoofers in your theater or listening room. There are a good number of shallow and long subwoofer on the market now, all of which are easier to hide than the traditional large cube black box. Get creative with how to conceal the group of these devices in the front and back of your room!

CHOOSING YOUR SPEAKERS

If there is one thing you should remember from this very long series on how to manage the bass of your home theater, that would be that you don't want a set of large speakers with extended bass response. Each one of them would need to be able to produce bass levels that are at least 105dB at the listening area, and as a total system, the group would need to be able to play 115dB of bass. To me that looks like a pair of 15" woofers in each speaker. That's big, and may not even work since there could be very large frequency response errors at some seats in the room. Bottom line is that without subwoofers, speakers would be too big, would require a lot of cone area and amplifier power, and some very careful tuning in order to get around the acoustical issues caused by standing waves.

Picking the right speakers for best bass in your system also takes some careful consideration. Here is a set of bullets, in no particular order:

- **Low frequency extension.** In general, it is good for your speakers to make it down to 80Hz without audible overload in the loudest passages of your favorite action moves. That generally looks like a good quality 6.5" woofer in smaller rooms, dual 6.5" woofers in mid-sized rooms, and larger drivers for big rooms. Watch out that your speakers don't try to couple 10" woofers with 1" tweeters as that just can't splice evenly for good dispersion performance. The woofer would beam significantly before handing off to the tweeter...

In most of the rooms you would be using, the standing wave resonances will start around 80Hz and extend down to about 30Hz, so even if your speakers could play lower than 80Hz, that wouldn't be useful. In smaller rooms, this rule could be pushed up to 100Hz.

- **Cabinet type.** Just like in subwoofers, there are many cabinet and driver configurations. I generally prefer the predictability of sealed cabinets, which will naturally fall off at about 12dB/octave with a Butterworth filter character below the stated 3dB attenuation point (aka f3). While Butterworth is also a brand of syrup, I can assure you that pancakes have nothing to do with bass frequencies here. It is named after the British physicist Stephen Butterworth who wrote the book on the math behind maximally flat amplitude filters way back in 1930 (https://en.wikipedia.org/wiki/Butterworth_filter). Ported cabinets will have much steeper falloff slopes, with phase rotations that make it hard to splice the speaker to the subwoofer in the crossover region.

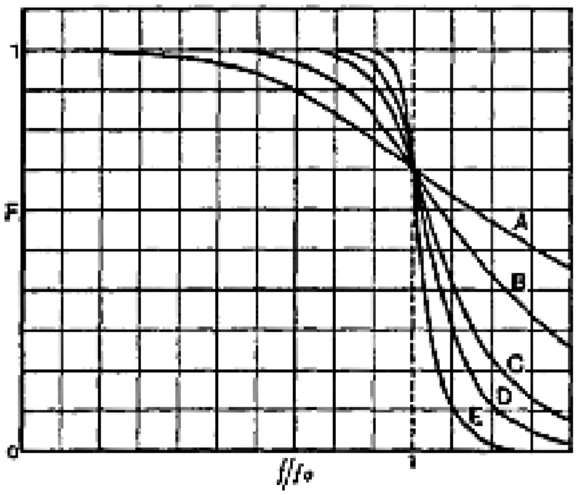


Fig. 3.

There will be much more discussion on this topic in a section below.

- **Maximum Output Level.** Similarly to the subwoofer scheme, there is a target maximum level for your speakers. The front Left, Center, Right speakers should be able to produce at least 100dB SPL long-term, and 105dB SPL bursts, all the way down to the subwoofer crossover frequency region. The Sides, Backs, Wides, and Tops should each be able to do 97dB long, and 102dB bursts at the main seats. Here again, getting accurate data on this point from manufacturers is challenging, but try anyway. Again, be on the lookout for the CEDIA-standardized

Performance Facts specification sheets. The maximum level data is typically measured at 1 meter from the speakers under anechoic conditions, so you will need to figure out how that translates to the sound pressure in your listening area. Once you know the 1m anechoic numbers, for a 3,000ft³ room, subtract 7dB from the stated maxima. For a 6,000ft³ room, subtract 10dB. For a 9,000ft³ room, subtract 13dB. For a 12,000ft³ room, subtract 16dB.

- **Other Considerations.** The impedance minima can be challenging for power amps so make sure they are well aligned. The overload character can either be smooth or jarring, so make sure to pick models that are well-behaved. And, of course, make sure the speakers fit in the wall, on the wall, behind the room's stretched fabric dress, in the cabinetry, or on the bookcases you plan to use.

PICKING THE CROSSOVER FREQUENCY

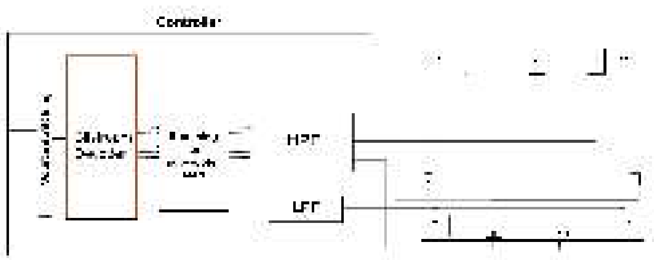
THE STANDING WAVE REGION AND SPEAKER EXTENSION

In part 3, we discussed how to calculate the theoretical frequency region in which your room may have strong standing wave resonances, known as the Schroeder Frequency. No, that's not the piano player in the Peanuts cartoon; it's the illustrious physicist and acoustician Manfred Schroeder (https://en.wikipedia.org/wiki/Manfred_R._Schroeder).

You could just start off setting the crossover frequency right above that standing wave region as long as your speakers can handle bass there. Also, remember not to worry too much about resonances that are predicted to be above the 4th harmonic. I know that's a weird way to determine the cross-over frequency! Most installers start from the lower limit of the speakers; but there is a lot more to getting good bass.

To better understand the subwoofer crossover system let's take a look at this diagram of what goes on inside a surround sound controller.

Controller Cross-Over Diagram



The multiple signals that come out of the bitstream decoder run through a summing network to produce the feed to the subwoofers. This includes the Low Frequency Effects channel (aka LFE or 0.1 channel), which is offset up 10dB from the level of all the other channels. The subwoofer feed then has a Low-Pass-Filter (LPF) applied to it at whatever frequency, slope, and filter type is best for the room and system. The LPF is a filter that only passes the low frequencies (yes indeed). Meanwhile, the Front, Surround, and Top channels have a set of complementary

High-Pass-Filters (that only pass high frequencies) applied to them at whatever frequencies, slopes, and filter types are best for the speakers, room, and overall system.

The subwoofer crossover isn't always engaged. In order to use it you need to tell your surround controller that you have a subwoofer, and that you want to turn on the suite of the speaker high-pass filter + signal summation + subwoofer lowpass filter processing inside the digital signal processing. Each manufacturer uses their own way to describe this in the setup menus, but it generally looks something like this:

LOUDSPEAKER CONFIGURATION

- **Subwoofer: Yes**
- **Loudspeaker: Small**
- **Crossover: 80Hz**
- **Crossover HPF: 12dB**
- **Crossover LPF: 24dB**

Here's what all this means:
"**Subwoofer: Yes**" tells the controller that you have a subwoofer and that at least the LFE signals are to be fed there.

"**Loudspeaker: Small**" tells the controller that you want to apply a high-pass filter to the speaker feed, and to direct the bass below that filter frequency to the subwoofer. The other choices are "None", whereby the controller routes the signal to the adjacent channels, or wherever is the best alternative (Not applicable to the Left and Right channels; you have to start with those at least...), and "Large", where the controller feeds full bandwidth signal to the speaker output. As I have stated numerous times, this mode shouldn't be used in home theaters if you want good bass because your speakers can't usually handle that much bass, and standing waves will prevent you from even getting good bass.

"**Crossover: 80Hz**" tells the controller to set the high-pass and low pass filters at 80Hz. Note that on some of the higher end and more advanced controllers, you can set different frequencies. For the high and low pass filters. Only do this if you have precision acoustical measurement equipment and analysis, and if you know what you are looking for. I have rarely found the need to set different frequency points.

"**Crossover HPF: 12dB**" sets the slope of the high-pass filter to 12dB per Octave, aka 2nd order. This is the most common use, and will complement the natural acoustic rolloff of most small and mid-sized speakers, which is also 12dB per Octave. Together, the electronic and acoustical filters will yield 24dB per Octave, usually with a Linkwitz-Riley character and will match the subwoofer lowpass filter feed (more on this below). Some of the more advanced controllers offer up a range of slopes, and that can come in handy if you know the speaker character, and if you have precision acoustical analysis equipment.

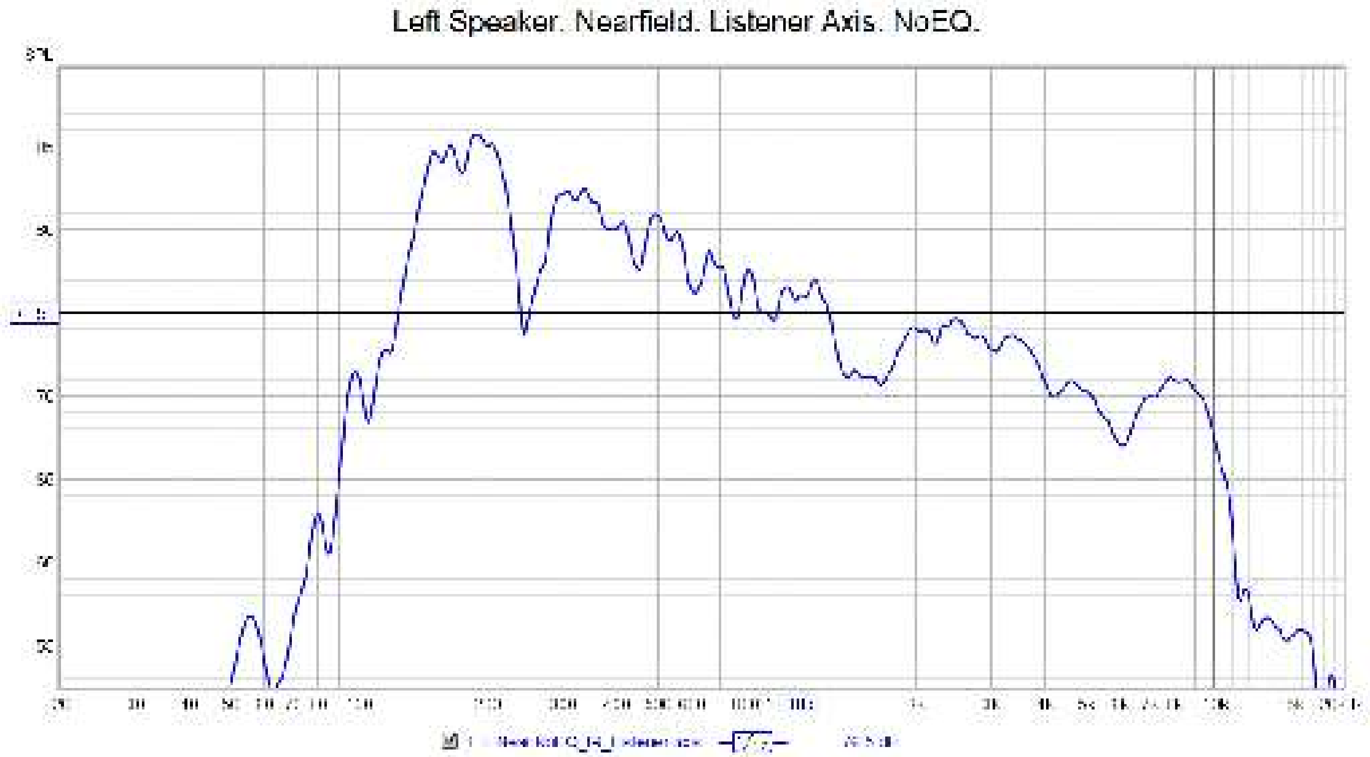
“Crossover LPF: 24dB” sets the slope of the high-pass filter to 24dB per Octave, aka 4th order. This is the most common use, and will match the electro-acoustic character of the speaker on the other end of the crossover. This all assumes that your subwoofer is reasonably linear up to at least twice the crossover frequency, which is not always the case with band-pass subwoofers. Some of the more advanced controllers offer up a range of slopes, and that can come in handy if you know the subwoofer character, and if you have precision acoustical analysis equipment.

Boy, I hope all that was clear!

Here’s a step-by-step procedure for determining the best crossover selections.

1. Gather the right tools. You will need a measurement microphone, which can be one of the simple but effective USB test mics such as the Dayton Audio UMM6, or the UMIK-1. You can also look at the Behringer ECM8000 if you have a microphone preamp and USB interface. For the best work, you can get four microphones and a switcher, called a multiplexer.
Get a boom mic stand. One that you can easily swing around the base location in order to get an average of the response around the arc of the boom extension.
You will also need an acoustical measurement and analysis application. I suggest getting Room EQ Wizard (REW), which is a free download, but please give them a donation for all the excellent work these guys have done over the years.
For some measurements you will need test discs. The 5.1 Audio Toolkit DVD (Yes it’s old), or any of the Dolby Atmos demo Blu-Ray discs. Both of these are available for purchase online.

2. Determine the low frequency cutoff of each speaker. Measure the nearfield response of the speaker at about 24 inches (60cm) from the front surface, on the listener axis. Place the microphone at a midpoint between the tweeter and midrange or woofer. With REW you can use either the Impulse Response measurement or Periodic Pink noise source. Either way, you will need to feed the system with the output of your computer or laptop, using either its headphone output, or the HDMI output. If you have a USB audio interface, use that output feed. It will get a bit complicated to feed signals other than the main Left and Right channels, unless you have an Apple computer, where you can tell REW to code the signals to other channels. You can try using the “All Channel Stereo” mode of your controller and disconnect or mute the speakers you don’t want to measure; that gets a bit complicated. Another way to feed a test signal is to use one of the test discs mentioned above. With systems that have separate controllers and amplifiers, I sometimes just feed the test signal to the Left channel, and plug the line level feed of the amplifier + speaker to be tested to that output. Either way you go about it, you will need to select the "Speaker: Large" mode for all the speakers, so as to feed full range signals to the outputs and determine what the speaker can actually do. Once you have figured out how to feed each speaker, and have a nearfield measurement of the sound it emits into the room, look at the low frequency response. Where does it start to fall off, and where is it about 3dB down from the main mid-frequency levels? Sometimes it gets hard to look at all this objectively because some speakers have very uneven response. And often the speaker rolloff is very different to what the manufacturer claims in their spec sheets... Here is a measurement I just made a few days ago.

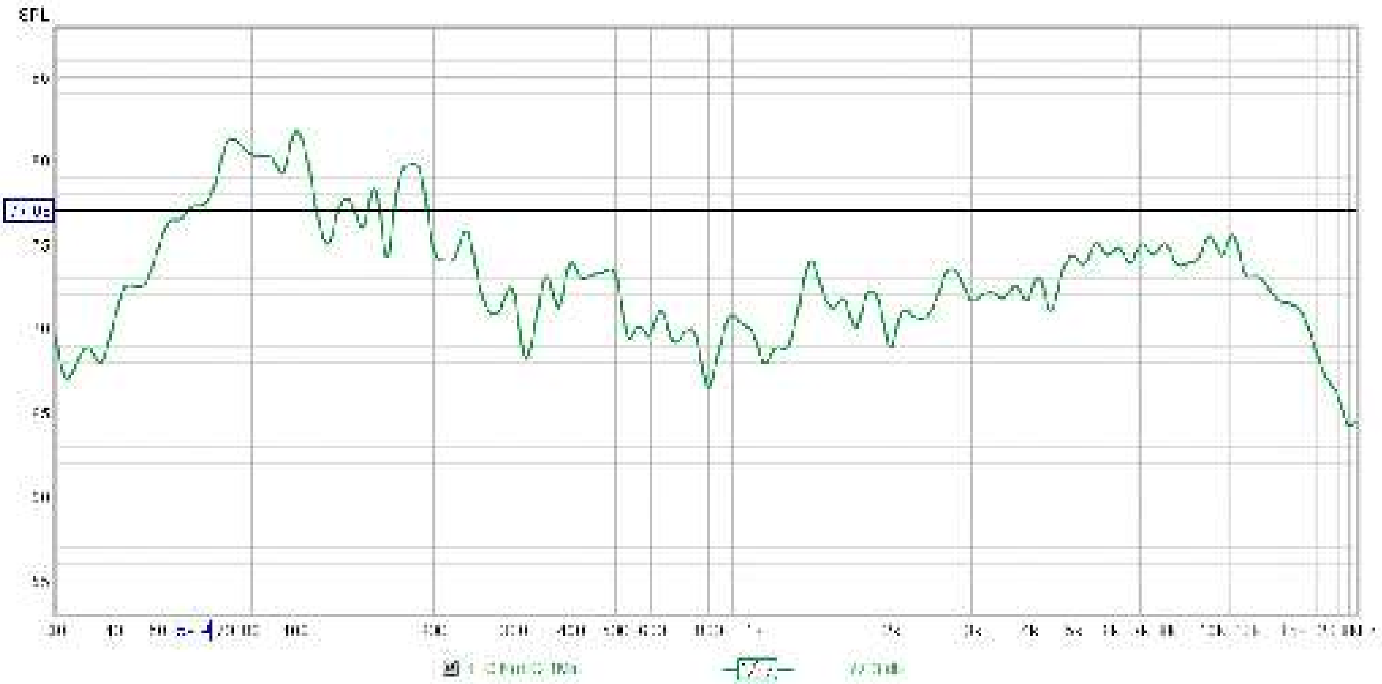


This rather expensive speaker has a frequency response that is far from smooth! It claims to have bass extension to 60Hz, but what I see here is that 60Hz is down 20dB from the 1kHz marker, and 30dB down from the peak at around 200Hz... Like they say, trust, but verify. I would call the natural rolloff of this speaker as about 120Hz, and set the crossover frequency at 120Hz. Yes, that is pretty high, and getting close to the point where you may localize the subwoofers.

Here is another recent measurement on a different speaker at another installation.
The data sheet of this less expensive product claims 45Hz bass extension at -6dB. I would say that, rela

tive to the bump in the 80Hz region, it is -3dB at 60Hz, and -6dB at 50Hz; pretty close! You could set the Crossover of this speaker as low as 60Hz, after you have determined where the main standing wave issues are.

C Speaker. NoEQ. 3dB down point is at 60Hz.



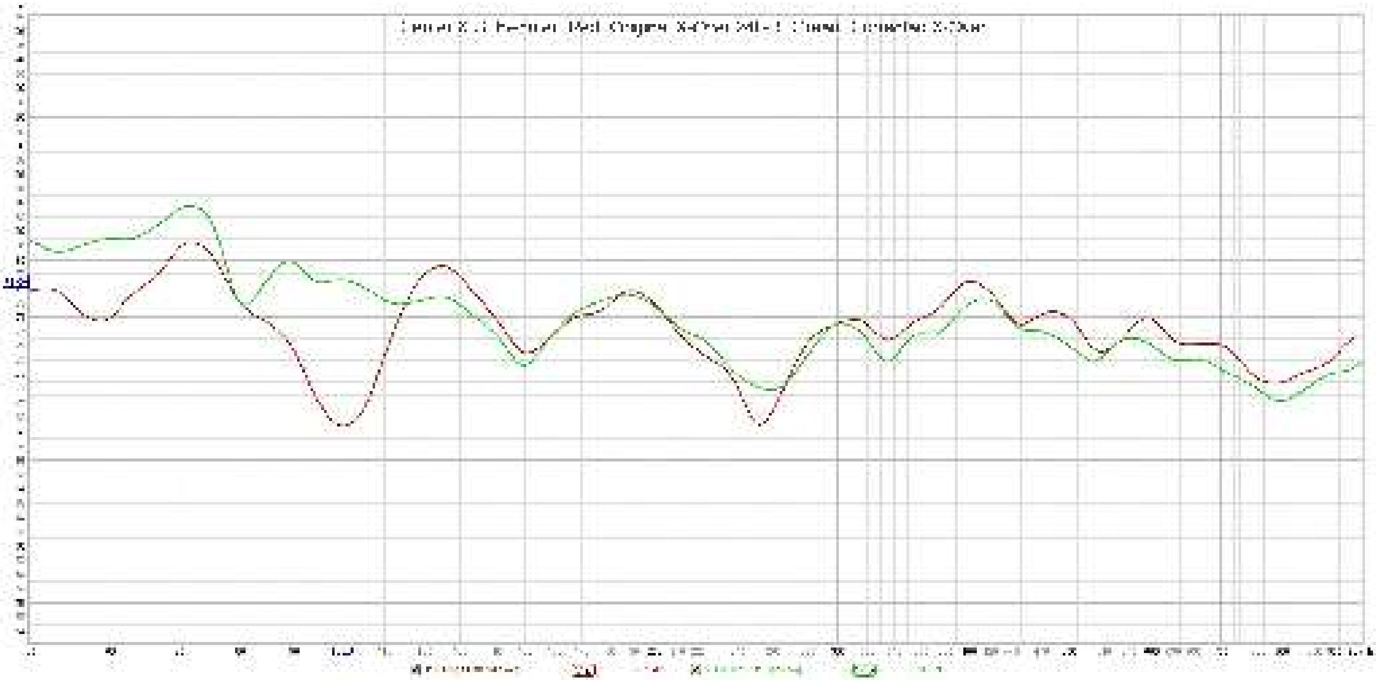
Repeat this test for each and every speaker in your room. Identical speakers should show the same rolloff, but you may see some differences based on the acoustical boundaries around each speaker. Just take an average of these results.

3. Low Frequency Cutoff at High SPL. Just when you thought you were done with this test, I am going to advocate to those of you who do meticulous work that you perform one more check. Just because a speaker can play down to reasonably low frequencies at moderate levels, does not mean it will handle those signals at high sound pressure level (SPL). It is good to repeat the test after you have engaged the high-pass filter at the cutoff, and turn the level up to about 100dB in the nearfield. Yes, that will be loud, but will correspond to only about 90dB at your listening position, and you do want to make sure the speaker can play all that without misbehaving. First measure the response with the high-pass filter engaged at moderate SPL, then remeasure the response at high SPL. The response should remain the same, and the speaker should not exhibit any overload. Maybe also try playing single tone sweeps down to the low frequency cutoff you are targeting, and listen to how the woofers are taking it. With REW analysis and impulse response measurements you can even take a look at the distortion percentages. Avoid anything that goes much above 10% at these high levels. You can try going up in crossover frequency to see what happens when you go from say 60Hz to 80Hz high-pass filtering. You may get a bit more headroom, and that is very useful. I know, this is getting pretty deep, and getting deep into our bass quality is what this article series is all about!

4. Figure out the standing wave activity of your room. We already talked about calculating the "Schroeder Frequency" and also about looking up the 4^{th} harmonics in the standing wave overlaps between length/width/height resonances. You can also check what the room is actually doing with your speakers and subwoofers playing. Starting with the cross-over at 80Hz, measure the bass response at several seats in the room from the Center speaker + Subwoofers. There is a frequency below which the responses vary a lot from seat to seat. That's a good place to set the crossover so that you can make use of subwoofer locations to eradicate the core standing wave issues.

5. Select the right combination of crossover slopes and subwoofer polarity. Once you have decided what crossover frequency you want to use, it is time to see how well the speakers and the subwoofer integrate with each other. Ideally, the transition is smooth without a dip in the middle of the crossover region. Use your microphone and analyzer, place the mic in the main listening area, and swing the boom around, with the analyzer in continuous averaging mode, in order to get a spatial average. If you see a deep null, try inverting the polarity of the subwoofer. If the response levels out completely, you may want to investigate why there is a polarity inversion. It could come from incorrectly designed or built products, or wiring errors. It could also come from non-complementary phase responses of the subwoofer vs. speaker. This gets more complicated... If you have one of the higher-end surround controllers, and it allows a selection of crossover slopes, you can try switching that around to see if the dip gets any better. With the products that give you independent control of the low-pass and high-pass filters slopes and even filter types (Butterworth, Linkwitz-Riley, or Bessel) you can really dig in there and find the most compatible filter set to give you the smoothest response throughout the crossover region.

How much effect does this have? Take a look at an example chart of the same Center Speaker + Subwoofer system crossed over with different slopes.



The Red chart was the original crossover set at 90Hz, with Linkwitz-Riley slopes of 24dB/Octave for both high and low pass filters. It turned out that the system was misaligned, and the phase of the signals coming out of the subwoofer and the speaker were causing a cancelation. The dip spanned from 80Hz to 115Hz, and was almost 10dB at its worst. That's very audible! The Green chart is the same crossover frequency setting but with 24dB/Octave Linkwitz-Riley Low pass to the subwoofer, and 12dB/Octave Butterworth to the Center speaker. With the different crossover slopes, the phase response is now better aligned, and the response is smoother in the 80 to 120Hz region (note that other corrections were also made between the two measurements outside the crossover region; ignore those differences).

Once you have completed your product selection, placed it all in the right locations, and set the subwoofer crossovers to the optimal values, it will be time to tune the subwoofer array and speaker bass response with equalization, delay, and level adjustments.

Let's Summarize

In this fourth part of the article series, we went over some of the guidelines for selection of your speakers and subwoofers, and for proper adjustments of your subwoofer crossover. Once again it got pretty technical, but I had a lot of explaining to do! In the next part, we'll get into the bass optimization tuning process to yield the smoothest, loudest, and most dynamic low frequencies. Until then, **enjoy the ride!**

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