The Kairos and Continuum Three-Ways
(And other possibilities too)

Concept

I have seen the request many times for a three-way version of the Kairos or Continuum loudspeakers, and although many people choose to go the route of an active subwoofer, there's a lot that can be said for a properly designed three-way when it comes to smoothness, low distortion, and proper tonal balance, as well as having the simplicity of a passive design.

Recently, I had been contracted to design several large three-way loudspeakers, and I have found that I strongly prefer the smooth integration I hear from using shallower slopes between the woofer and midrange drivers. It occurred to me that with several small speakers all fitting neatly in a narrow window of sensitivity, it might be possible to design a woofer module that could (almost) universally work with several different small speakers and be just as effective.

To test this concept, I decided to use my Kairos and Continuum speakers for the test subjects. These speakers differ in sensitivity by about 2 dB (85.5 dB and 83.5 dB respectively) and about a half octave or so in bass extension (40 Hz vs. 60 Hz). My goal was to develop a single module that could convert both of these speakers into well-designed three-way designs by doing nothing more than hooking them up.

Not a Subwoofer….

Although people will be tempted to refer to this as a subwoofer module, it is not, in my opinion and here are the small, but subtle distinctions: In today's audio vernacular a "subwoofer" is nearly always a single separately powered speaker with active filters; there are very few passive subwoofers around these days. With a subwoofer there is usually a lot of variable adjustments (gain, phase, crossover point, etc.) that can be made, and let's face it, most subwoofers end up being set-up 3, 6, or 10 dB louder than the main speakers when people set them up by ear.

In this case the woofer module is a passive module, driven by the same amplifier driving the monitor speaker and crossing over to the monitor section with a passive crossover that will follow all of the rules we generally apply to passive crossovers. The resulting summed response through the crossover range will be flat, as any good three-way loudspeaker should be. It will also operate with a higher crossover frequency than normally used in a subwoofer, and there will be two of these modules, not one. Because of these distinctions I prefer to call it a woofer module. Of course, some will still prefer the term "subwoofer" and that is up to you. But keep in mind, my purpose here is to convert a two way monitor into a properly design three-way loudspeaker.

The (First) Woofer Driver

As with all driver selections there are trade-offs and limits we work with to fit it into a given system. In this case I have four basic criteria that I want my woofer to meet :

1.) It needs to ideally have a voltage sensitivity in the 85-87 dB/2.83V range so that it can passively blend successfully with the monitor speaker it will be paired with.

2.) It needs to work well in a fairly specifically sized enclosure that is nearly predetermined by the monitor speaker. I'll go into more detail on this later.

3.) It needs to be able to reach deep enough in the bass to make this project worthwhile.

4.) It needs to be able to move some air, so that it can keep up with the monitor speaker if pushed hard.

Even with these restrictions there are several woofers that can do the job. But after careful consideration, I chose to begin with the CSS SDX-10. Even though it is designed as a subwoofer it still has adequate upper frequency extension to work in a three-way. Its sensitivity is right where I need it to be for passive integration with the monitor. It will work in my predetermined enclosure very well, either sealed or vented. It can reach well into the bass with a vented F6 of 22 Hz for this enclosure. And finally, I had several people recommend 8" woofers for this project, I rejected the idea. I just don't like the idea of using a single 8" driver in a three-way. I don't think it's enough woofer to justify its use. A 10" driver steps it up a bit, but in this case with the XBL^2 motor and 18.5 mm of Xmax, it is capable of moving enough air to please anyone.

Something else that factors in here is the cost of the driver and maybe more importantly, the cost to performance ratio. The SDX-10 is a very well-made driver with heavy cast frame, a fairly high-end motor, a nice attractive stiff paper composite cone, and big rubber surround, and at the same time it is considerably less expensive than many other drivers of the same size and performance.

The Enclosure

I mentioned above that the enclosure size was pretty much predetermined. Years ago I was reading an interview with David Wilson of Wilson Audio Loudspeakers. David was discussing the development of the "Puppy", the woofer module sitting under the Wilson Watt monitor. He made the comment that the dimensions for the Puppy were already pretty much set before they even started. He said, we wanted the height to be the same as we would use for a stand for the Watt. We wanted a width that looked correct with the Watt sitting on top, so it couldn't be too wide. And we wanted a depth not much deeper than the Watt. This defined the enclosure and drove the selection of the Dynaudio woofers they originally used.

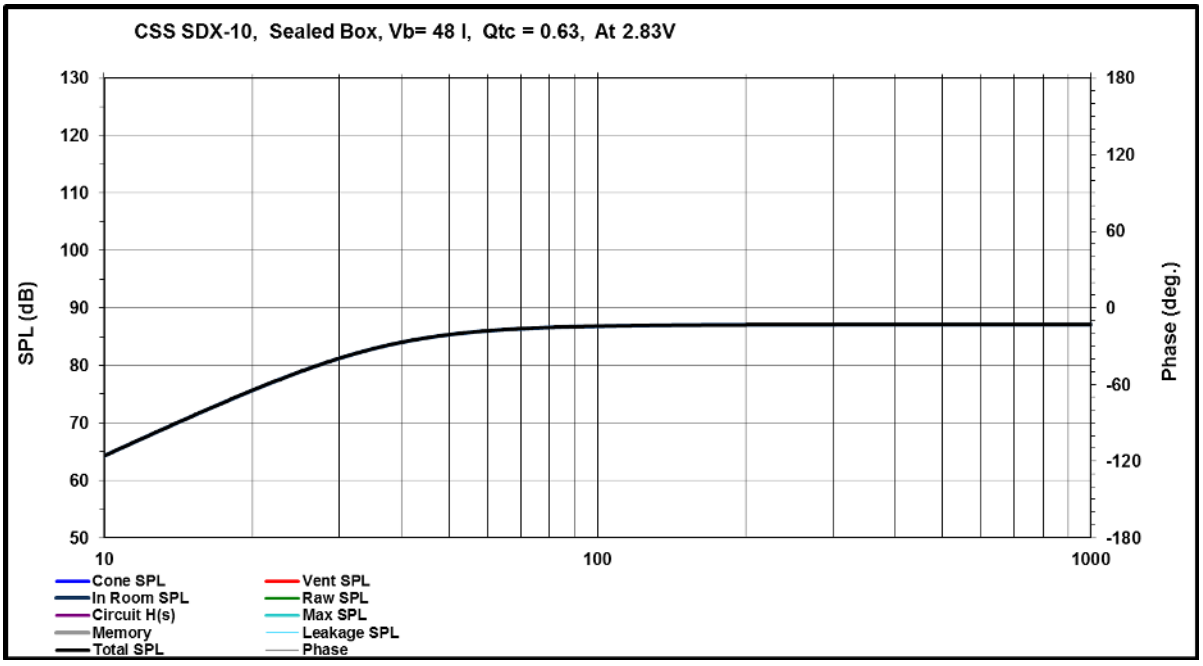
We were faced with a very similar set of constraints here as well. Because the Kairos or the Continuum would be sitting on top I chose a height of 24-25", which is the same as the stands I use for these speakers, and places the tweeters at the correct height. For width I chose 12", which looks about right with the Kairos sitting on top, but still looks OK with the Continuum up there as well. And finally, my

test cabinet has a depth of 14". However, below under "options" I will explain how you can play around with these numbers a little if you want a smaller module, and even build everything into one cabinet if you want. I will also cover woofer placement in the enclosure there as well.

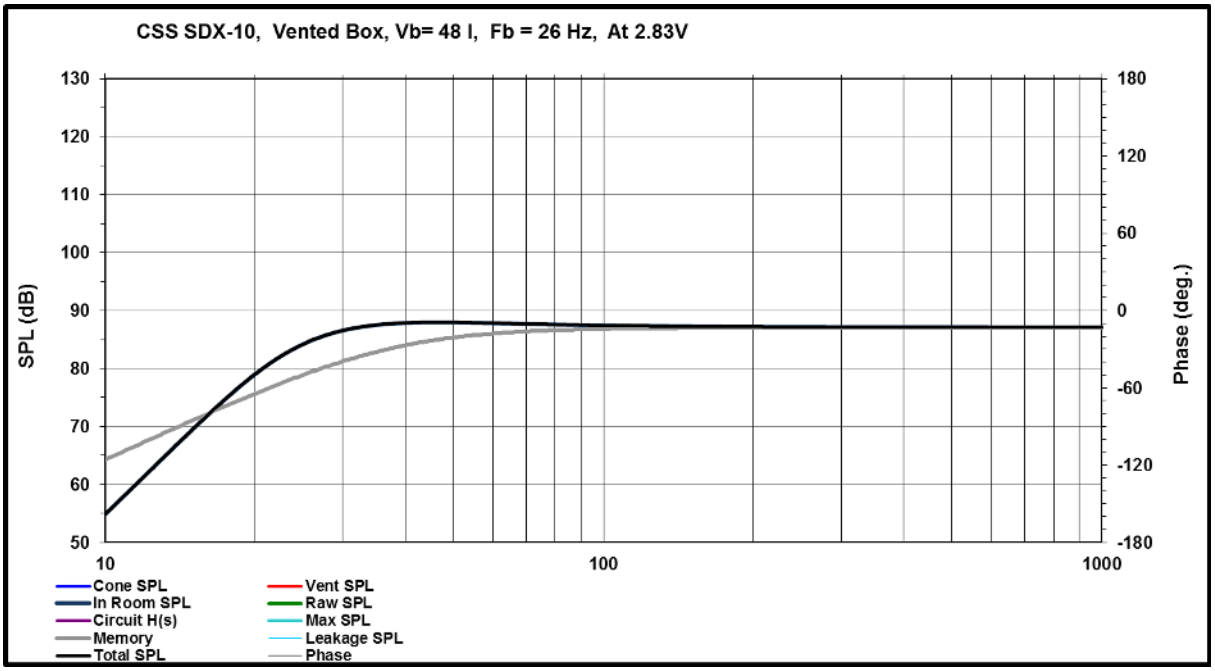
Bass Alignments: Sealed and Vented

The CSS SDX-10 has very nice parameters for a small sealed enclosure, and many people like the shallower roll-off of sealed systems in a lot of smaller rooms. On the other hand, this woofer will also work in a vented or passive radiator enclosure as well. I began my design stage with the woofer in a sealed box. From the dimensions I gave above the enclosure will have a net internal volume of 46-48 liters depending on the bracing someone chooses to use.

For all of the following simulations I used the actual measured series resistance of the woofer crossover in the modeling. The SDX-10 in this sealed box has a Qtc of .63. This gives the system an F3 of 40 Hz, F6 of 29 Hz, and F10 of 22 Hz. This is the most conservative of the options. For some people this will be acceptable, but for many this will not be the bass extension they may desire. Here is the graph of the SDX-10 in this sealed alignment:



This brings us to the vented option. Using the same enclosure, I decided to install a 3" diameter port. In playing around I found that I preferred the bass response when tuned to 26 Hz. I also found that the port only needed to be 10" long to accomplish this, even though box modelers will approximate a longer port. I did not mount the port in a corner, rather it is immediately below the woofer and centered on the baffle. The vented alignment results in an F3 of 26 Hz, and F6 of 22 Hz, and an F10 of 19 Hz. Here is the graph of the vented alignment with the sealed response in gray:



I found the extra low bass in the vented system more appealing to me personally.

The (Second) Woofer Driver

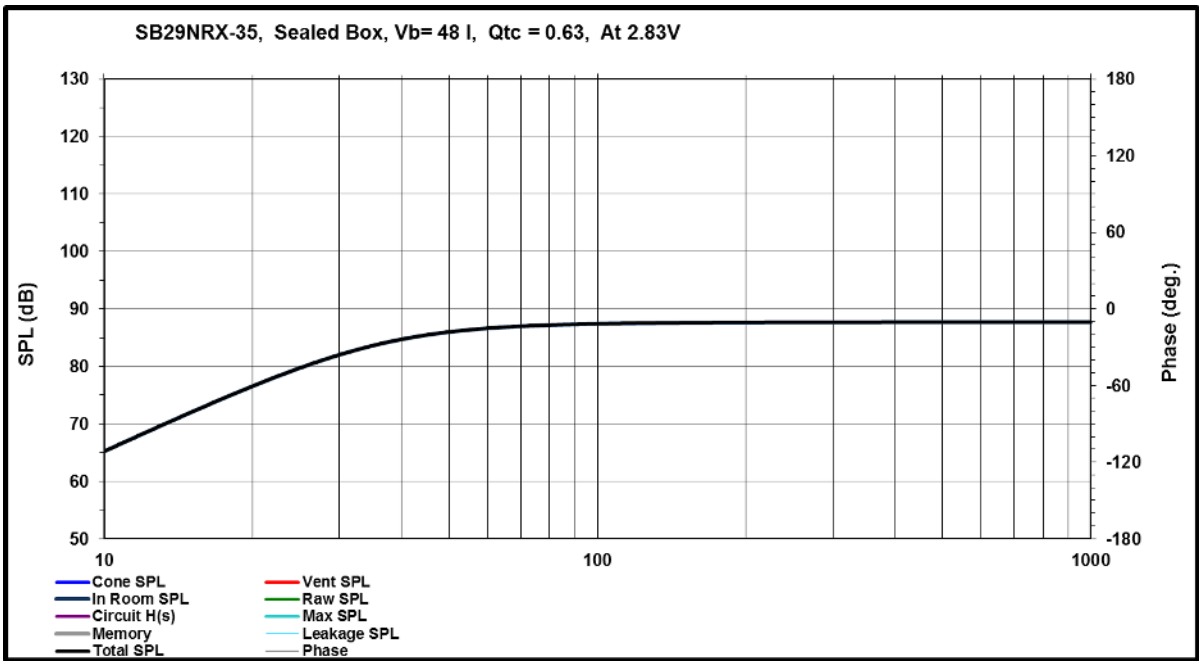
I began my listening sessions with the Continuum as the monitor speaker and was very pleased with the tonal balance of the system with the CSS SDX-10 woofer module. Everything was running according to plan. Then I switched over to the Kairos and things changed - slightly. I knew the Kairos had a couple dB more sensitivity, but I was pretty confident that the woofer module could accommodate that acceptably. However, despite the fact that measurements seemed to indicate that the overall balance was very flat, and that the CSS module matched the Kairos well in level, I felt the bass was a bit light subjectively when using the Kairos and the SDX-10 together. This is not a problem when working with a powered subwoofer, but with a passive system the difference in sensitivity becomes critical.

I was quite satisfied with the Continuum / CSS combo, but with the Kairos I began to think that I wanted a little more bass energy with some music. I knew this was a subjective thing though, and my measurements indicated that the response was still flat with the CSS woofer. I guess this was coming down to personal preference. At this point I put the project on hold and began to consider experimenting with some other woofers.

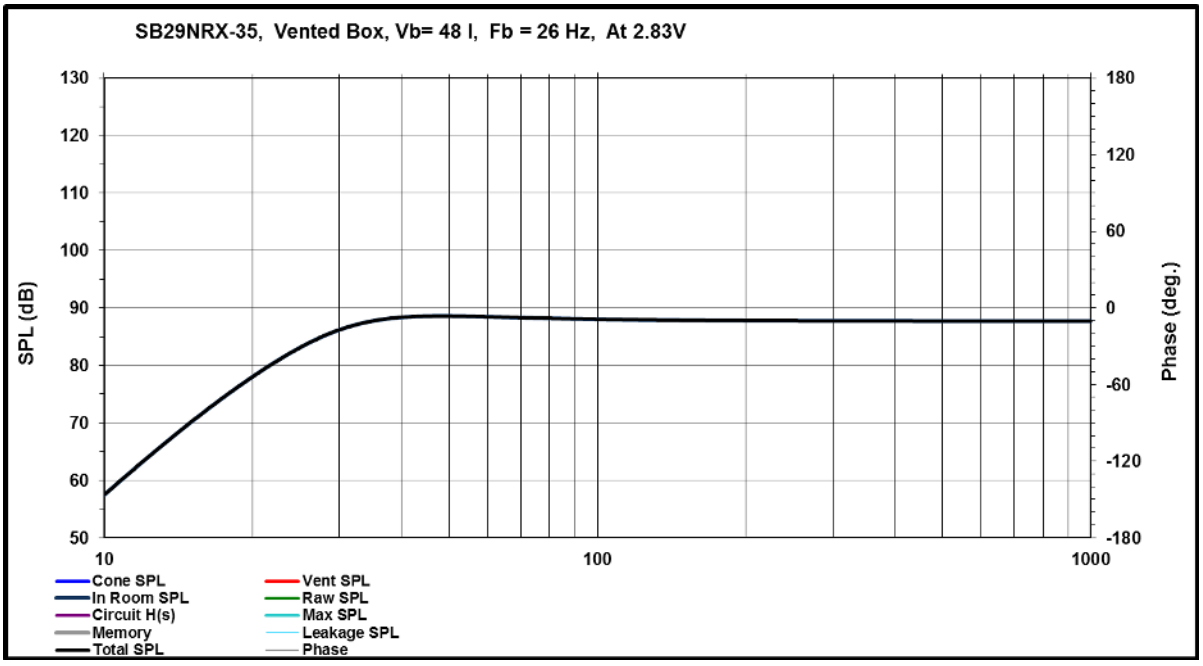
After reviewing a lot of woofers, I knew I wanted one with a build quality that would match well with the Satori drivers in the Kairos, but I didn't want the cost to become prohibitively high either. I ultimately settled on the SB Acoustics SB29NRX-75 woofer. When this woofer arrived I was immediately impressed by the excellent build quality and appearance of the driver. It had a large vented motor and heavy cast frame, and again, a very attractive appearance. I needed this woofer to work in the same size enclosure, and if it worked out, then we would possibly have two options to work with.

Bass Alignments with Woofer 2

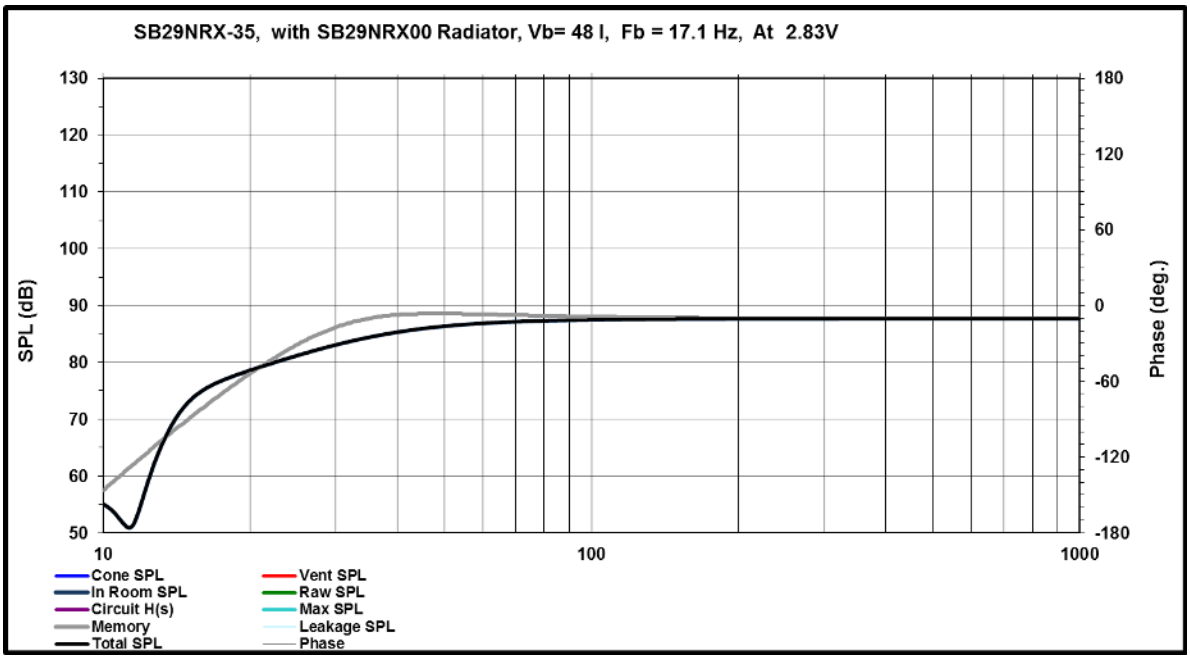
Using the SB29NRX in the sealed enclosure resulted in a sealed alignment very similar to the SDX-10. Qtc was .63 (the same as the SDX-10). The system had an F3 of 40 Hz, an F6 of 29, and an F10 22. Essentially identical performance, but with a bit higher sensitivty. Here is the graph:



When used in the same vented box, results were again similar, with an F3 of 29, and F6 of 24, and an F10 of 20 Hz. Here is that graph:



The SB29 has another option that may be attractive to some people. SB Acoustics makes a passive radiator that cosmetically matches the SB29NRX-75 woofer. This passive radiator comes with a weight that is glued in place and non-removable. It does, however, have a small disc attached with a screw that can be removed to reduce the moving mass slightly. I do recommend removing the disc. It is unfortunate that more weight cannot be removed so the tuning can be raised a bit more, but here is the response with the SB29 woofer and the matching passive radiator:



The passive radiator tunes the enclosure to a low 17 Hz, which blends with room gain about the same as a sealed design, but with a bit more extension. In the graph above the black line is with the passive radiator and the gray line is the vented response. With the passive radiator the system has an F3 of 36 Hz, and F6 of 26 Hz, and an F10 of 18 Hz. If you are factoring in typical room gain, the passive radiator system could result in very smooth and very deep in-room response.

Listening with Woofer 2

With the Kairos hooked up with the SB woofer in the same vented module the bass balance was much more impressive than before and I was really enjoying it. Measurements, however, revealed that the SB29NRX was 4 dB more sensitive than the SDX-10, even though the ratings were much closer than that. While the system response measured very flat with the SDX-10, the response measurements with the SB29NRX revealed a rising response below the crossover point with about a 4 -5 dB emphasis in the mid – low bass range. It turns out that left to my own devices I seem to prefer a little bass emphasis.

Switching back to the Continuum revealed that the SB29 was a bit too sensitive for this combination and subjectively there seemed to be too much bass energy. For the Continuum, the SDX-10 was the better choice. However, just as I knew that there would be people who would prefer a sealed system, while others would prefer vented, I knew that some would want a flat bass balance and others would prefer

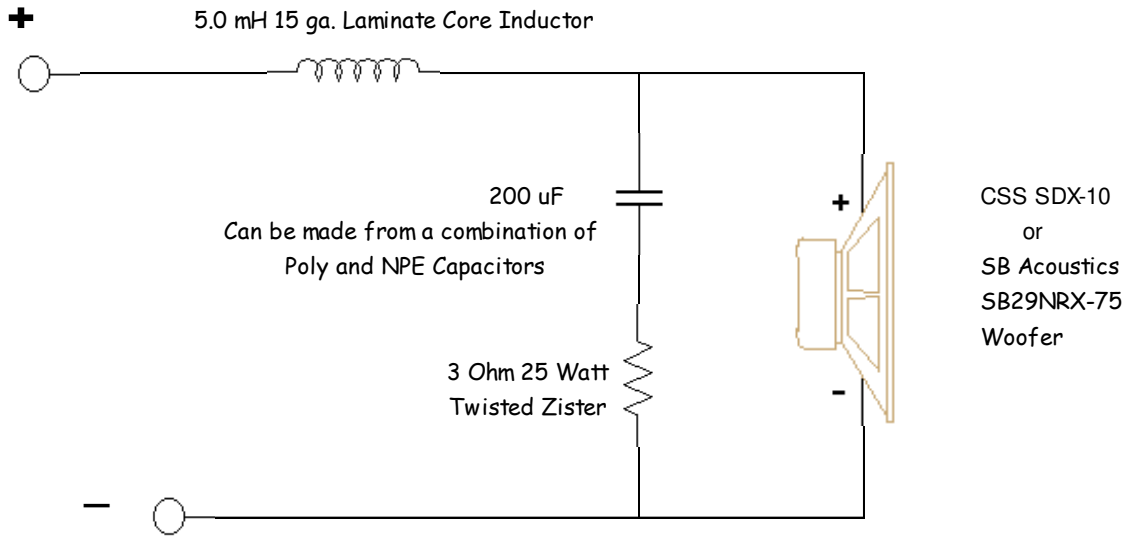
the system with the bass emphasis. At this point I decided to let the builder decide. Both woofers work fine with this system – same enclosure, same port tuning. It's just a matter of what kind of bass balance you prefer, or it may come down to how large or small your listening room is too. My family room and kitchen are a pretty large area without a lot of room gain, and the speakers were several feet from the walls as well. For many people the CSS woofer will be enough with either monitor, but others will enjoy the extra bass provided by the SB29 woofer. Again, this will come down to personal preference. Because of this, I will leave both woofers in as options in this design. Personally, I preferred the SDX-10 with the Continuum and the SB29NRX with the Kairos, and in the future I will probably refer to these combinations as the three-way deisgns. This also made the Kairos three-way an all SB Acoustics speaker system. More thoughts and options will be covered at the end.

The (sorta) Universal Crossover

As I noted at the beginning, I have found that I greatly prefer the sound of shallow slope crossovers in the lower frequency range. They just seem to sound more coherent and better integrated. I have also found that in order to make this type of crossover work correctly it must employ some damping resistors to deal with the driver reactive impedances.

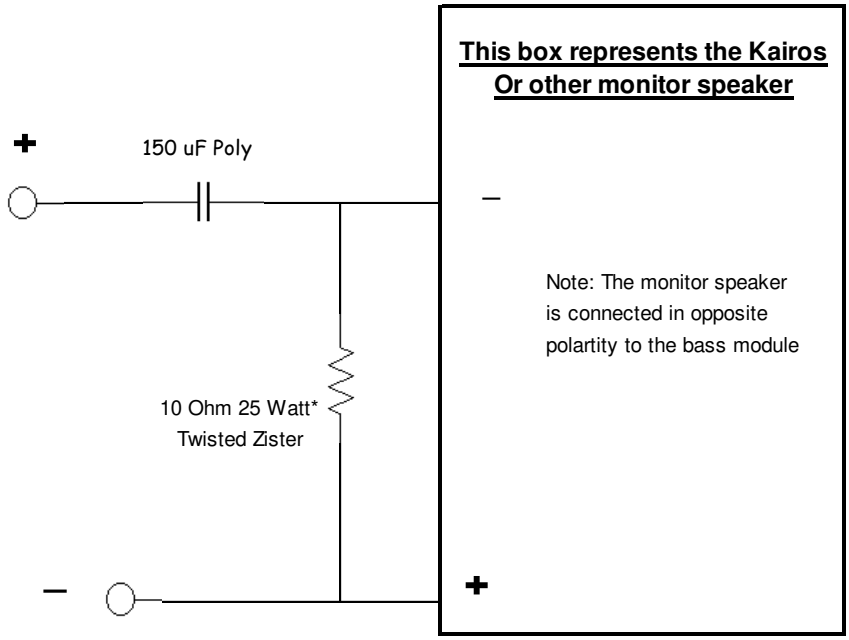
I call this a "universal crossover" because the low pass section works well with a lot of different woofers since most of them break-up or roll-off well beyond the crossover point. And the high pass section does equally well for a large number of monitor speakers if they are sealed and have a nominal impedance of 8 ohms. The crossover point is at approximately 200 Hz, which provides a nice transition between the bass and the vocal range. The acoustic slopes are approximately 2nd order Linkwitz – Riley slopes, which is the reason most of the set-ups will require a reverse polarity connection between the woofer module and the monitor. I will begin with the crossover diagrams and then explain the operation in more detail.

Here is the lowpass crossover for the bass module:

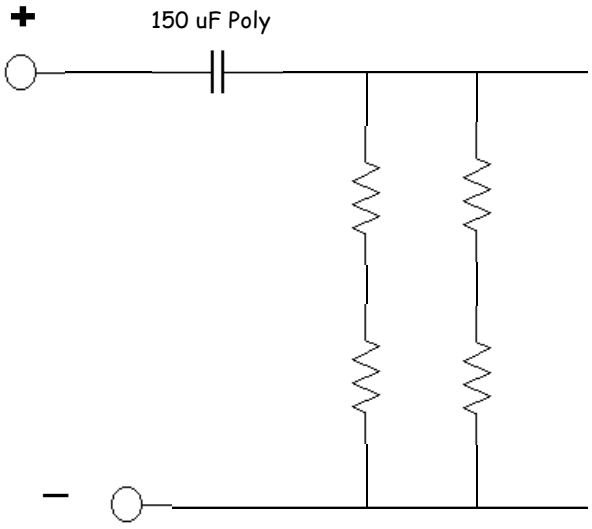


The lowpass crossover consists of a second order filter with a 3 ohm damping resistor. The purpose of this resistor is to damp the rise in response that occurs from the interaction between the crossover inductor and the capacitive part of the driver's in-box resonance. The result is a second order L-R response.

The highpass section for the monitor is simple and is shown here:



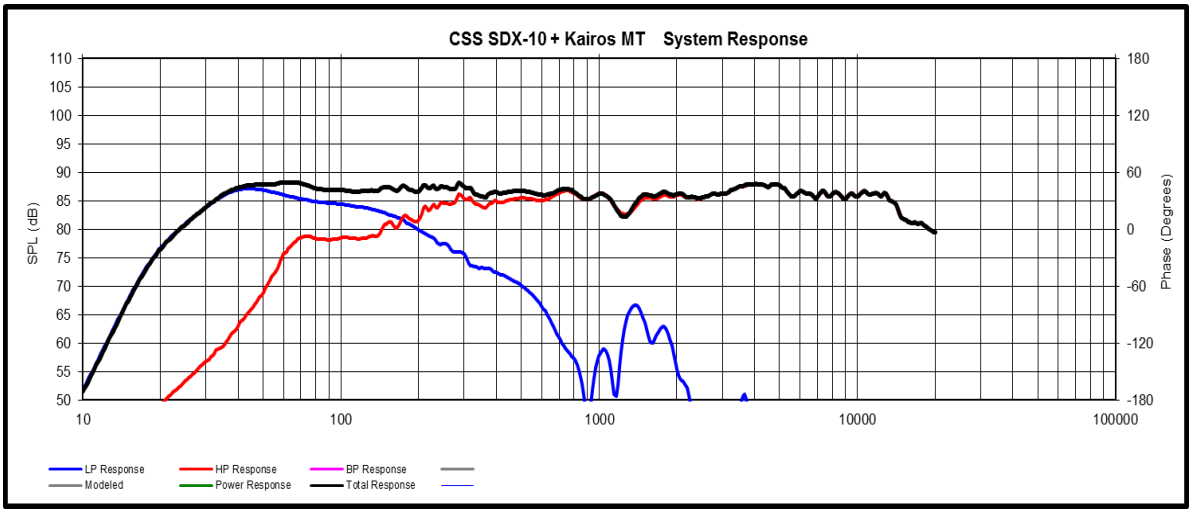
For higher power applications you may make the 10 ohm resistor by placing two 20 ohms resistors in parallel, or by using 4 -10 ohm resistors connected as shown below :



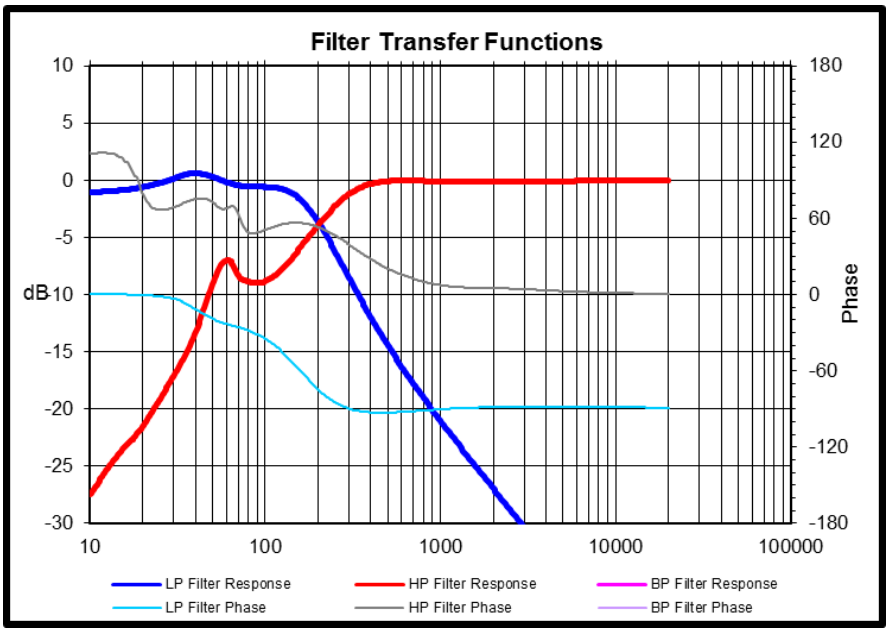
4 – 10 Ohm resistors wired in series /Parallel for a combined resistance of 10 Ohms, but with double the power handling

In this case the 10 ohm resistor is necessary to flatten the sealed box impedance peak of the woofer in the monitor, so the high pass crossover does not have an excessive peak at this frequency and much better controlled behavior. It does also lower the overall impedance of the monitor speaker, but as long as the monitor is nominally 8 ohms or higher it will not be a problem. This is the case with both the Continuum and the Kairos, as well as many other small monitor loudspeakers. So even though I designed this module to mate with the Kairos and Continuum monitors many of you may decide to try it as a woofer module for existing stand mounted monitors other than these, and it is likely that it will work well if care is taken to match the sensitivities between the monitor and the selected bass module. I won't be surprised if I don't see it implemented with lots of different speakers.

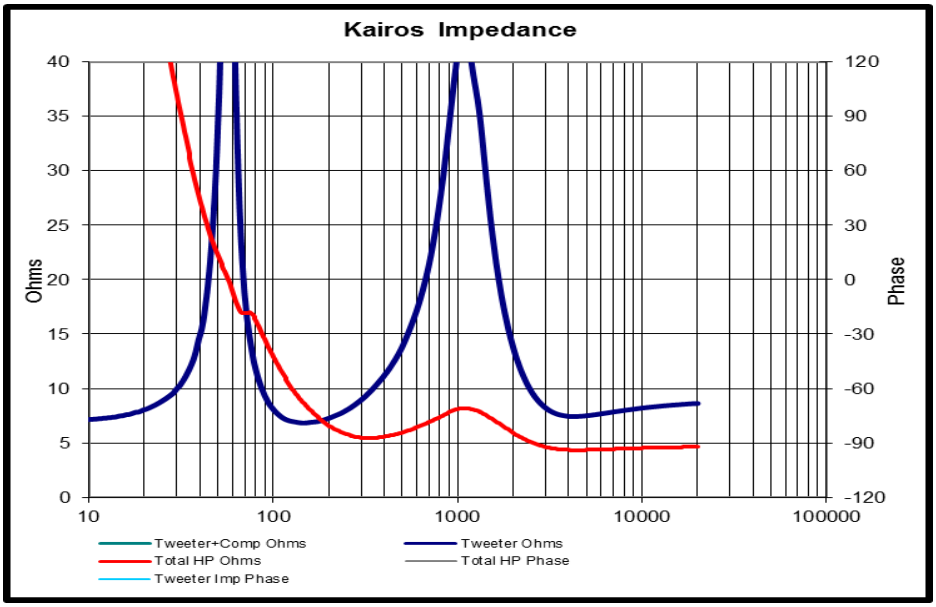
Here is the acoustic crossover using actual measurements of the Kairos and the bass module using the sealed version of the SDX-10:



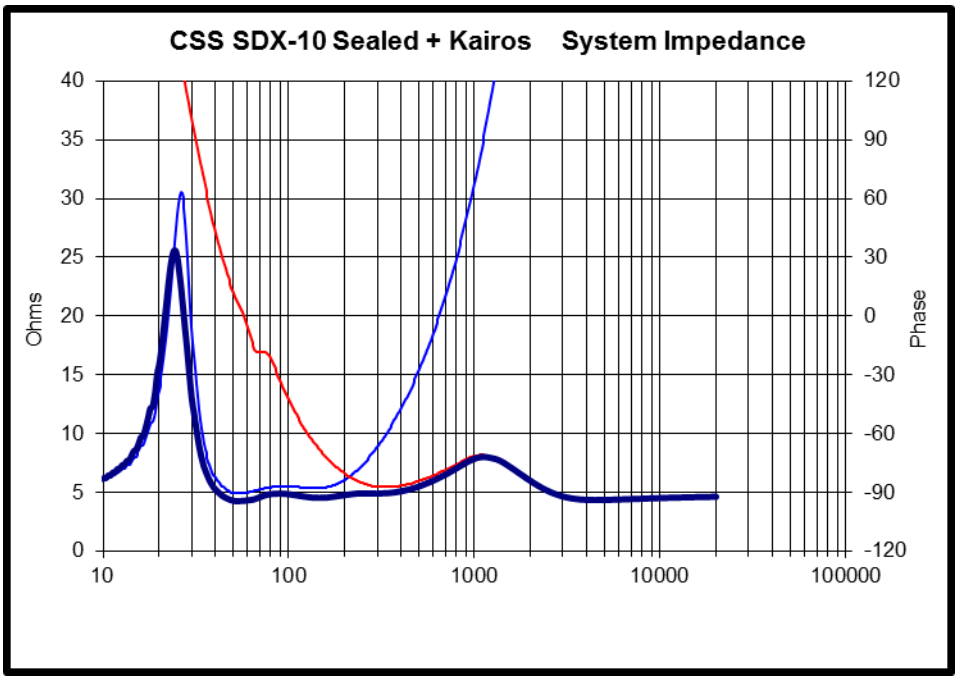
Here are the filter transfer functions when loaded with the woofer and monitor impedances. There is still a bit of hump from the Satori woofer's in-box impedance peak, but it's not real bad:



This graph shows the sealed Kairos with and without the high pass crossover. You can see the effect of the 10 ohm damping resistors across the Kairos' range, but it only lowers the Kairos impedance to about 5 ohms:



Finally, here is the total system impedance of the Kairos, the sealed CSS SDX-10 woofer module and the low and high pass crossover networks:

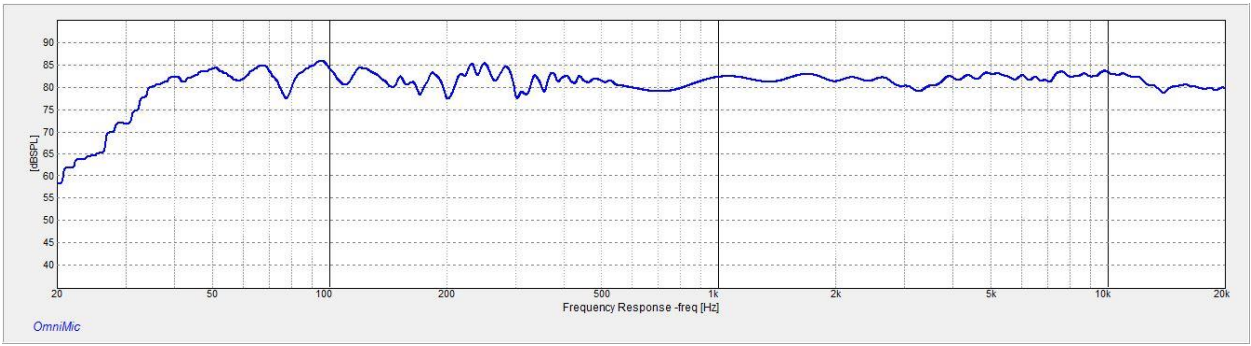


The Continuum impedance is almost exactly the same. This should be an easy load for any amplifier to drive.

Acoustical Measurements

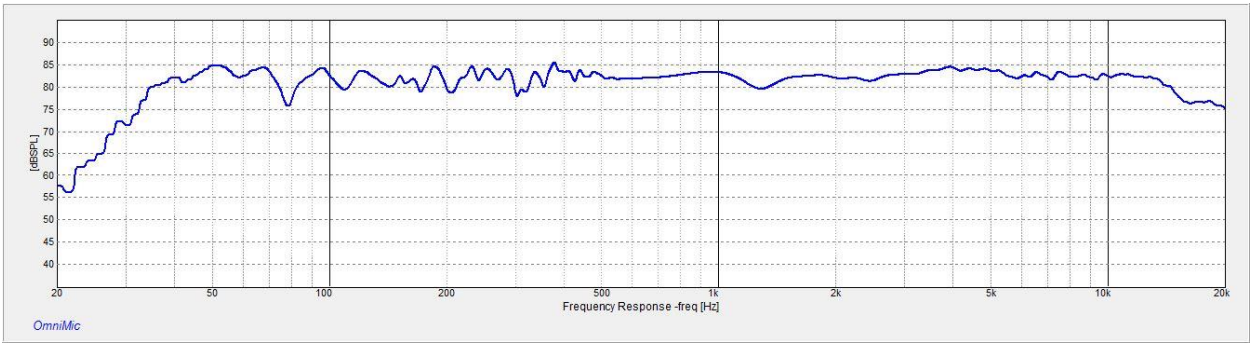
I have grabbed several response measurements in an attempt to show how different combination measure. Unfortunately, these measurements involve lower frequencies taken inside my home in my family room. As a result room reflections significantly enter into the data, but even with this being the case I believe I will still be able to communicate what I am trying to show from this data, and hopefully, give the reader the information they will need to be able to make the best decision for selection the best options for them.

Working first with the CSS SDX-10 Here is the measured response at one meter on the tweeter axis of the Continuum with the CSS module underneath and the passive crossover connected :



I personally, preferred the CSS module with the Continuum as a three way.

This next graph shows the CSS module with the Kairos on top using the identical crossover:

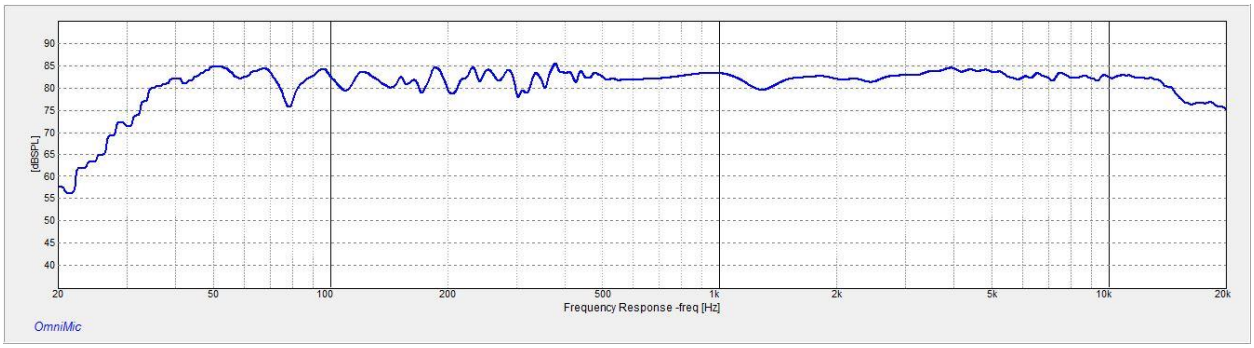


As you can see, both set-ups looks exceptionally well-balanced, including the Kairos , which is why many purists will like the CSS module best because there is no excess bass emphasis. Other people, however, will want the SB module in order to have a small amount of bass emphasis.

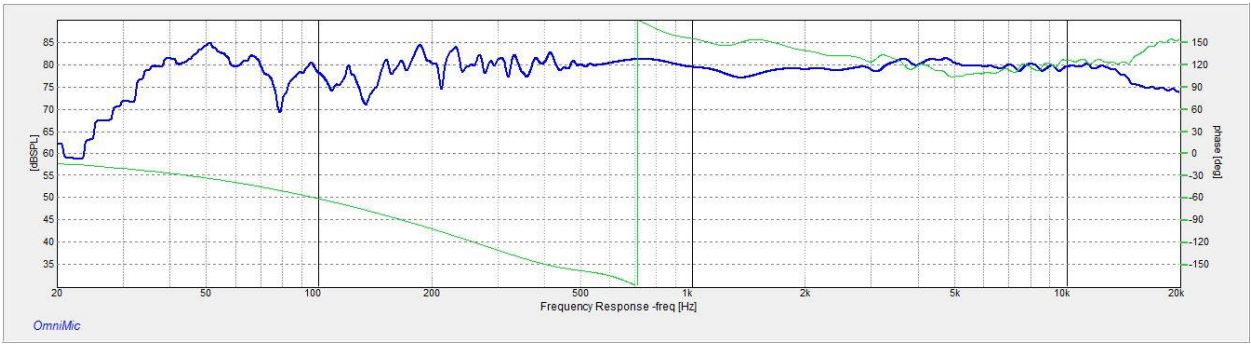
Remember in both of these plots the monitor is connected with reverse polarity from the bass module. This results in a flat summation through the crossover range around approximately 200 Hz.

Regarding the position of the woofer, since my woofer is mounted toward on end of the enclosure I could test the system with the woofer near the floor or near the monitor at the top. This does change the measured response slightly, but I could not hear a difference when playing musical material in my room. So, even though the near-floor position looks smoother on-axis, I actually did the bulk of my test with the woofer at the top of the module because I thought it looked better that way.

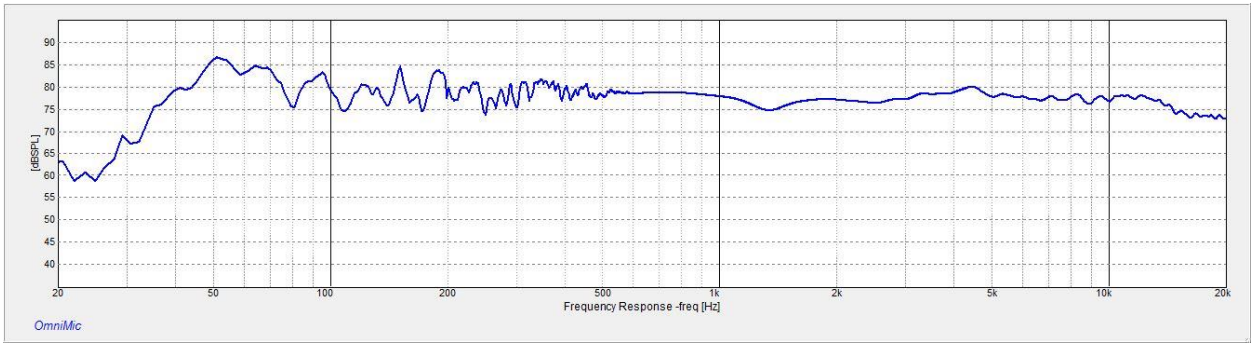
Here is the Kairos and CSS module with the woofer at the floor:



This graph shows the response with the woofer near the top, close to the monitor speaker:

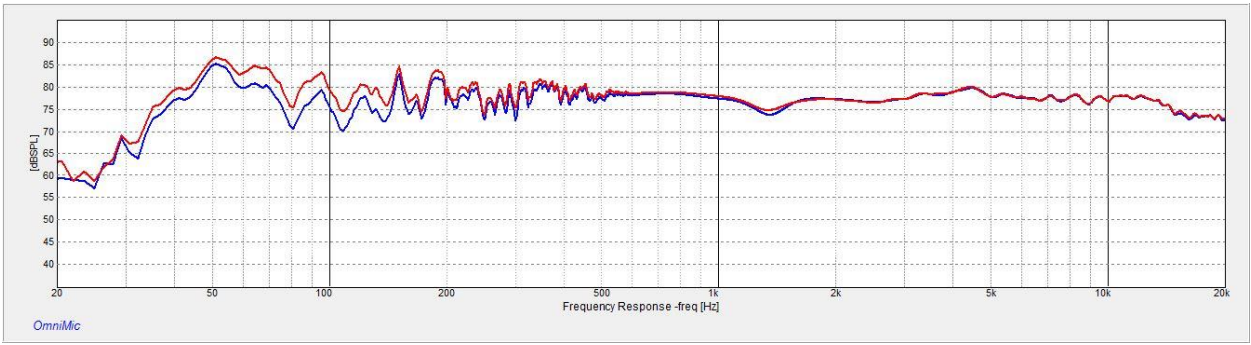


Now moving on to some measurements with the SB Acoustics module; here we have the Kairos with the SB module:



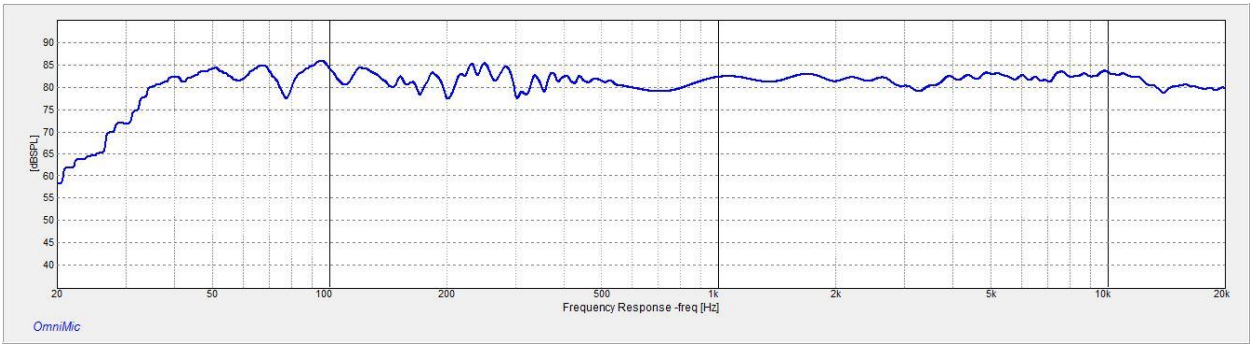
As you can see the extra sensitivity of the SB29NRX gives a slightly rising response into the midbass.

For a direct comparison of the difference I captured the Kairos set-up with the CSS SDX-10 and the SB29NRX-75 and have overlaid them. From this graphs you can see the relative difference between the two woofers in this application. (The way both lines move up and down together shows the consistent effects of the room).

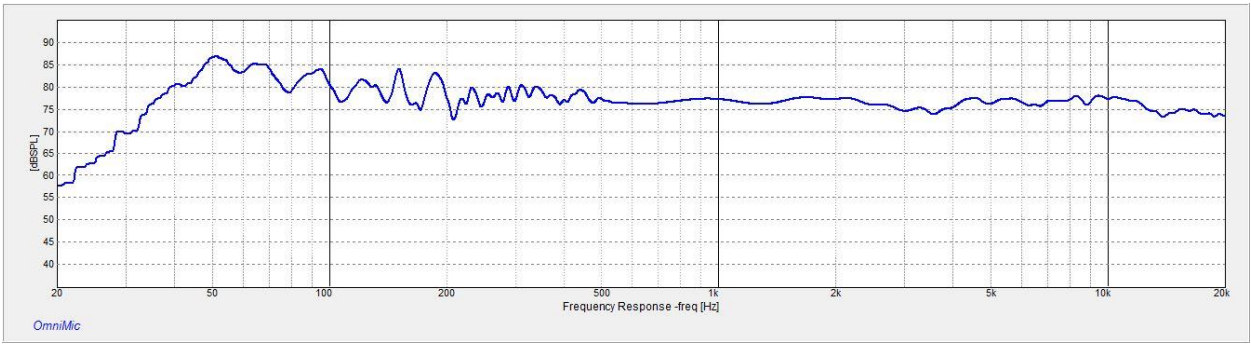


In the graph above the blue line is the CSS module with the woofer at the top and the red line is the SB Acoustics module with the woofer at the top. The difference begins to show up below 140 Hz and has its greatest difference down to about 50 Hz where the two woofers begin to the come closer together.

I had mentioned that I preferred the Continuum with the CSS woofer module. For comparison here is the response of that combination once again:

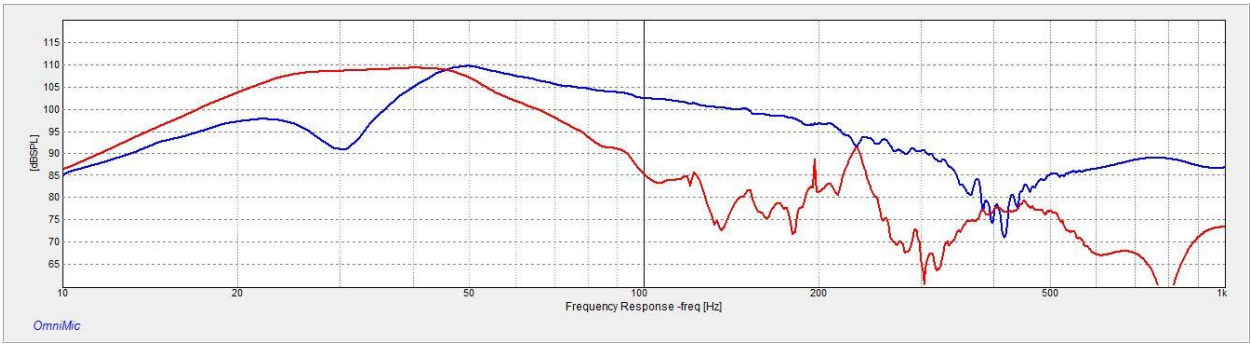


And here is the response of the Continuum with the SB Acoustics module:

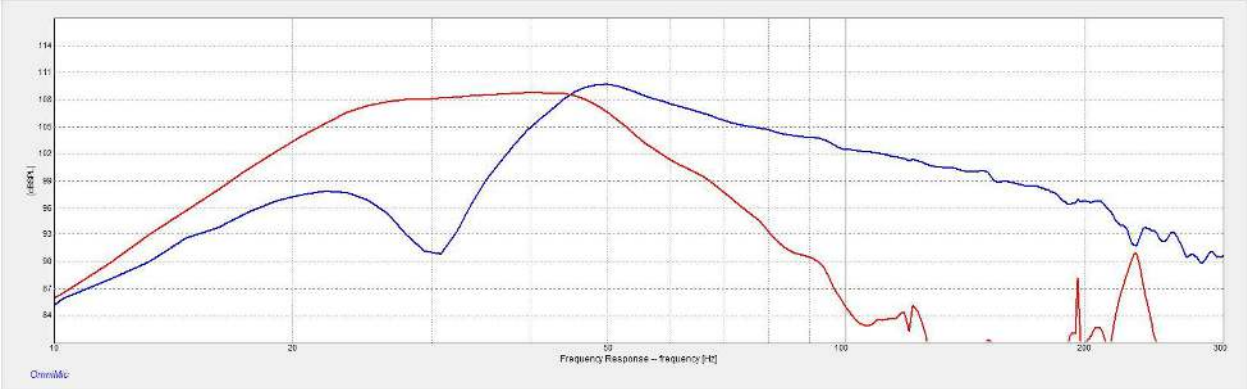


In this case I found the bass to have too much emphasis to be pleasing to my ear.

Early on I took some measurements of the port and woofer cone nearfield. These were with a little shorted port that tuned the cabinet closer to 30 Hz. Since then I lengthened the port as I explained in the beginning and lowered the box tuning to about 26 Hz. But the graphs will still give a good idea of the port's contribution to the low end response of the system:



If we zoom in a bit it looks like this:



A Few Pics of the Test Set-ups

The Kairos on the CSS Bass Module with the woofer at the top and port near the bottom:

The Original Continuum in the same position:

Now, isn't that the makings of a nice three-way?

I also tried it with the newer Corian Continuum as well:

The SB29NRX-75 has a little larger frame than the standard 10” woofer. Here is a shot of it with the Kairos:

The Kairos Three-way – all SBA Drivers.

And one more of the new Continuum Three-way Concept with the CSS Module:

Brainstorming (Builder Options)

At this point many of you have probably noticed that this isn't the typical DIY speaker plan with all of the details filled in, especially with all of the options I have tossed out there. Well, that was intentional and it is about to get even fuzzier. This is because I wanted to lay a foundation for converting my Kairos and Continuum loudspeakers into satisfying, well-executed, three-ways designs, complete with a somewhat universal passive crossover, but beyond this I wanted to leave a lot of room for the builder to express their own creativity.

We have already discussed using either the CSS SDX-10 or the SB Acoustic SB29NRX-75 woofers, using them sealed or vented, and locating them near the floor or near the monitor speaker, but now we will brainstorm some other options as well.

Although I didn't take pictures or measurements I also turned the woofer module 90 degrees and listened with the woofer mounted on the side. Due to the low crossover point I could really hear no discernable difference in this location compared to facing straight ahead when I was at my normal listening distance of about 8 feet away. So, based on this, I think side-mounting is a viable option for anyone who would prefer to go this route.

And, although my test set-up is crude, another option could be a simple rectangular box that was finished in such a way as to allow different positions to be available if desired – sorta using the box to think outside the box here.

At the same time, another excellent option would be to build the entire three-way speaker as one finished enclosure with whatever styling the builder may prefer, and simply place the entire crossover inside the enclosure. It wouldn't have to be modular at all, and a lot of creative options could be expressed here. It could be anything from a narrow, straight tower with the woofer on the side, to something that looks a lot like a Wilson Audio Sophia III (Which I always thought were pretty cool looking).

Another idea might be to make the bass module with some type of mounting at the top where the Continuum or Kairos could be slid into place and locked down to secure it, but could also be removed later if desired.

As mentioned earlier, crossovers can be placed inside the woofer module, or they could be built into external enclosures of their own with custom runs of speaker cable to connect the speakers. These custom runs could implement connecters like Speak-Ons or whatever type you may choose.

The port can be a tube or slot, placed on the front, back or bottom. Or you can go with something crazy and do a side-mounted SB29NRX-75 with a matching SB29 passive radiator on the other side.

The bottom line is that this paper is a guide, a starting point, for a successful three-way build, but a lot of the details are up to you. Be creative and make it reflect who you are.

Jeff Bagby, 2015