The Live Edge Dipoles

By Perry Marshall

With plans & links to digital crossover files

We were visiting family in Nebraska during Christmas. The topic of live edge furniture came up, and my wife suggested we make a live edge table for my office. Maggie my niece said, “Perry you guys have *got* to visit the sawmill in Palmyra Nebraska, it’s an incredibly cool place!”

So on New Years Day, I drove from Lincoln down to Palmyra (population 545) and visited Big Red Sawmill, which is run by an older gentleman and his three sons. I picked out an oak slab for my table. But having just recently built my first-ever dipole system, I couldn’t help but admire their collection of gorgeous hardwoods.

That day, the desire to build the Live Edge Dipoles was born.

My first dipoles had been a pair of rather pedestrian looking triangles, but the dipole sound astonished me. Early the first morning after I got them working, I was playing a solo classical guitar album. It was seven in the morning, and the music was whisper quiet. Still I couldn’t help but notice how big, round, full bodied and rich the sound of that single classical guitar was.

A set of bookshelf speakers with outstanding measurements sounded downright boxy and constricted by comparison… and I was hooked. (Details on the dipole speaker pictured on the right are available at www.tinyurl.com/dipoleplans.)

I had originally designed these just for the fun of doing something different, but they turned out to be the best sounding system I’d ever made.

I built my first set of speakers 38 years ago when I was 13. I’ve been involved in the audio industry in various degrees ever since. I spent three years designing speakers professionally at Jensen, where I worked on projects for Honda, Mazda, Acura and Chrysler.

I have built almost every kind of speaker you can imagine: Acoustic suspension, bass reflex, bandpass, transmission lines, back loaded horns, infinite baffle, shaded arrays; full range drivers and ribbons; motional feedback subwoofers, systems for cars, homes and live sound reinforcement.

What I have found is that sealed and ported speakers are the most “textbook correct” and straightforward to design… but horns, transmission lines and dipoles are a lot more musical and more fun to listen to.

They are also much harder to get right. These are for the folks at the adult table, because bad designs can sound horrible. But when you really get it right, you nail it – the sound is incredible.

When my friends visit, most of them have never heard anything like it. And judging from reactions on Facebook, most people have never seen anything like these either!

I showed pictures of the edge dipoles to a dozen clients (NOT audiophiles, nor married to audiophiles) on a business Zoom call, during “Zoom Happy Hour” after business was done. Two women on the call gave a “whoop” the moment I put them on the screen. I said, “I have never in my life heard women do that when they saw a pair of speakers!” My pal Susan Winter said, “That’s because it’s never happened before. Not ever in the history of mankind.”

If I may say so myself, they sound superb. When you play classic Miles Davis recordings, they have a huge, lifelike, warm, present sound. Trumpets sound incredibly real, as does upright bass. If you play electronic music like the *Matrix* soundtrack, they easily keep up with the deep bass and synthesizers. If you play Rush or Porcupine Tree, they handle the dynamics and bass with ease.

If you play string quartets and choirs, they have a presence and realism that gives me goosebumps and brings my 21-year-old son to tears.

The Live Edge Dipoles do everything well:

PERFORMANCE SUMMARY

- 25Hz to 25KHz with silky-smooth response *in a real room that has real reflections.* Not just in an anechoic chamber.
- True Constant Directivity sound pattern 25Hz to 25KHz so imaging is superb anywhere in the room
- Open Baffle Dipole sounds great even *behind* the speakers
- High Efficiency – 95dB 1 watt/1 meter on average. Sounds great and plays loud even with "flea watt" single ended vacuum tube amps
- High Power Handling and High Output – 100 watts & 115 dB full range, 1000 watts & 125 dB with subwoofer
- Near-perfect impulse response
- Near-perfect phase response
- <1% Distortion
- Live Edge design is so beautiful, non-audiophile wives of non-audiophile men gasped when I showed these on a screen in a Zoom meeting.

Back loaded horns, TLs and dipoles harness the back wave of the speaker for important purposes. Which is much messier and far more complex. If your goal is a ruler flat +/-1dB frequency response that you can stick on a piece of paper and claim ultimate perfection, then don't even try. (Frankly in a textbook design it's not all that hard to do that anyway, with 21st century digital signal processing.)

But as I've matured as an engineer, designer and artist, I've come to realize that pursuing academic perfection in the quest for perfect measurements is an exercise in futility. The majority of speakers designed according to those criteria are uninspiring and clinical anyway. Often they sound boxy and they certainly don't sound like real music.

E.J. Jordan once said "art is science with more than seven variables" and this is a great truth. One of the realities that designers of TLs, horns and dipoles accept is that as soon as you put your speaker in a real room, your dreams of perfection go out the window. Many pretend otherwise, but mature designers work with the room instead of ignoring it.

In speaker design, the elephant in the room *is* the room.

When I designed my first dipoles, I discovered that radiation pattern is one of the most important and overlooked aspects of a speaker. A good radiation pattern makes a *huge* contribution to how realistic the sound is. A speaker with great response on axis and bad response off axis will inevitably sound unnatural. That's because the room reflections are all telling your ears "this is fake sound." With a good dipole, you frequently find yourself marveling at how realistic the illusion of live sound is.

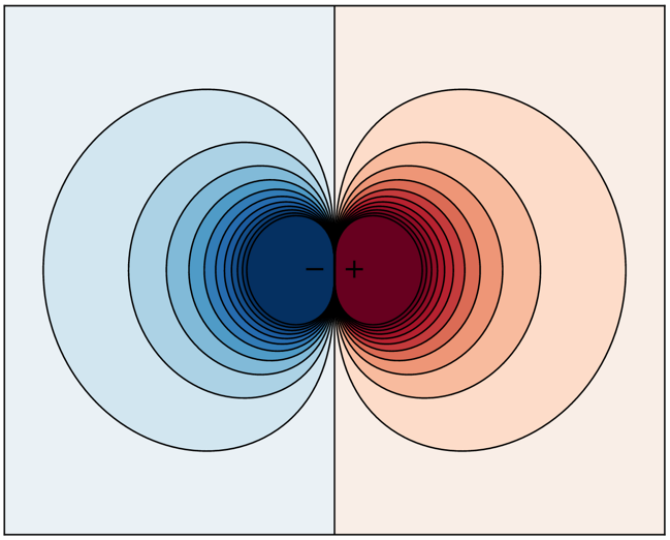
You might argue that an omnidirectional radiation pattern is ideal, but in my experience, Constant Directivity is what you really want. Constant Directivity means that you have flat frequency response on axis, and then as you turn the speaker in any direction, the level steadily drops as you go off axis but the octave to octave balance remains flat.

Then you can position the speakers so that the imaging is great *anywhere* in the room.

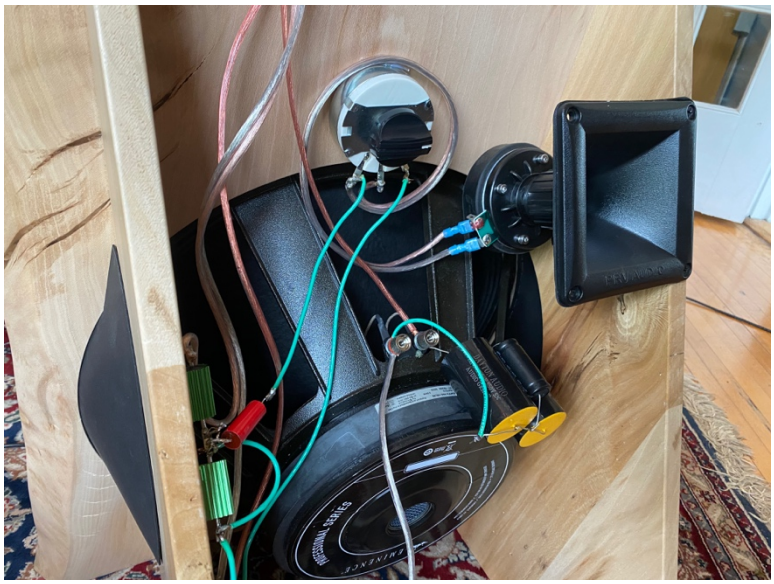
The way to achieve Constant Directivity in a tweeter is to use a Constant Directivity horn. Horns are harder to work with – they usually don't have perfectly flat on-axis response, and you have resonances and complex impedance loads to deal with. However, CD horns are mathematically optimized towards this ideal radiation pattern, and the good ones achieve it.

A constant directivity woofer is impossible, however – *unless you use a dipole.* A dipole gives a "figure 8" radiation pattern where the front and back give strong on-axis response, and the backwave progressively cancels the front wave was you move off axis.

On the side, which is top and bottom in this diagram, the front and back waves cancel out:



So… if you design a dipole using a coaxial woofer where the tweeter is a Constant Directivity horn – and if you add a CD horn tweeter on the back to make back and front symmetrical – you get a true Constant Directivity response both front and back. The dipole configuration automatically makes the woofer into a Constant Directivity source.



(I find omitting the back tweeter causes the high end to mismatch the dipole bass and midrange. So I added a tweeter on the back, along with a level control. You can see it in the upper half of this photo.)

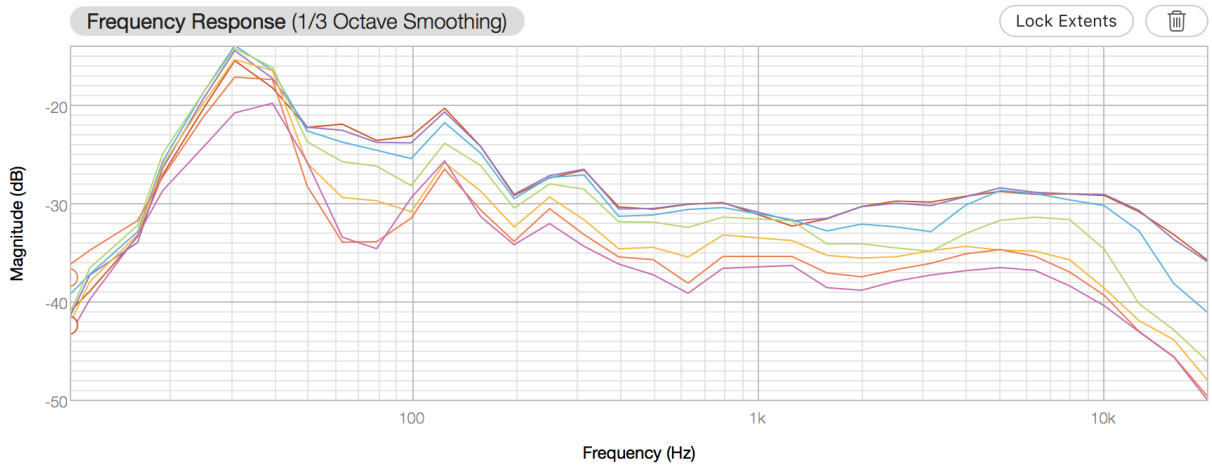
So you design the speaker for radiation pattern, dipole Constant Directivity pattern across the entire range… then you fix any frequency response problems with Digital Signal Processing.

This gives you an amazing speaker that gives you imaging and sound staging that are **physically impossible** for conventional speakers with cones and domes to achieve.

With the Live Edge Dipoles, you can walk all over the room – even stand on the far side of the left or right speaker, and you still clearly hear the other speaker across the room and the imaging is still stable. **There is no**

one "sweet spot." Music sounds fantastic anywhere you go in the room. In fact you can walk around and *behind* the speakers and they still sound great! When you walk towards the speakers and go behind them, the acoustic image stays in place.

This, in addition to careful attention to phase and impulse response (more about that later) makes for fantastic imaging.



Above: a family of response curves taken in my listening room, about 4 feet from the speaker, at 0, 15, 30, 45, 60, 75 and 90 degrees. You see that across the entire range, the response is strong at 0, 15 and 30 degrees. Then beyond 30 degrees the level drops faster and is down about 10dB at the side, at 90 degrees.

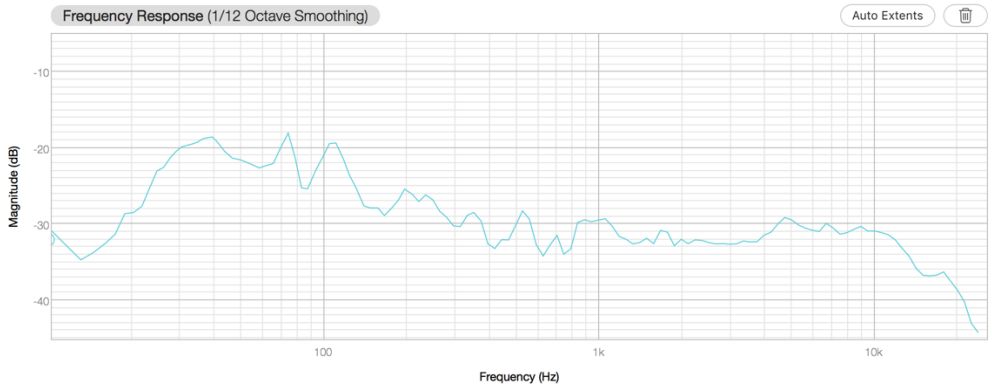
I've seen a few speakers that achieve this above 500 or 1000 Hz; I've never seen any other speakers that achieve this from 25 Hz to 20KHz.

Design Priorities

Of course accurate frequency response is a major objective, as it is for all speaker designers. But I have several other priorities as well:

- Lifelike presentation of acoustic instruments like string bass
- Extremely high resolution of drums, percussion and plucked instruments
- A huge soundstage
- High efficiency
- High output
- Very deep bass
- Flat phase response, accurate impulse and step response
- Separate amplifiers for low and high frequencies

In a real room, flat frequency response in the lab translates to the low bass being about 10-15 dB stronger than the highs. That sounds natural to most people. I achieved that as you can see here; this is a 1/12 octave average of 7 different positions:



I have made no attempt to gate off room reflections. To most listeners, this response sounds “neutral” in my room.

Highly Efficient: I chose the Eminence Kappa Pro 18LF woofer. 18-inch pro bass driver. 98 dB sensitivity for 1 watt, +/-8mm excursion (Xmax), and mounted in my dipole configuration, the resonance is 27Hz with a Qt of 0.5.

Traditionally, dipole designers prefer high-Q woofers. But none of the available high Q woofers had 8mm of excursion. And since I’m fixing frequency response problems with DSP, it doesn’t matter that much.

I chose the 8” Radian 5208 coaxial mid bass + Constant Directivity horn tweeter (16 ohm tweeter version, aluminum diaphragm). There are very few companies that make coaxial drivers with Constant Directivity tweeters: Faital, Radian, Selenium and B&C come to mind; there aren’t many others.

The 8” radians have 95 dB sensitivity in the midrange and the tweeters deliver 105 dB.

The average efficiency is about 95 dB. I drive these with 60-watt amplifiers and I’ve never seen my amps overload no matter how hard I push them.

High Output: The Eminence 18” woofer moves a ton of air. Bill Duddleston of Legacy Audio says: “If you can see the cone moving, it’s distorting.” You can see this cone moving when you’re playing loud music with lots of bass. But at normal levels the cone barely moves at all. It’s never possible to see the midrange cone moving.

There is something entirely different about a speaker that has “dynamic range to burn.” The music is effortless, powerful and unrestricted at all volume levels.

The dipole configuration in these speakers starts rolling off below 70 Hz. Below that, open-back cancellation starts kicking in. So after you factor in cancellation effects, you can think of these woofers as effectively being 18” woofers at 70 Hz, 13” woofers at 35 Hz and 9” woofers at 20 Hz. So in other words these have tons of output down to about 40. For most music these will play as loud as anyone would like. As you go down below 40Hz the workload goes up rapidly. Below 30 Hz at high levels they begin to sound strained.

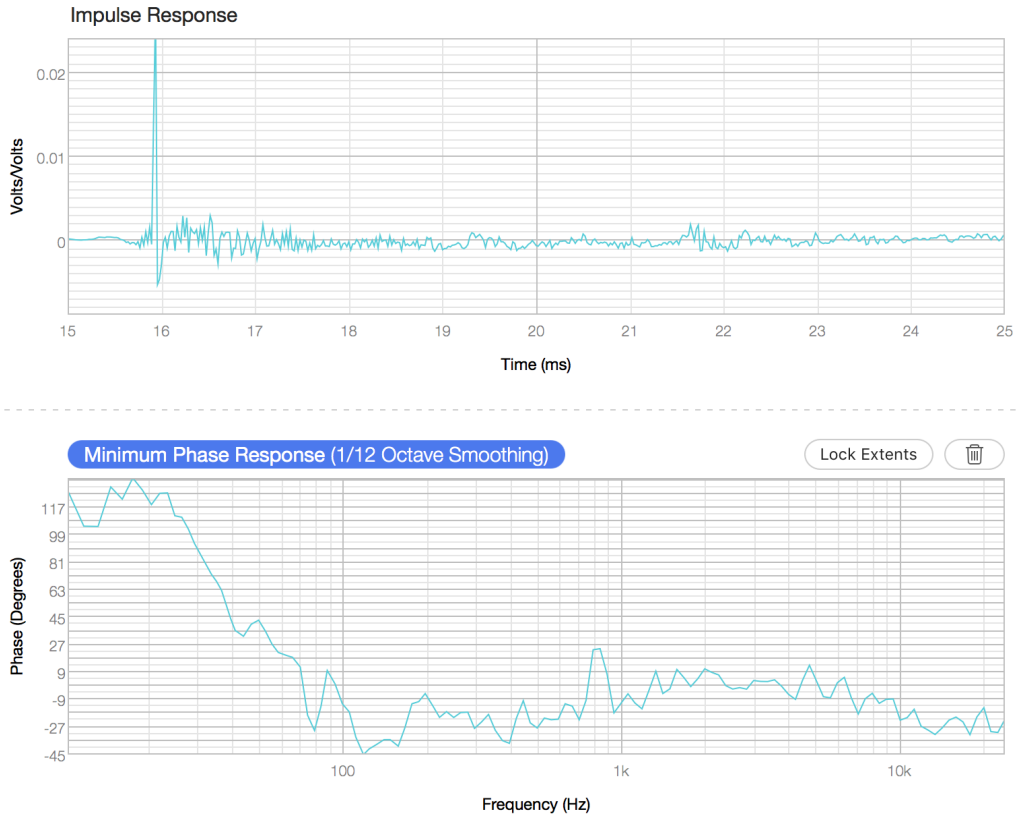
CROSSOVER DETAILS

I could have triamped these, but I decided to biamp instead. That dramatically reduced complexity because it enabled me to use a two way MiniDSP 2x4HD digital crossover. The bass amp drives both woofer and midrange, and the treble amp drives the tweeters. Crossover frequencies are 200Hz and 2KHz. The DSP aligns the impulse timing of the drivers to within 0.01 millisecond.

This necessitated adding a *very* simple series first order crossover between the 18" woofer and the 8" midrange. A series crossover gives you fewer impedance problems than a parallel crossover. This is effectively a 6dB/octave crossover. However, 6dB crossovers are problematic because it's almost impossible in the real world to achieve 6dB – you almost always end up with something closer to 12dB.

12dB crossovers have too much phase shift, and I could hear the woofer and midrange fighting with each other. That's why I wired the midrange in reverse polarity, then compensated for the phase shift using a Finite Impulse Response DSP filter (Eclipse Audio software).

I also used FIR DSP correction on the tweeter. This solves phase shift problems and gives you an incredibly clean impulse response and you see below. This the impulse response for the entire system as a whole:



Impulse response should look like an upside-down T, and it does, with only a touch of overhang. And as you can see, the phase response is +/- 45 degrees from 40 Hz to 25 KHz with no polarity reversals or phase rotations. 99.5% of speakers would butcher the impulse. 99.5% of speaker designers ignore phase response and only give a shrug to impulse response.

It has long been asserted that you cannot hear phase anomalies, so it doesn't matter.

I've never understood that argument. Most audiophiles have arguments about stuff you *can* hear but can't measure… But why would you completely ignore a problem you can **easily** and **obviously** measure???

Answer: because phase shift is actually *very* hard to solve without DSP. So designers just wimp out on it and say it doesn't matter. With DSP it is solvable, though. And companies like Thiel, Vandersteen and Duntech built product lines around linear phase even with passive crossovers and earned well-deserved respect for doing so.

I believe impulse and phase information make a major contribution to stereo imaging and resolution. Even though hardly anyone can listen to a speaker and say "Hey dude, I think your tweeter had inverted polarity."

If your speakers have good impulse response, they will also image well. And having experimented extensively with all kinds of crossovers and slopes, I can attest that you *can* hear group delay and phase rotations of steep filters, especially below 1000Hz, and especially when you play well recorded drums. Impulse matters. I can hear it, my teenagers can hear it, and you can too.

How Do They Sound?

These are truly High Definition speakers because they reveal *everything.* Stereo images are incredibly detailed and holographic, much like celebrated mini monitors are famous for… except the stereo image is *huge*.

Most speakers, truth be told, make musical instruments sound like they are being played by people who are three feet tall. With the Live Edge Dipoles, a double bass sounds the *size* of a double bass. Instruments and performers sound *larger* than life, which is gratifying.

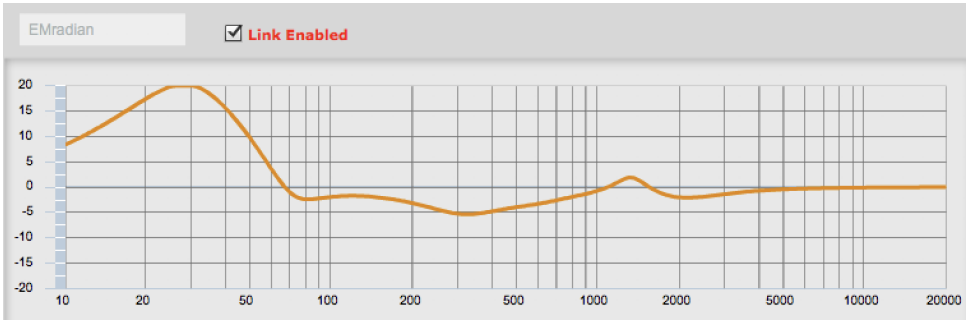
I long had a prejudice against horns. When I was 17 years old I heard the Klipschorns and although they were powerful and impressive, I thought they were terrible. Thick bass, ragged midrange and spitty highs. I was completely unimpressed.

Well… now that horns are designed with Finite Element Analysis… now that you can fix almost any horn coloration with DSP… these sound like Magnepans or electrostatics or high-end domes. (Except that planars and electrostatics cannot deliver the precision and impact with percussion that these can… not even close. Planar drivers wilt when you play heavy percussion. These excel.) Not to mention that planars and electrostatics have a narrow sweet spot and these sound great everywhere.

Maybe I could say they sound like electrostatics when you're playing choral music and they sound like Klipsch when you're playing ZZ Top or Mickey Hart. Seriously, these have the finesse of a KEF, B&W or Duntech, with the transparency of a Martin Logan, and the dynamic range of a Klipsch. With deeper bass than almost all of those brands.

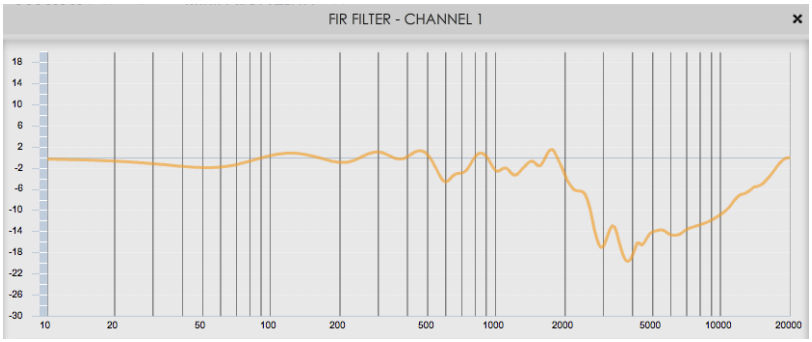
And the horns do not sound like horns *at all.* They just sound like great tweeters. And again, because of the Constant Directivity they image well everywhere in the room. Planars and electrostatics can't do that.

Below is the digital EQ curve that sounds best with these woofers:



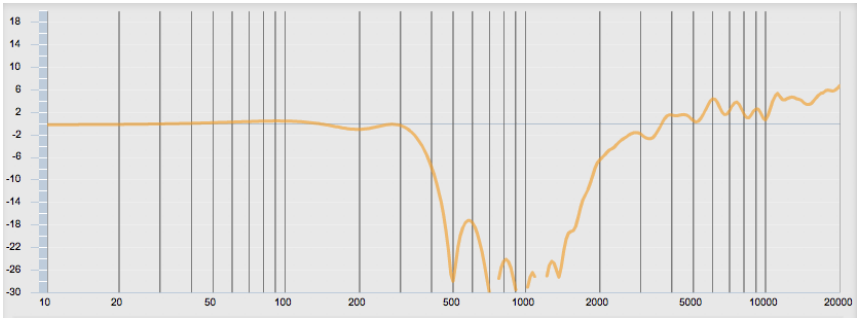
As you can see I have 20dB of boost at 29 Hz with a gentle roll off below that point. In my room, which is 12x14 feet, these can play as loud as I like on almost any music. As you can see from the other response curves, bass declines rapidly below 25Hz. Yes, there are a very few albums where you can tell that the dipoles are running out of steam at ultra-low frequencies. But on 95% of music these things shake the house.

The midrange EQ you see above only serves to correct some minor problems. The crossover function for the midrange is performed by this FIR DSP filter:

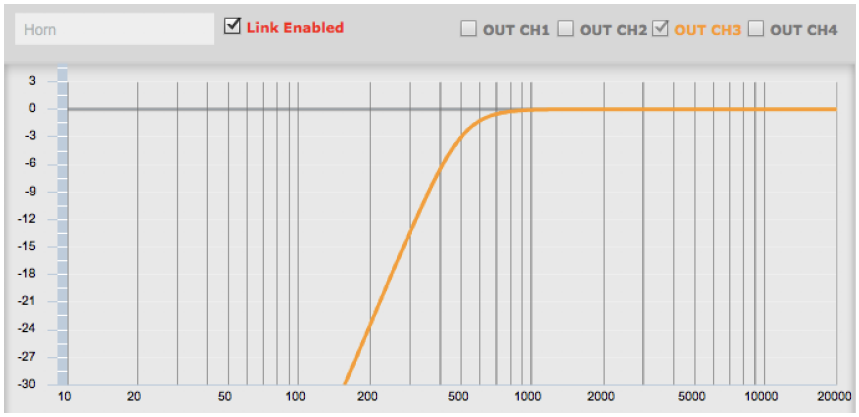


Together these filters tailor the 18” woofer + 8” midrange combination.

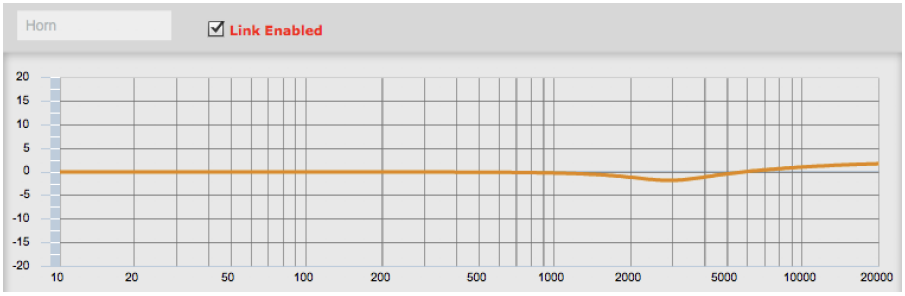
The tweeter is a combo of FIR filter, below, which only addresses the overlap with the midrange at 2KHz…



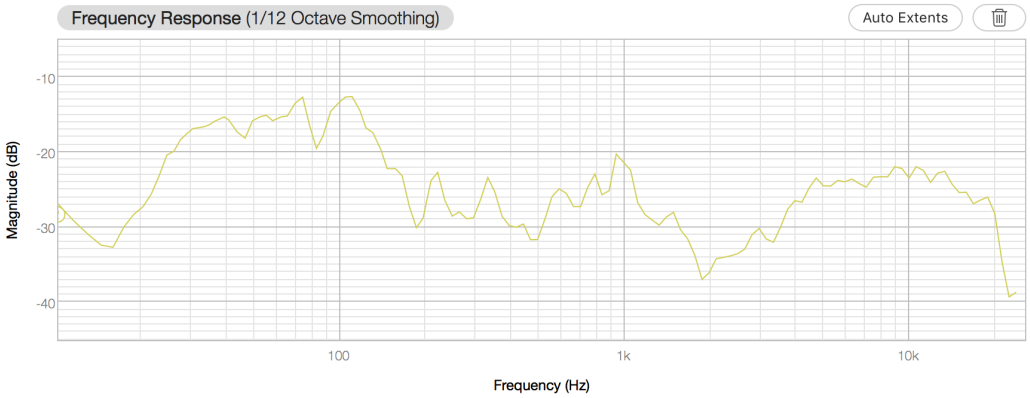
Which is combined with an 18dB/octave IIR filter to finish what the FIR filter couldn’t…



…And a little bit of EQ to dial in the exact tonality:

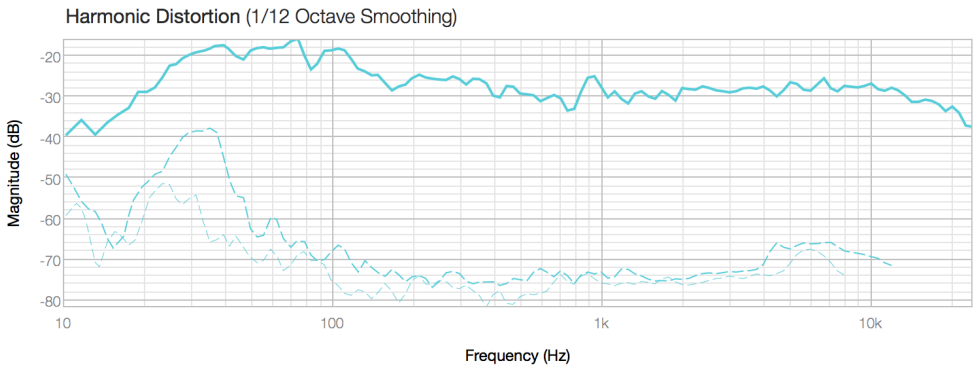


On the back is a PRV WG175PH horn tweeter. Its response is similar enough to the Radian Coaxial for my purposes. An L-Pad lets me turn it up louder, or turn it completely down. This curve is when set at 3 o'clock.

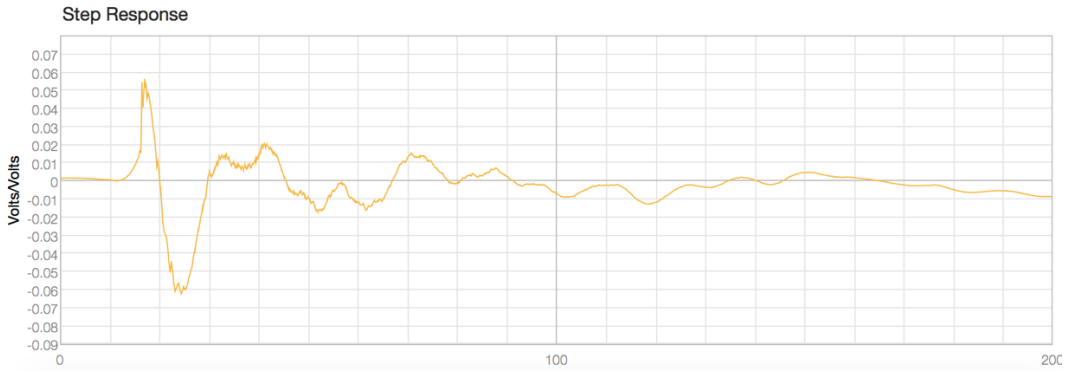


The above curve is taken on the backside of the speaker. I don't feel it's necessary to achieve perfect flat frequency response on the back, so I didn't try very hard, but it's reasonably good.

Below is harmonic distortion. Above 50Hz it's less than 1%.



Step response is the speaker's response to a sudden change from 0 volts to 1 volt. It shows you how much the woofer cone flops around before it comes to a stop. This is clean and very well damped which indicates tight, well controlled bass.



Active Crossover DSP Files

…are in a ZIP file at
https://tinyurl.com/liveedgedsp

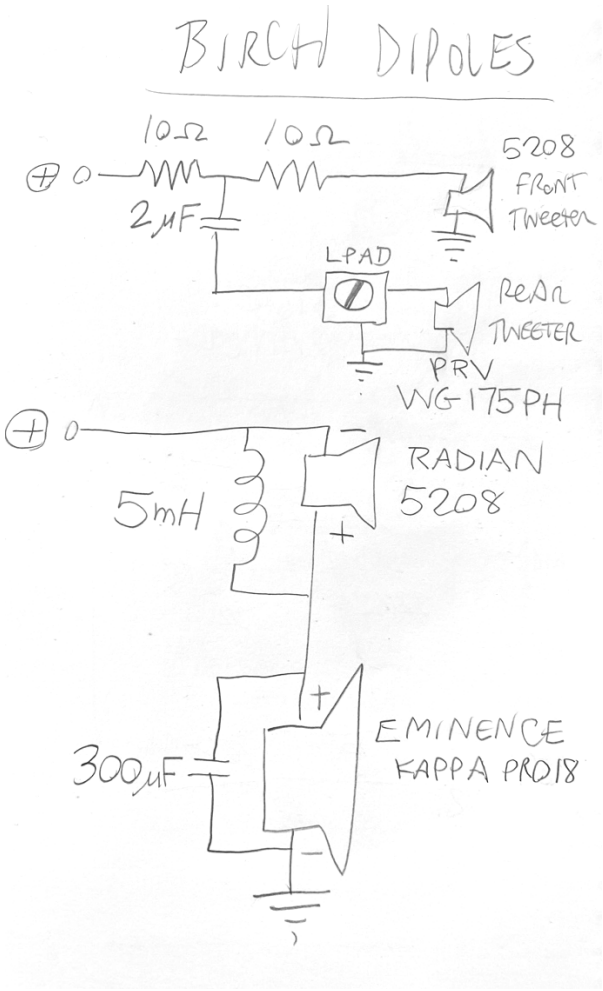
Important notes:

1) These will ONLY work in the MiniDSP 2x4HD. Any other DSP requires your own files.
2) These are based on actual measurements for *my* exact drivers. If you want to base these on the drivers you buy (you should!), you need to make your own measurements and convert them to a .bin file using a program such as Eclipse Audio FIR designer https://eclipseaudio.com/ and upload them to the DSP software.
3) You will have to adjust levels of the drivers, and perhaps even the time delay between them, to your situation.

Passive Crossover Schematic

Again the passive crossover just does the absolute minimum and the DSP does all the heavy lifting. All crossover parts were purchased from Parts Express:

5MH air core inductors
300uF is a combination of 200 uF electrolytic + 2x 47uF film capacitors
10 ohm 10-watt resistors
Dayton 50 watt L-Pads



Parts are all purchased from Parts Express, www.parts-express.com except for the Radian Coax, which I bought from www.radianaudio.com.

2 Eminence Kappa Pro 18LF 18” woofer
2 Radian 5208 8” coax mid-woofer with 16 ohm tweeter
2 PRV WG175PH horn tweeter
4 Binding Posts for speaker cables
2 L-Pad Part #260-255
1 MiniDSP 2x4 HD digital signal processor

You can use these with up to 1000 watts per channel of power; however below 50 Hz the power handling is realistically about 100 watts. That should hardly matter because most people will never end up using more than maybe 25 watts of actual power. They produce 95+ dB for one watt.

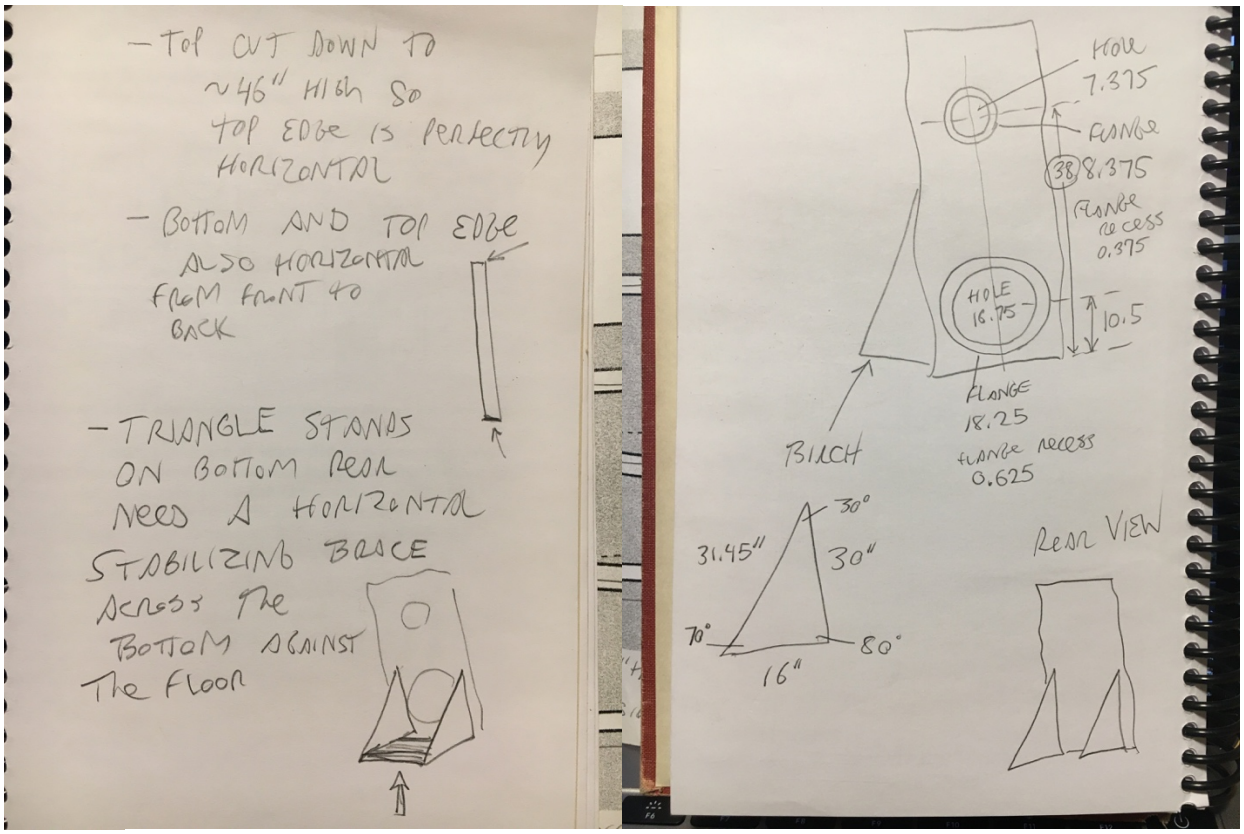
If you seriously intend to use 1000 watts and you really want to listen at 120dB, I recommend adding a subwoofer at about 80 Hz. I also recommend changing the crossover capacitors from 300uF to 100uF, which will raise the crossover frequency from 200Hz to 400Hz, shifting the burden away from the 8” midrange to the 18” woofer.

CABINETS

I bought slabs of birch from Big Red Sawmill in Nebraska. You can use any kind of wood or other material you like. I bet you could find some really cool applications of reclaimed wood. When I bought mine, I didn’t realize

that the panels were just a l-i-t-t-l-e too narrow to comfortably accommodate the support structure behind the 18” woofers.

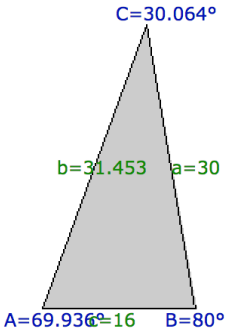
I hired Seth Cothron in Chicago to build the cabinets (instagram.com/studio38designs and he’s very skilled and easy to work with) and all I gave him was some sketch drawings and circles drawn on the wood:



Acute Scalene Triangle

Side a = 30
Side b = 31.4531
Side c = 16

Angle ∠A = 69.936° = 69°56'10" = 1.22062 rad
Angle ∠B = 80° = 1.39626 rad = 4/9π
Angle ∠C = 30.064° = 30°3'50" = 0.52471 rad



Area = 236.35386
Perimeter p = 77.4531
Semiperimeter s = 38.72655

Height h_a = 15.75692
Height h_b = 15.02897
Height h_c = 29.54423

Seth proceeded using his artistic sensibilities and a few weeks later sent me this stunning photo:

I took one look at those and I said, “Seth, these are GORGEOUS… but there’s only one problem… you weren’t supposed to cut those circles into the rear triangle pieces. Those make a huge leak that will cut down my bass response!” (Those holes would cost almost an octave of bass.)

Being the resourceful guy that he is, he created curved discs out of cardboard and fitted them to plug the holes. You can see them in this photo:

I was very happy with this solution, and because the cardboard is curved, thus stiff (and because there is not a great deal of pressure as there would be in a reflex box) no sound leaks through and they do not appear to color the sound.

When you build them, I suggest you choose wood that's an inch or two wider, thus giving you more room to work with. Seth cut grille frames with a CNC machine and I stretched fabric over those to complete the speakers.

My 16-year-old son sits down with me every week or two and we listen to a symphony together. Since Seth delivered the finished frames to me the second week of March, right before the COVID-19 lockdown, this has been my quarantine project. I have enjoyed *many* hours of listening to every kind of music you can imagine… the best speakers I've made in 38 years.

I encourage you to spin off your own variation on this project!

Perry Marshall, May 17, 2020, Chicago