LCCAM 10.3

A full range 3-way
Low-Cost Compact Active Monitor
10” woofer
5” midrange
Soft dome tweeter

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LCCAM 10.3

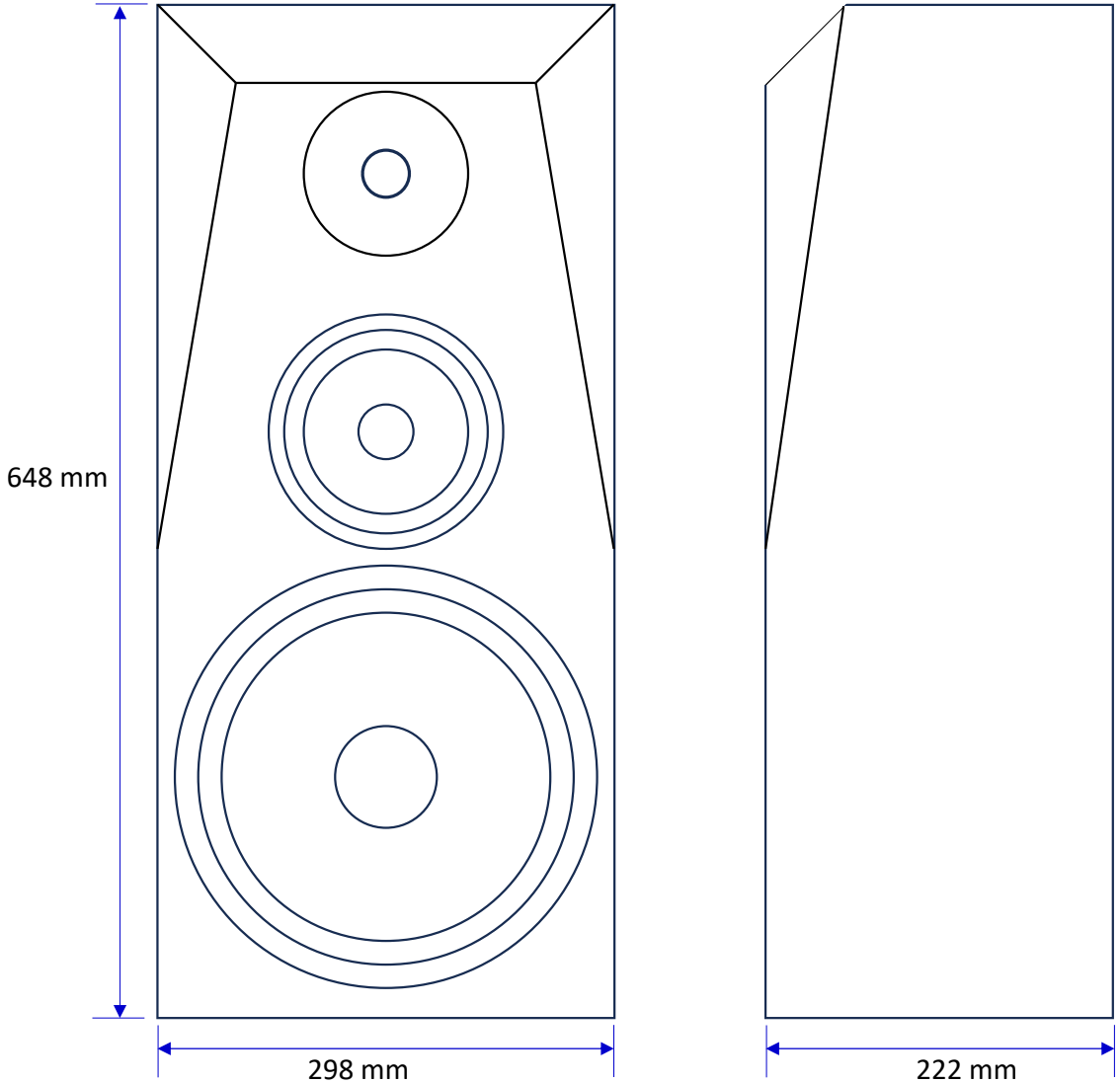
Low-Cost Compact Active Monitor
A full range 3-way
10” woofer, 5” midrange,
1” soft dome tweeter

Cabinet External Dimensions
648mm x 298mm x 222mm
(25.5” x 11.75” x 8.75”)

Weight 38 lb / 17.3 kg

26.2-liter enclosed volume
20.5-liter woofer volume

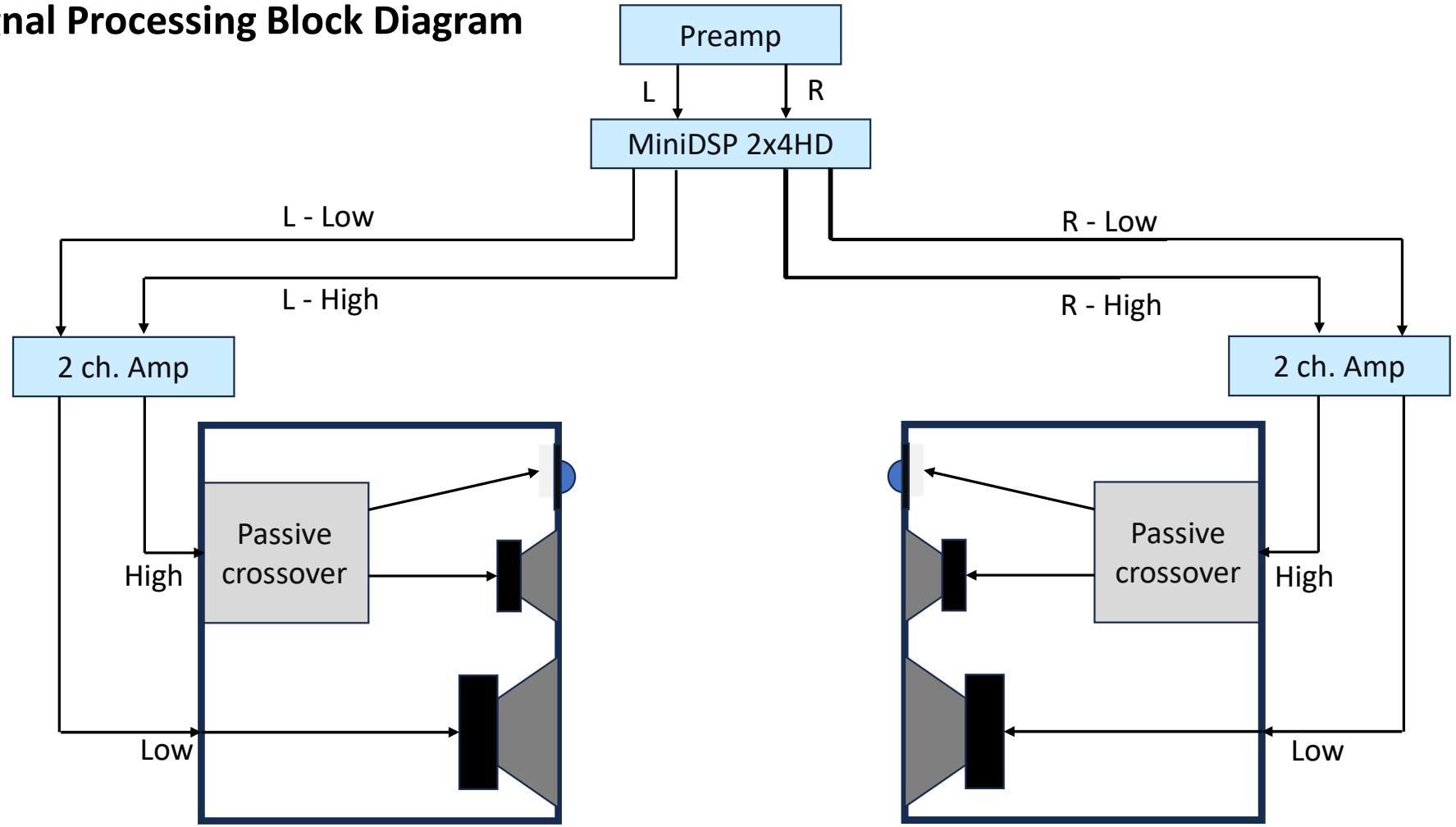
Drivers
Dayton RS270-4
SB15NBAC30-4
SB26STAC-C000-4



System Description

- Active/passive system with DSP using MiniDSP 2x4HD
  - Enables the end user to be in control of final voicing and room EQ
- 3-way design with crossovers at 300 Hz (2^{nd} order) and 2.1 kHz (4^{th} order)
  - **Active** DSP filter at 300 Hz
  - **Passive** internal filter at 2.1k
  - **Active** DSP response tailoring over the entire bandwidth
- A 2 channel amplifier is required for each speaker
  - Any reasonable 2-channel amplifier could be used. It may be attached to the speaker, or kept as a separate component.
- Sealed Box woofer design, with Linkwitz Transfer EQ to extend bass response to 38 Hz (-3 dB) and 24 Hz (-9 dB)
- Diffraction control and optimal baffle design provide a smooth, even Directivity Index (DI) and power response.

Signal Processing Block Diagram



Low-Cost

- Driver costs: $263 per side*
  - Drivers selected for their ratio of high performance to cost
- Electronics costs: $258 per side*
  - Affordable generic 2-channel amps are used
  - A single MiniDSP 2x4HD unit is shared between the two speakers
- This system has a low cost compared to other active 3-way speakers

* 2023 retail prices

Low-Cost

LCCAM System Cost, not including cabinets			
Item	**Cost ($)**	**Quantity**	**Net cost ($)**
Dayton RS270-4 (10" woofer)	130	2	260
SB15NBAC (5" driver)	80	2	160
SB26STAC (tweeter)	53	2	106
Passive Crossover parts	100	1	100
MiniDSP 2x4HD	235	1	235
2-ch class D amp, 100 W/ch	90	2	180
Total			**1041**

2023 retail prices

Compact

- Enclosed volume is 26.2 liter
  - Significantly less than other speakers with a 10” woofer and an F3 of 38 Hz and F9 of 24 Hz
- Near minimum possible width
  - Cabinet width is only slightly wider than woofer diameter
- Near minimum possible height
  - Height is only 126 mm taller than the three drivers stacked vertically
- Shallow depth of 222 mm
- Footprint of 222 x 298 mm (8.75” x 11.75”) is only slightly larger than a sheet of printer paper
- 17.3 kg / 38 lb weight is easily managed by one person

Performance Optimized with Simulation and Prototype Measurements

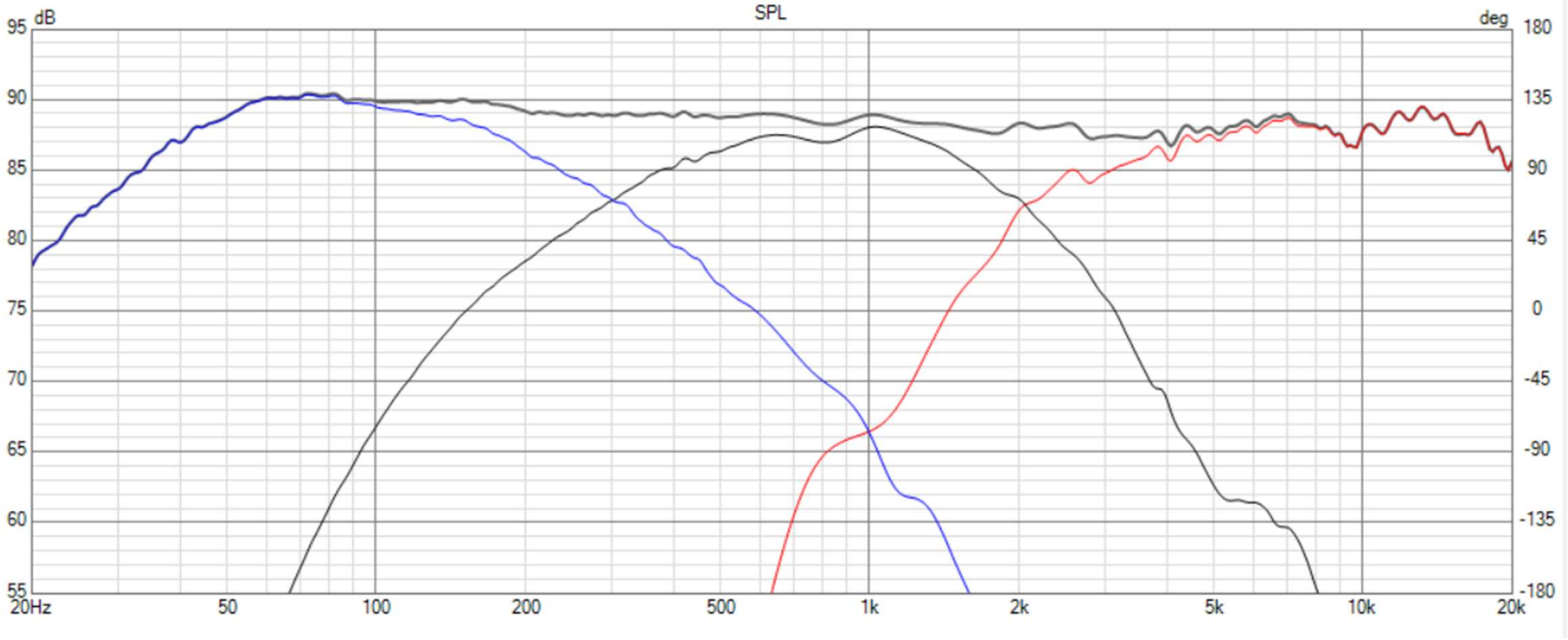
- VituixCad2 used throughout design process
  - optimize sound power, Directivity Index, Early reflections, and on-axis response
- Prototype cabinet was constructed
  - Collect data on Midrange + Tweeter
  - Used to optimize baffle layout, dimensions, and bevels
  - Used to assess several tweeter options

Active Speaker Flexibility with Passive Filter Advantages

- DSP allows the end user to control final voicing in their listening environment
- DSP supports room EQ such as Dirac or REW
- Analog passive filter at 2.1 kHz enables lower cost 2 channel electronics
- Passive notch filter at 9 kHz suppresses midrange resonance better than an active filter
- Aluminum cone woofer and midrange operate pistonically within their operating range (passband)

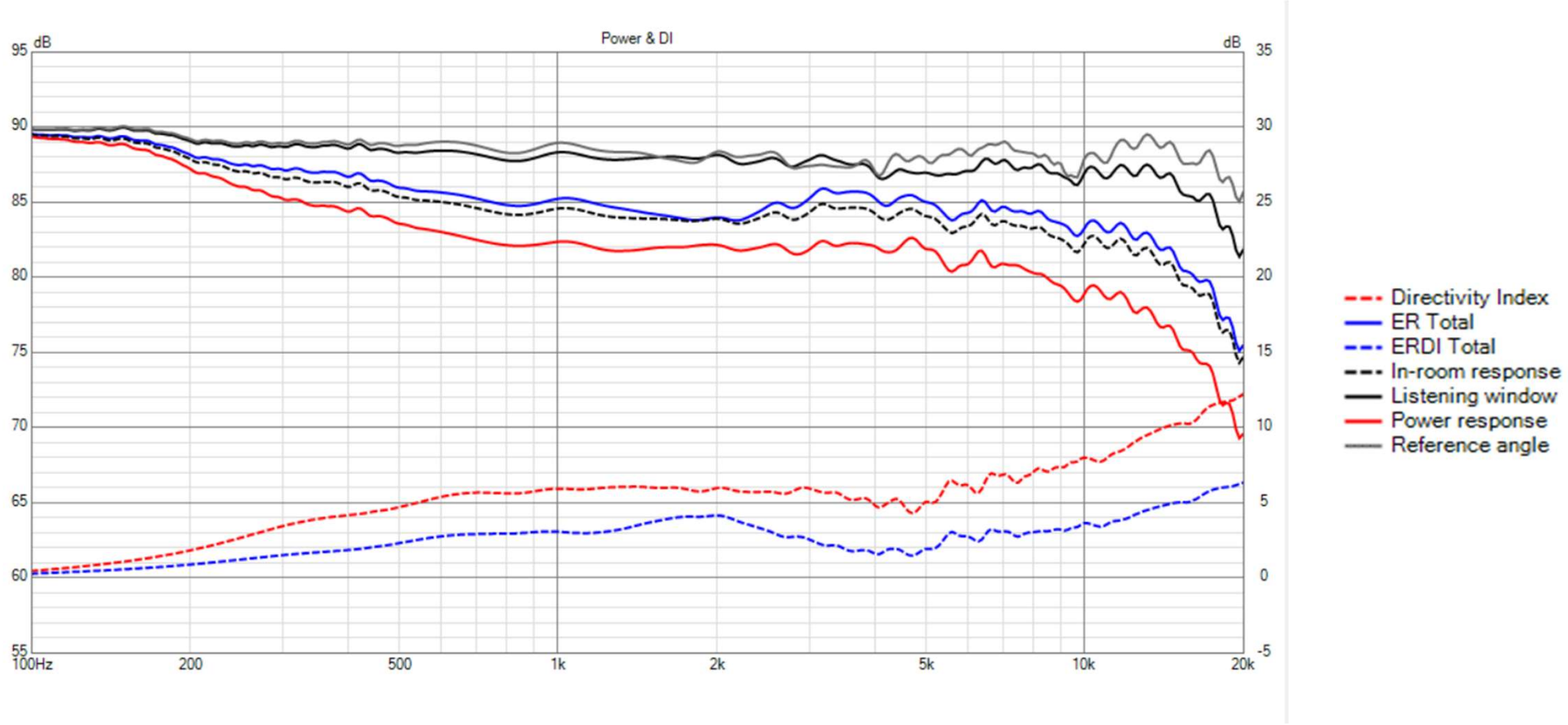
LCCAM 10.3 Performance

On Axis response of system and drivers



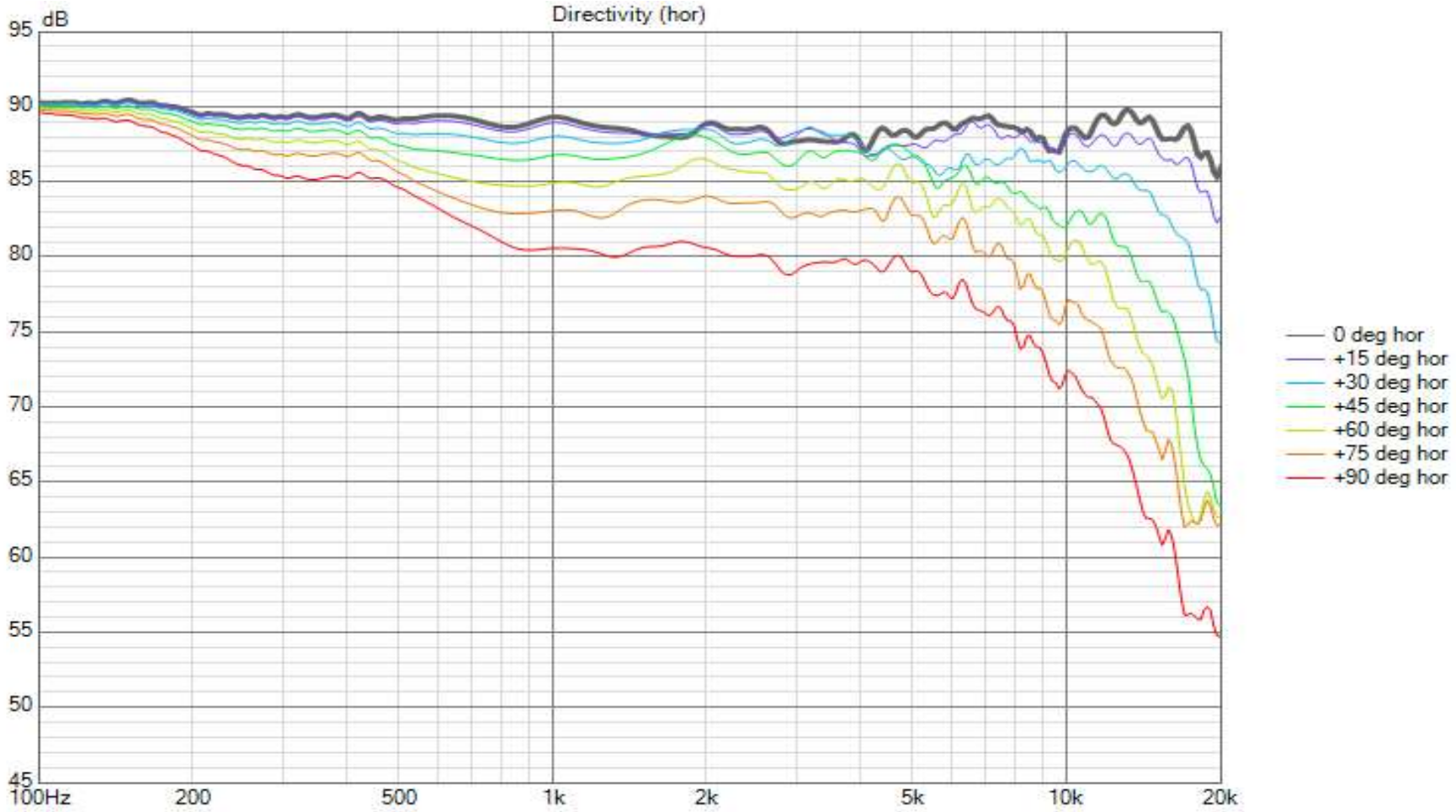
-3 dB at 38 Hz
-9 dB at 24 Hz

Power and DI response

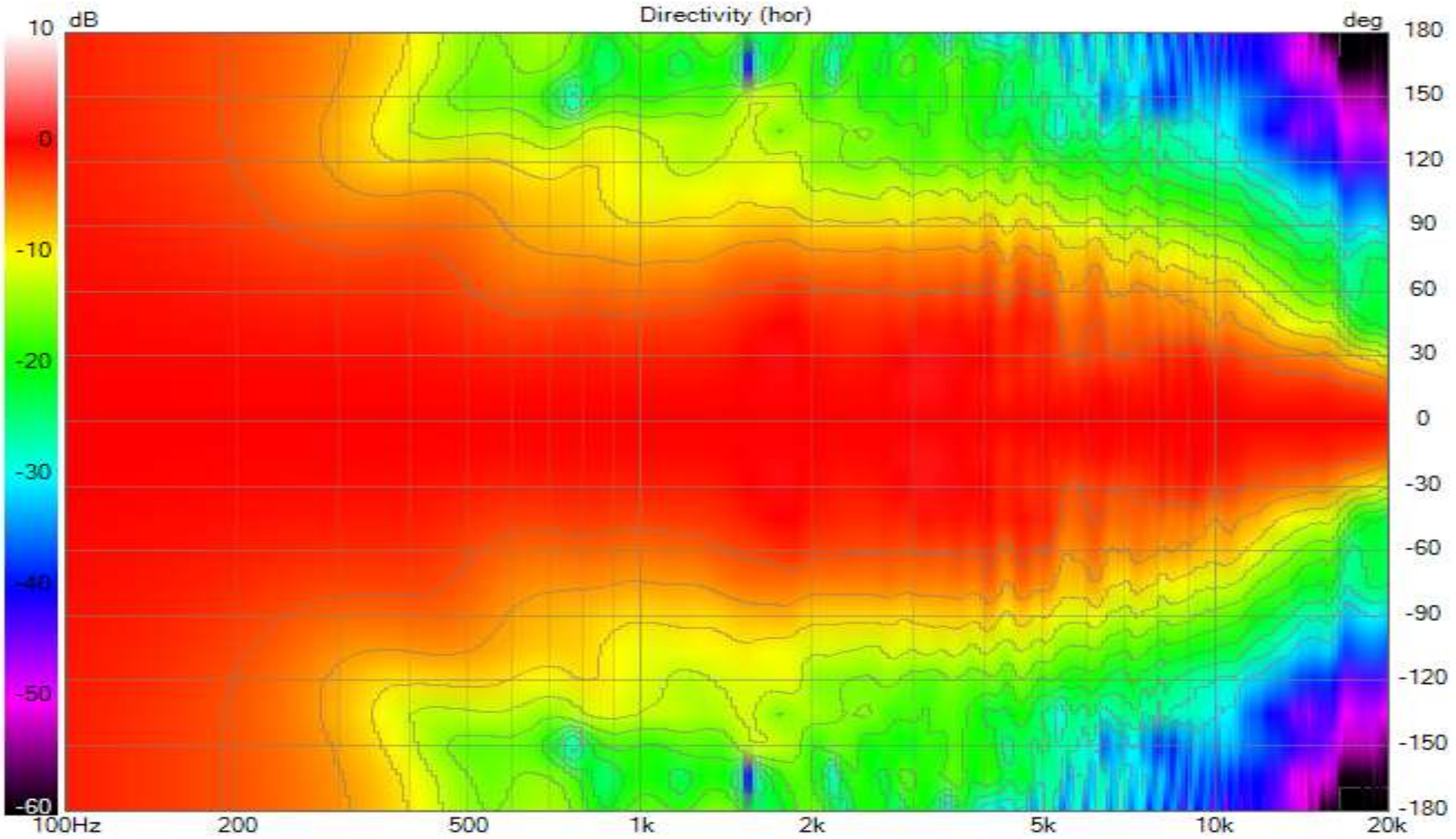


Optimal compromise between on-axis, listening window, predicted in-room, and power responses

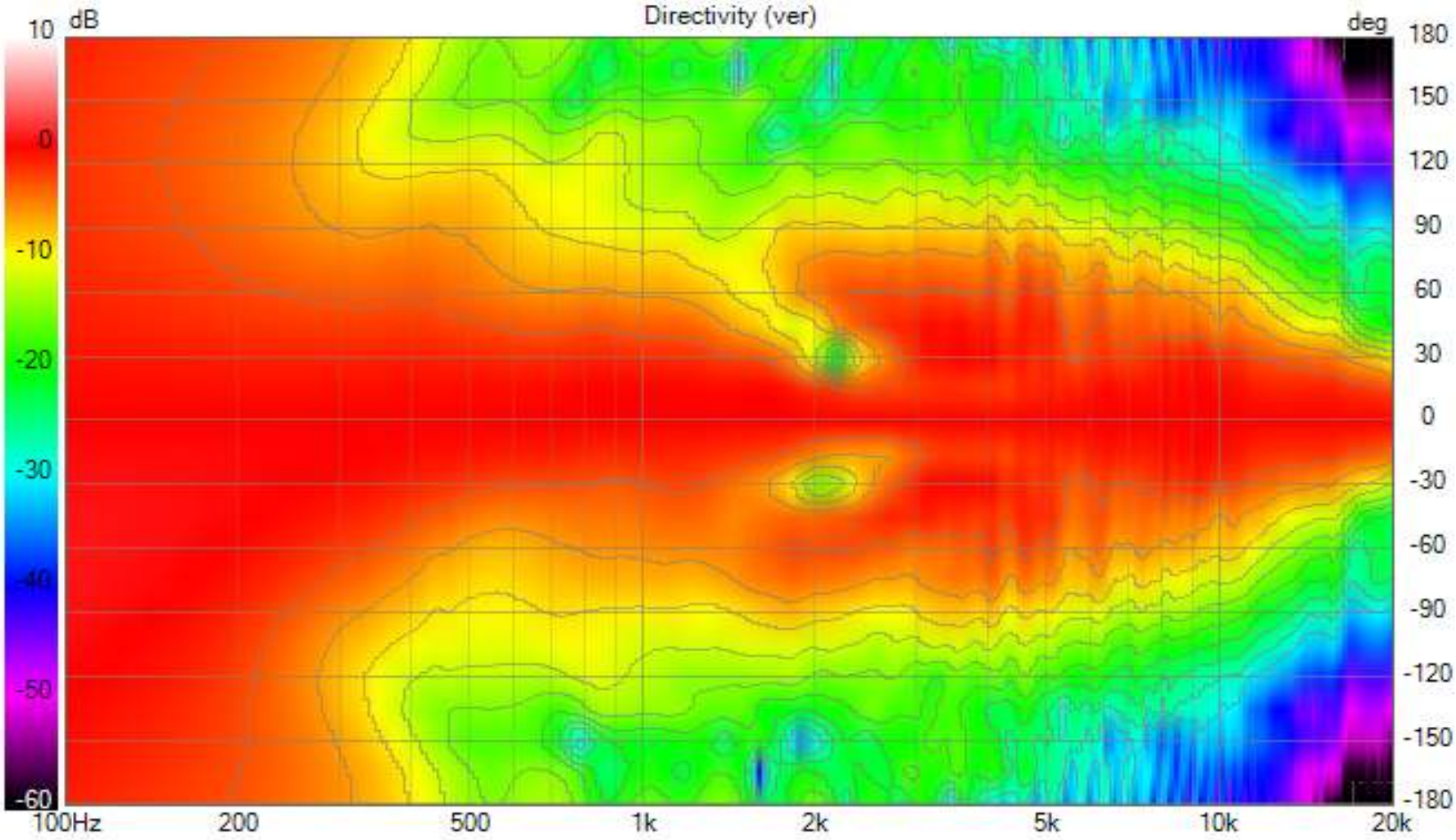
Horizontal Polar Response



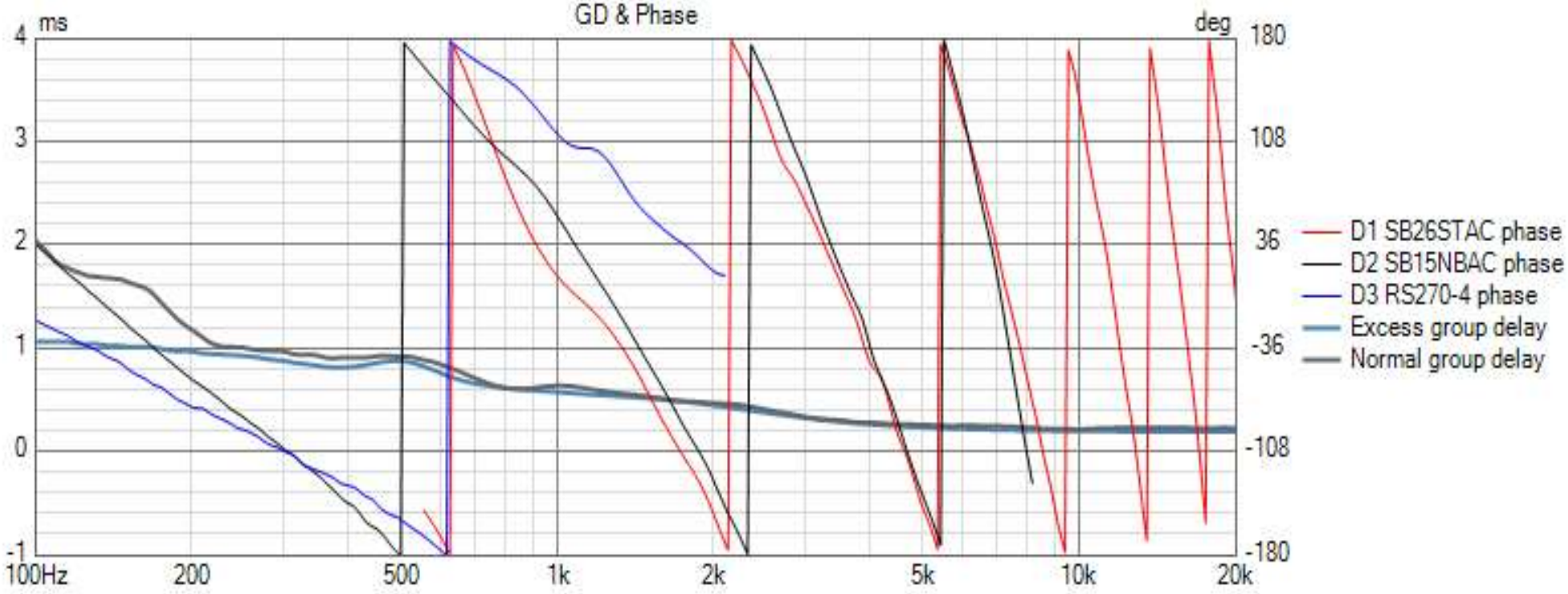
Horizontal Polar Response



Vertical Polar Response

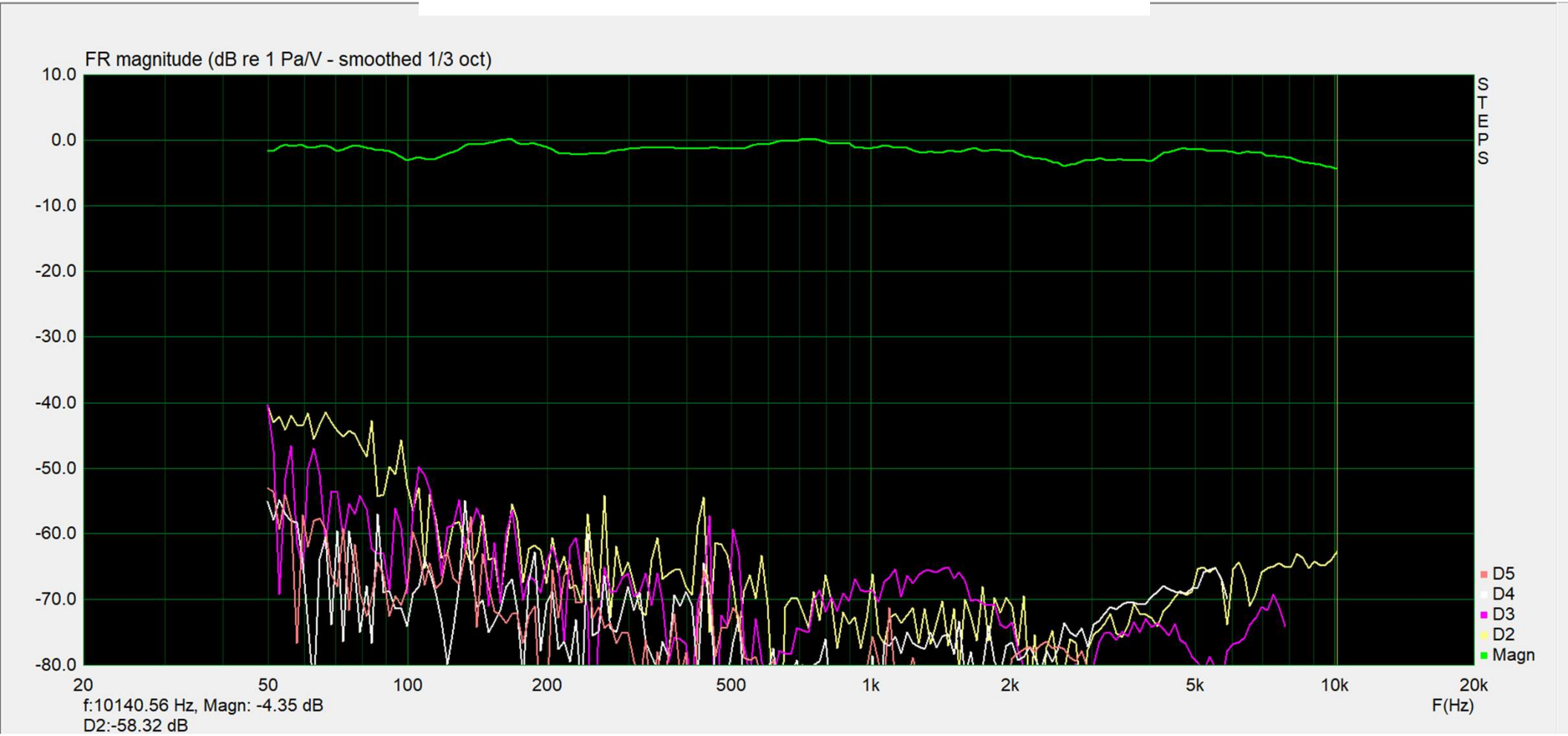


Group Delay and Phase



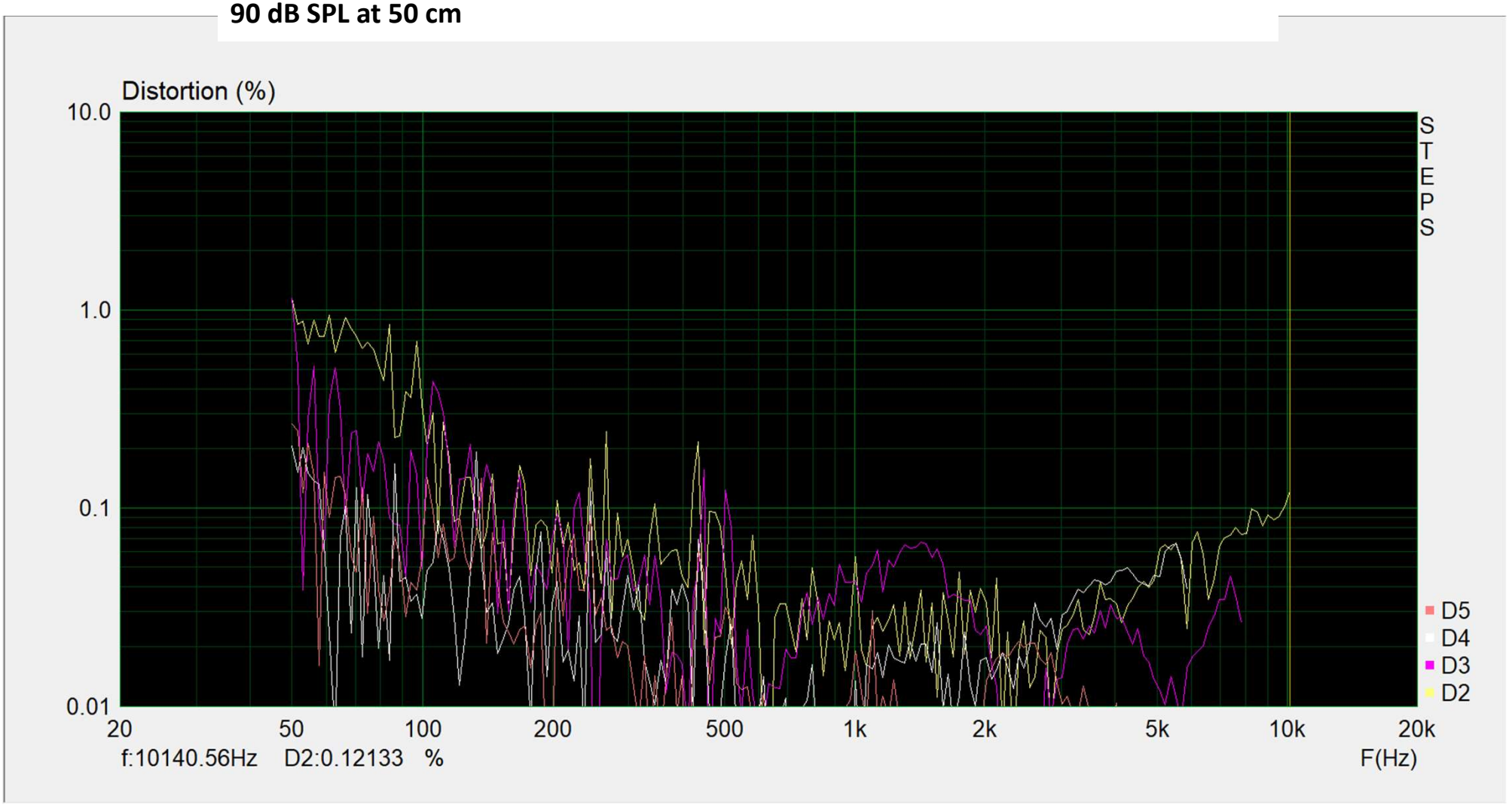
Harmonic Distortion, HD2 – HD5

90 dB SPL at 50 cm

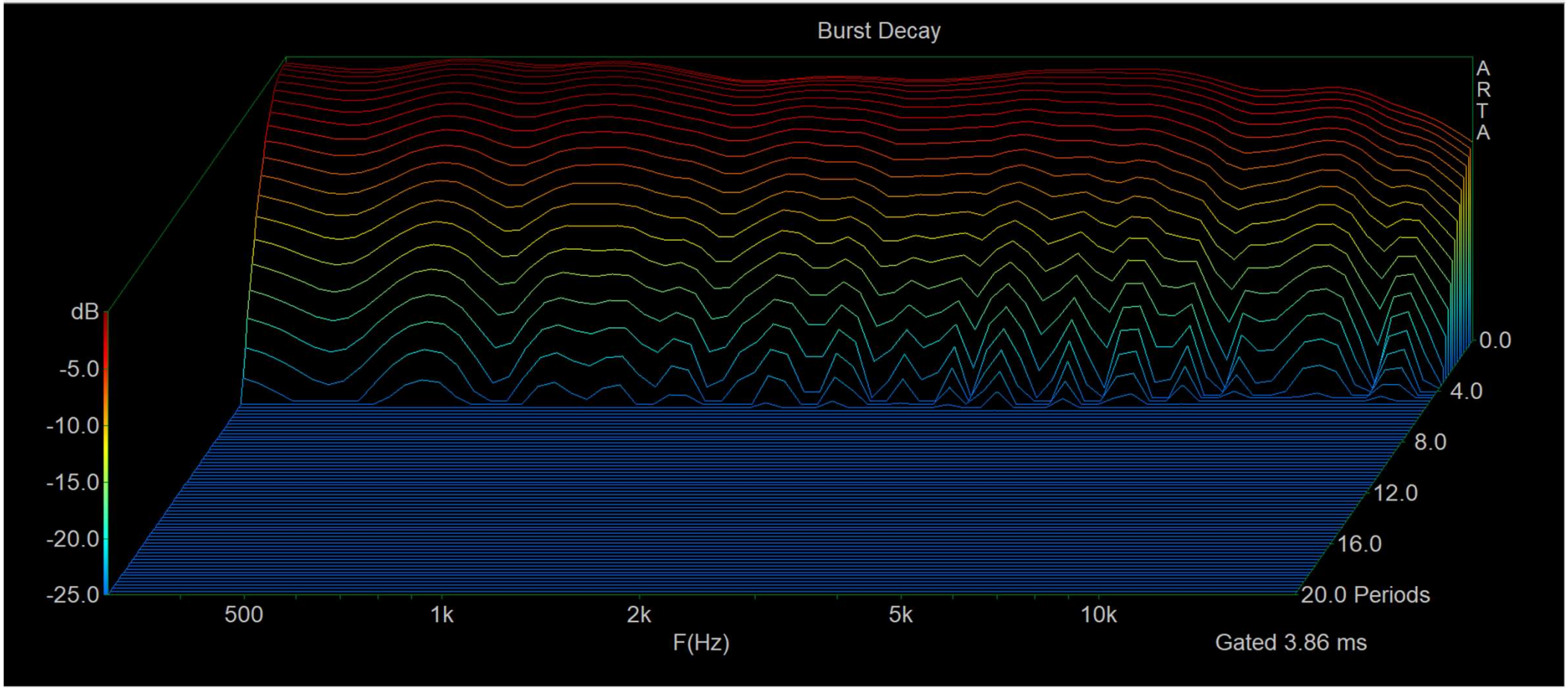


Harmonic Distortion, HD2 – HD5 as Percentage

90 dB SPL at 50 cm



Burst Decay Plot



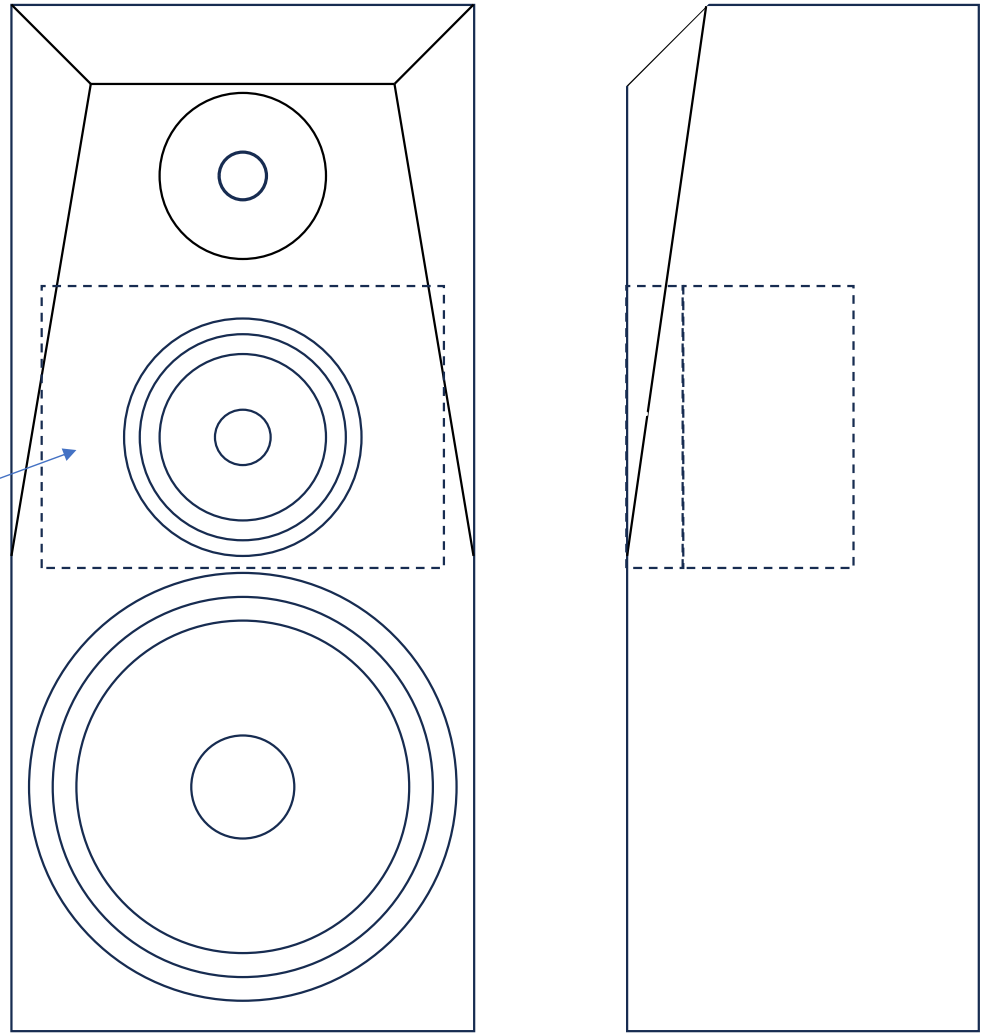
Cabinet Construction

Cabinet Internal Dimensions
610mm x 260mm x 165mm
(24” x 10.25” x 6.5”)

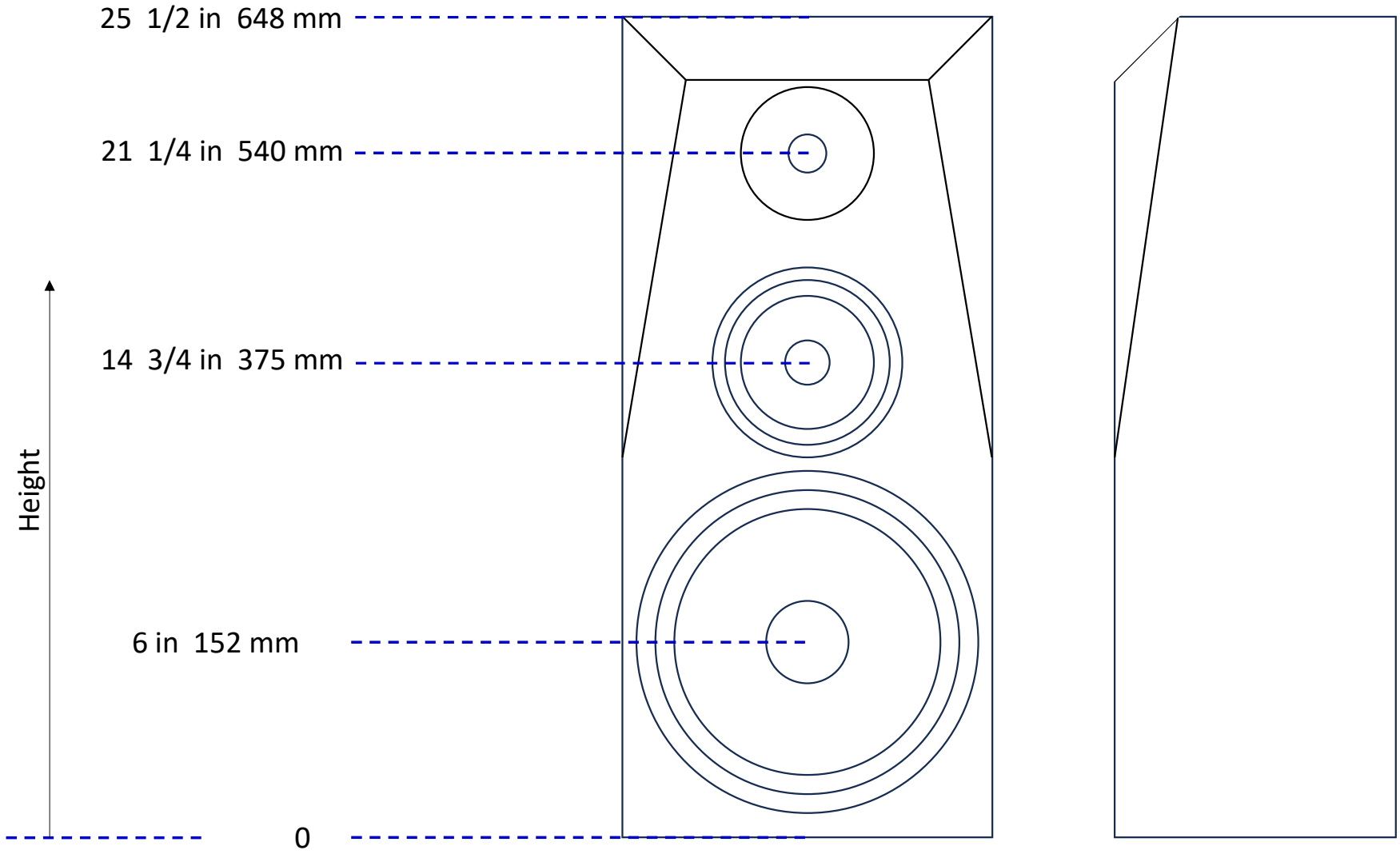
26.2 liter enclosed volume
20.5 liter woofer volume

Cabinet External Dimensions
648mm x 298mm x 222mm
(25.5” x 11.75” x 8.75”)

Mid Box
260mm x 191mm x 114mm
3.8 l net volume, 5.7 l gross



1”=100mm


25 1/2 in 648 mm
21 1/4 in 540 mm
14 3/4 in 375 mm
6 in 152 mm
0
Height

Panel Dimensions

Panel Dimensions						
		Inch			mm	
Inner baffle		10.25	24		260	610
Rear		10.25	24		260	610
Top/bottom		10.25	8		260	203
Outer baffle*		11.75	25.5		298	648
Side panel*		8	25.5		203	648
* Actual dimensions will depend on the sheet material thickness. These panels will need to be trimmed to fit						

A pair of speakers will require a 4’ x 8’ sheet of material

Cabinet Material

¾” (18 mm) cabinet grade sheet material is used for construction

I used Canadian birch plywood (5 core plies of popular with 2 birch veneer face plies)

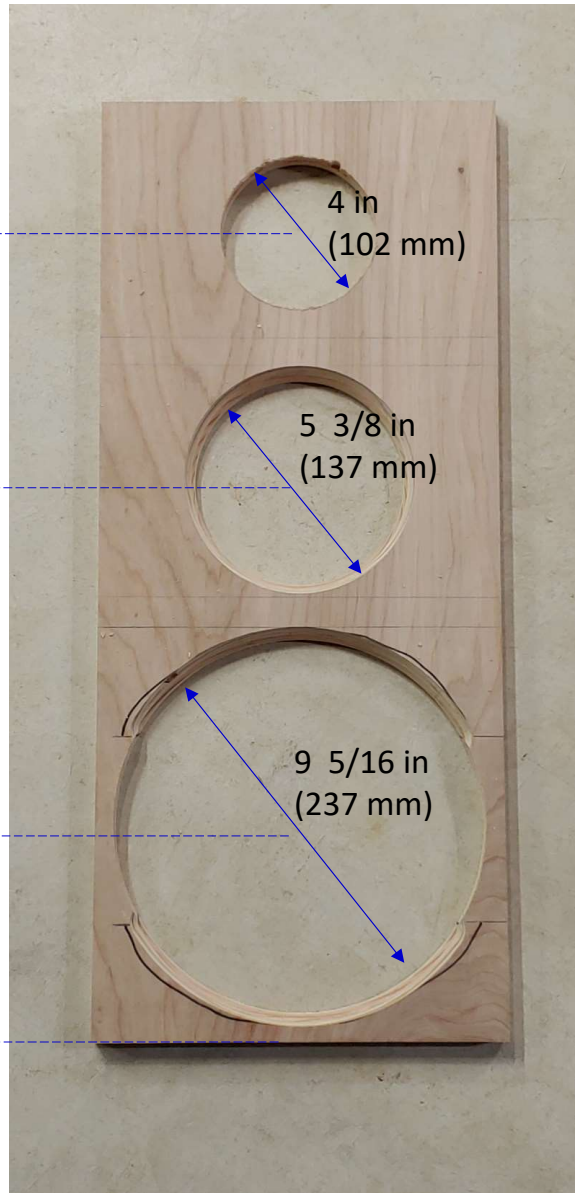
Alternate materials could be MDF, HDF, or Baltic Birch plywood.

Inner Baffle

Midrange hole with chamfer

Woofer hole with chamfer,

Region near edge not chamfered
Due to short edge distance



Inner Baffle

10 ¼ x 24 in
(260 x 610 mm)

Height measurements are relative to inner baffle

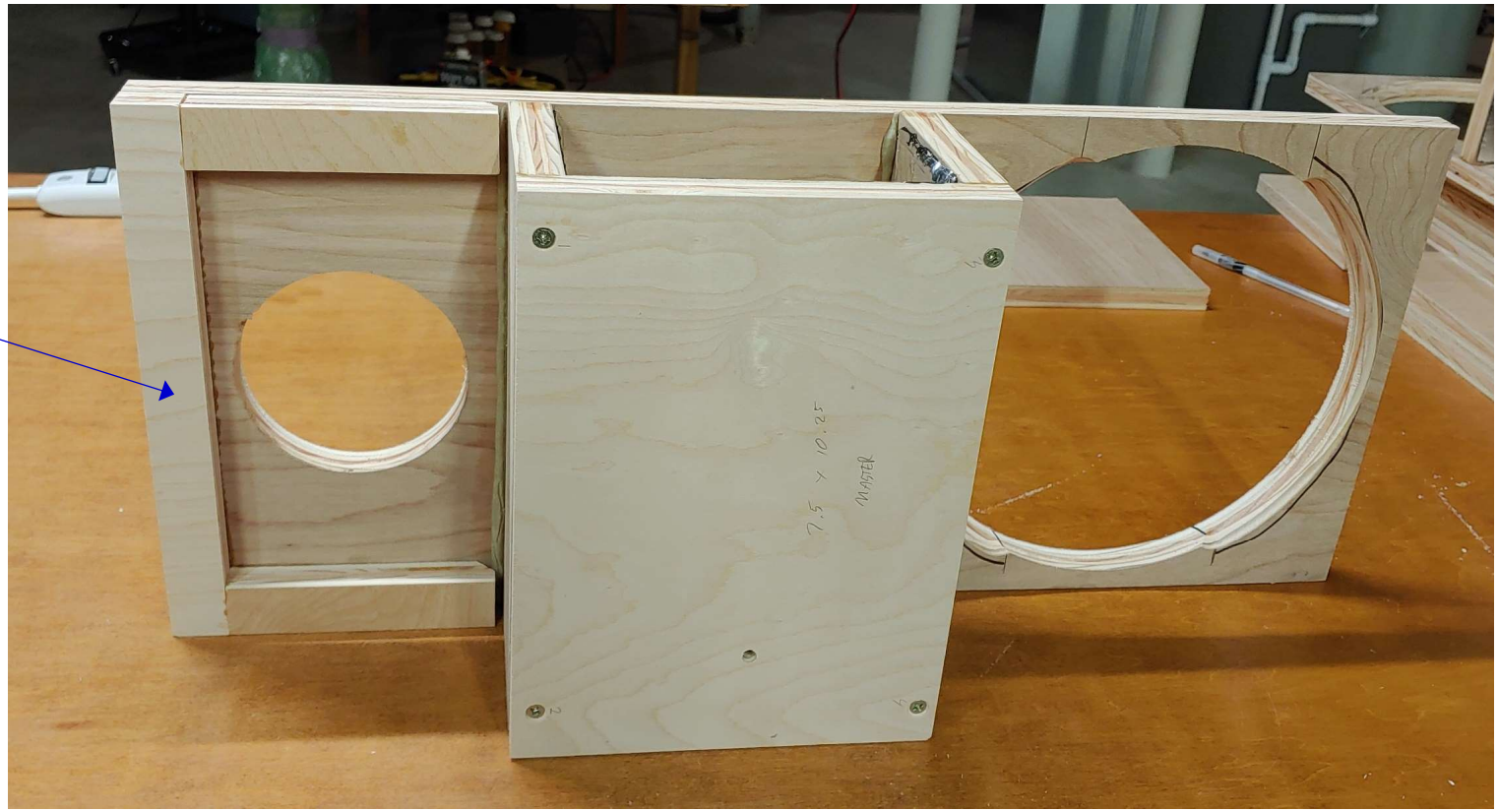
Midrange hole chamfered

Woofer hole partially chamfered

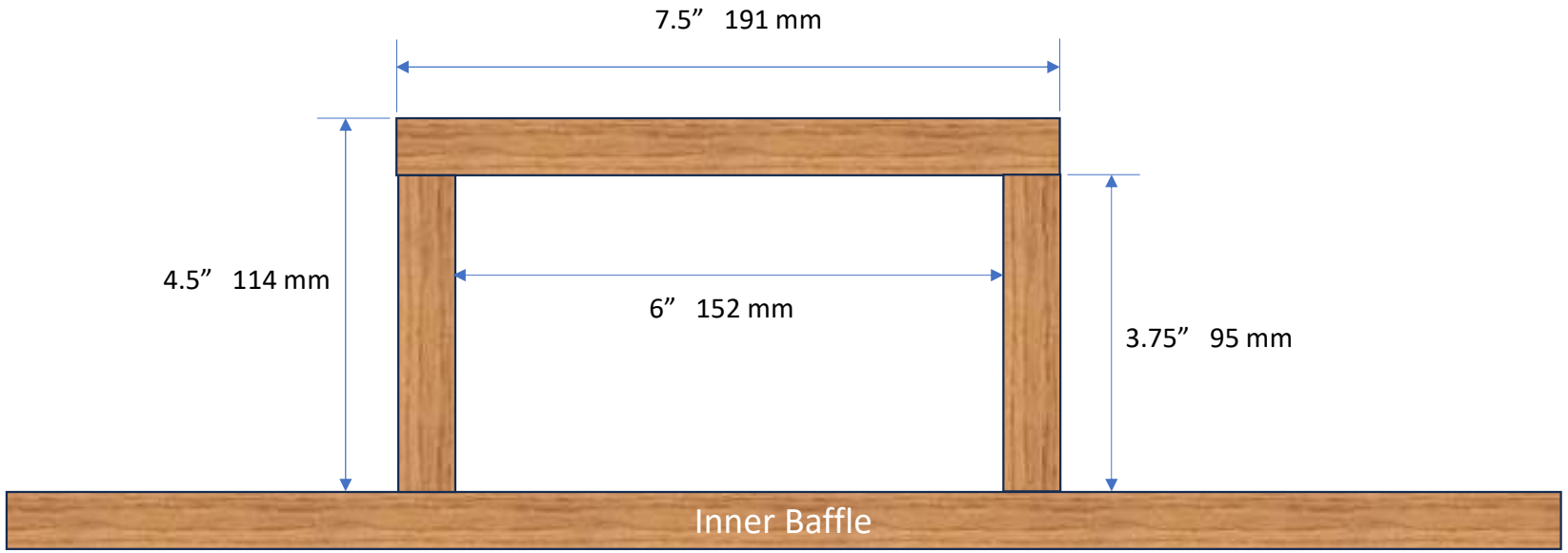
Region near edge not chamfered
Due to short edge distance

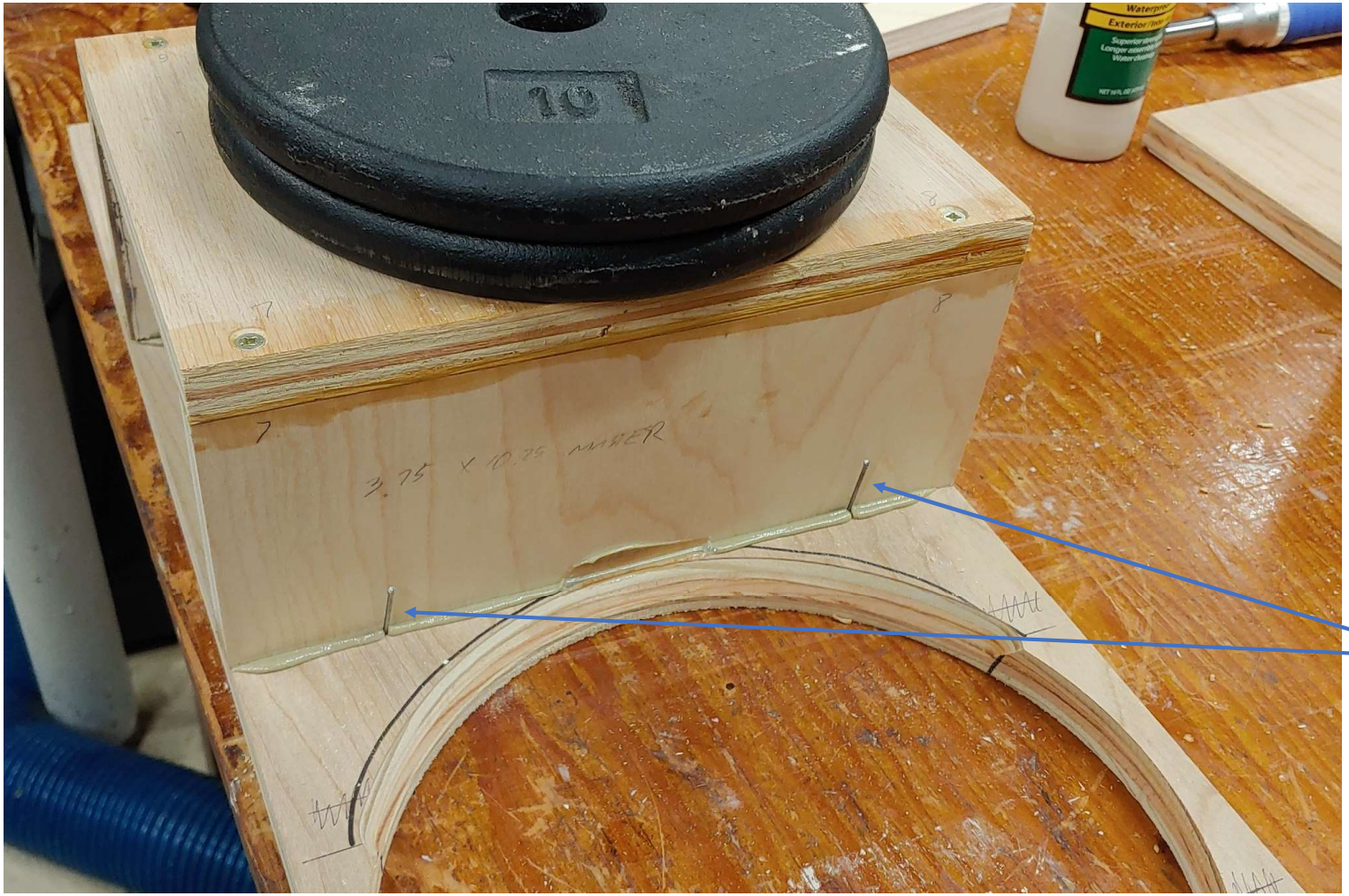
Midrange sub-enclosure is full width. Screws were used during assembly for convenience. Screws may be used (or not) at the discretion of the builder.

Corner gussets around tweeter provide additional thickness for the 50 mm wide bevels



Midrange Enclosure





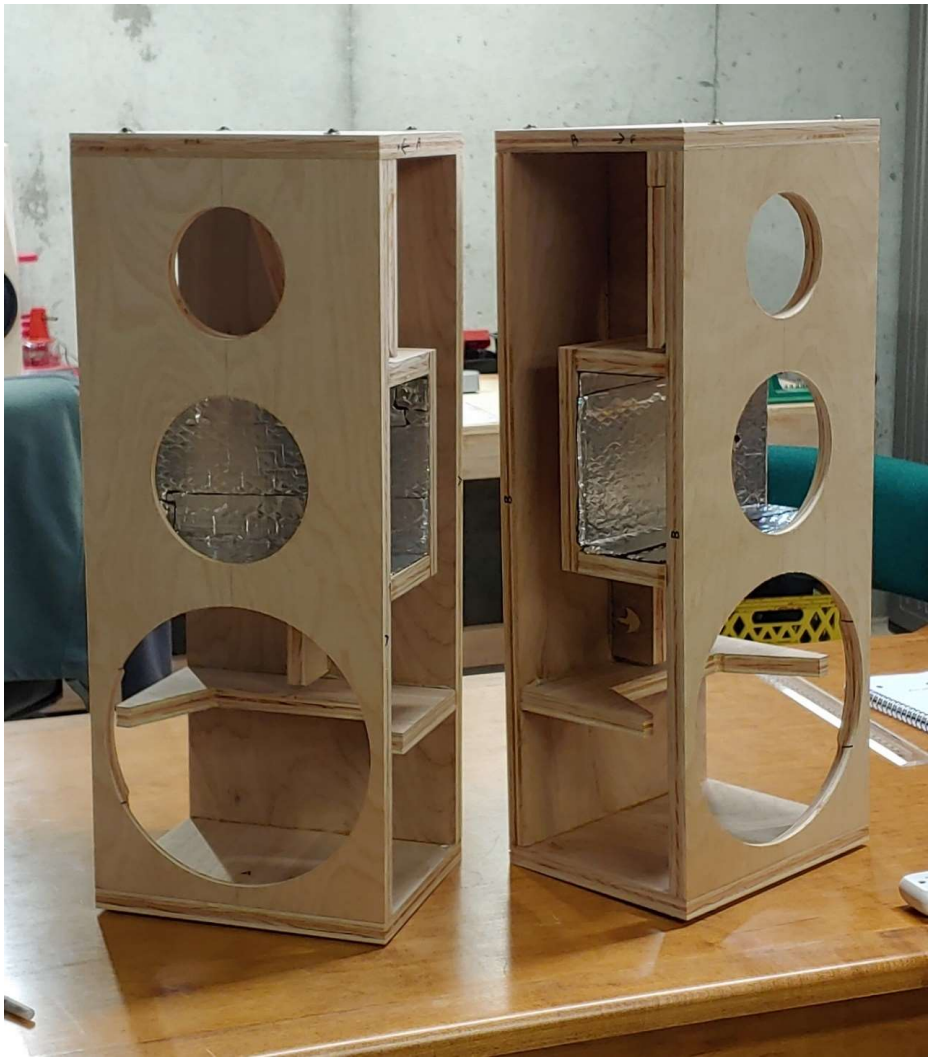
Adhesives

I used Titebond wood glue where the joints were tight fitting.

When I needed gap filling or high initial adhesion, I used latex or urethane based construction adhesive.

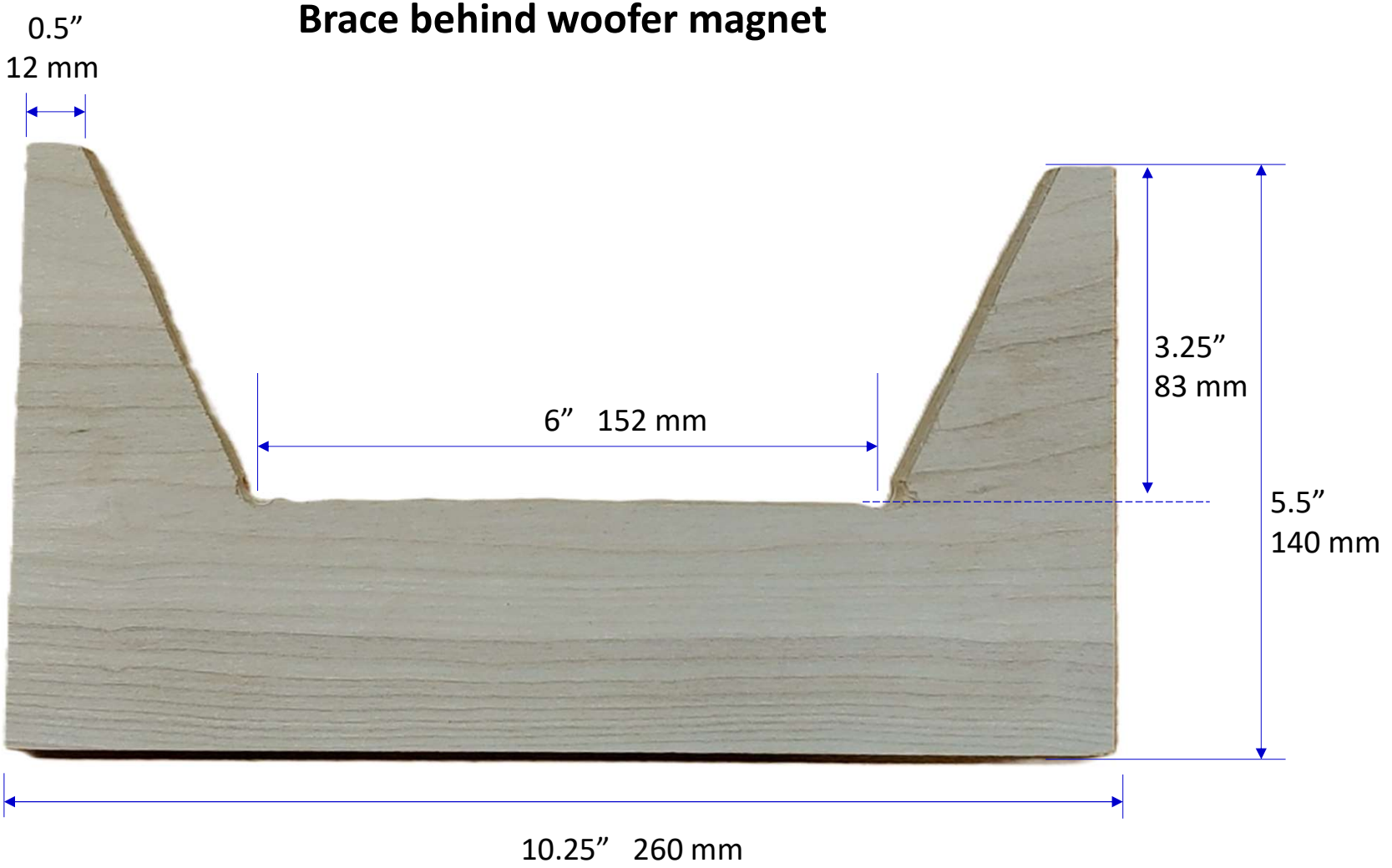
Small nails can be used as locator pins for easy alignment

After adhesive sets, nails are removed

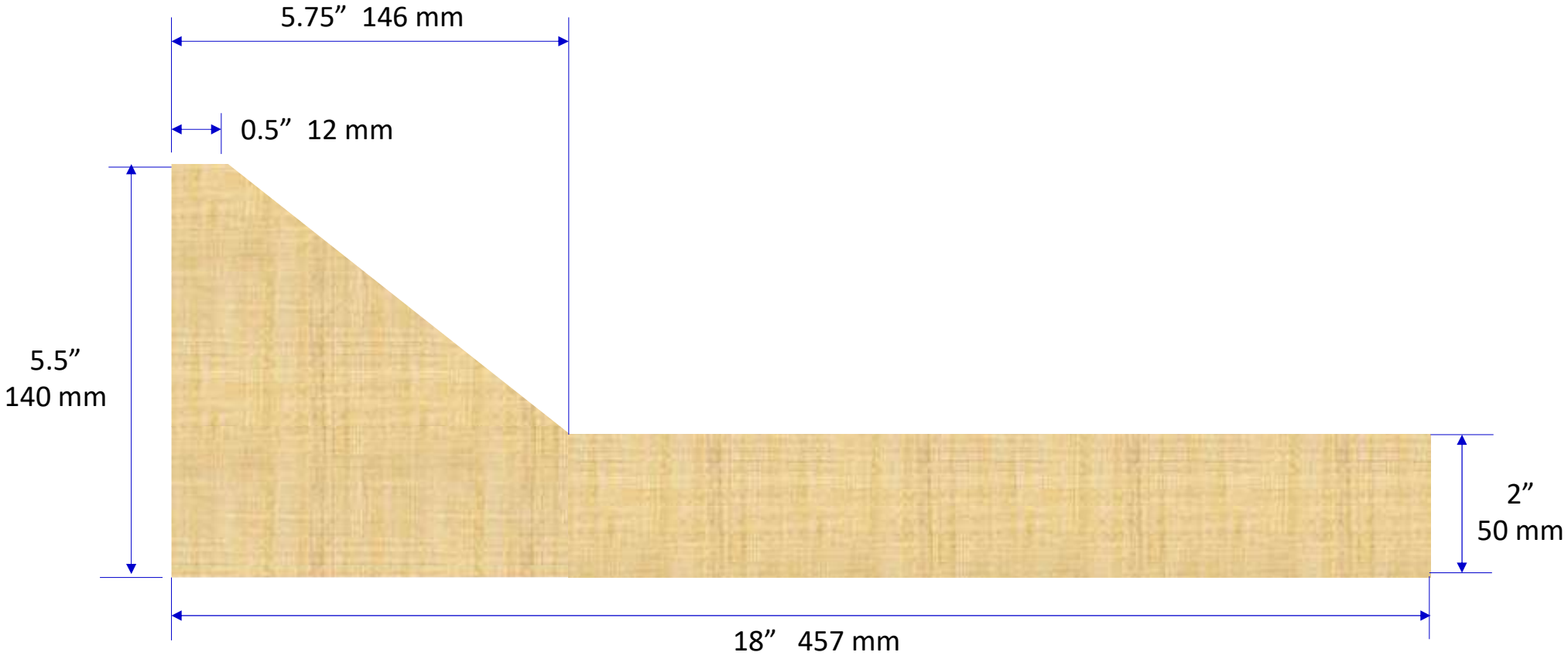


Inner Carcass before side panels are attached

Brace behind woofer magnet

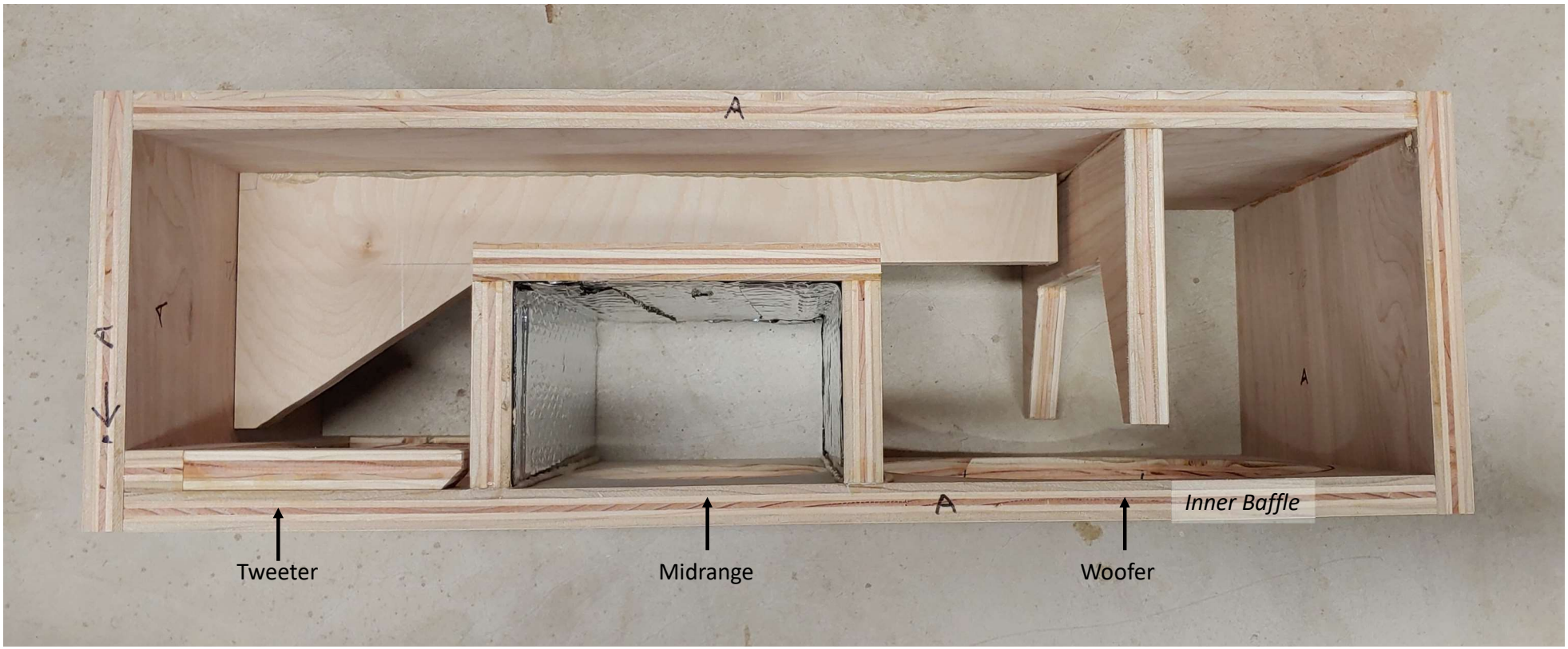


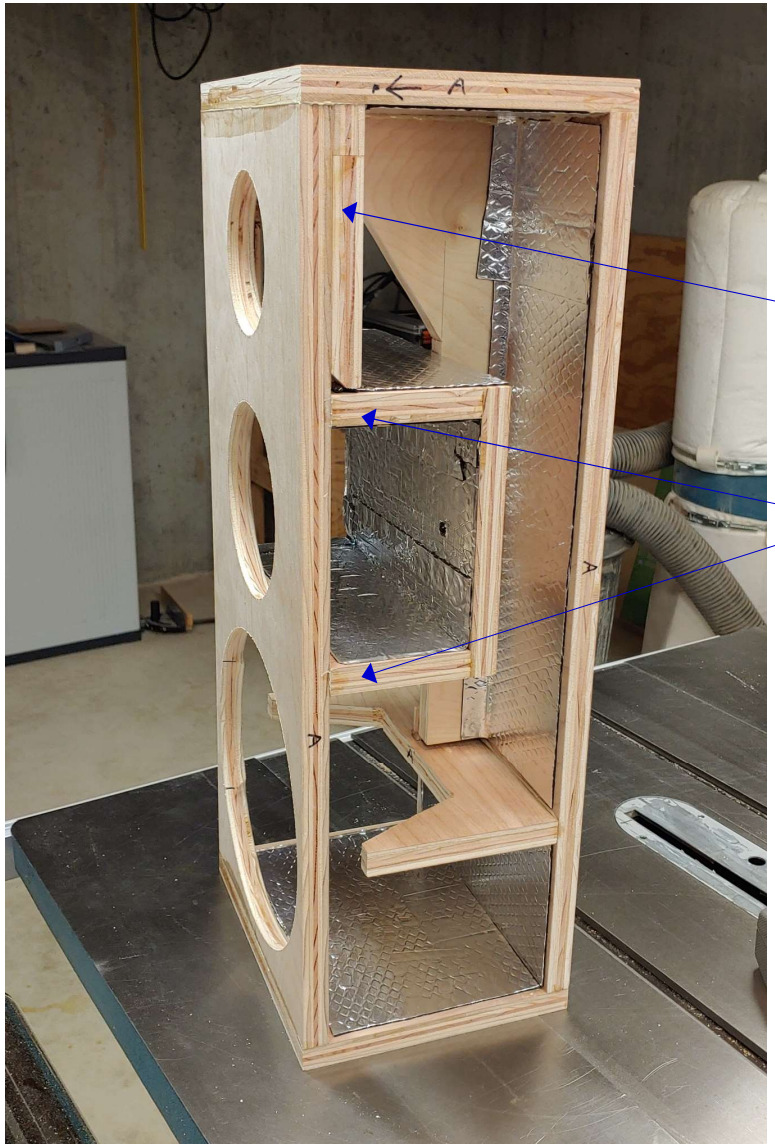
Vertical brace



Rear Assembly

Consisting of rear panel, bottom, woofer brace, and vertical brace


A
A
A
A
Inner Baffle
Tweeter
Midrange
Woofer



Inner carcass

Side walls and outer baffle to be added later

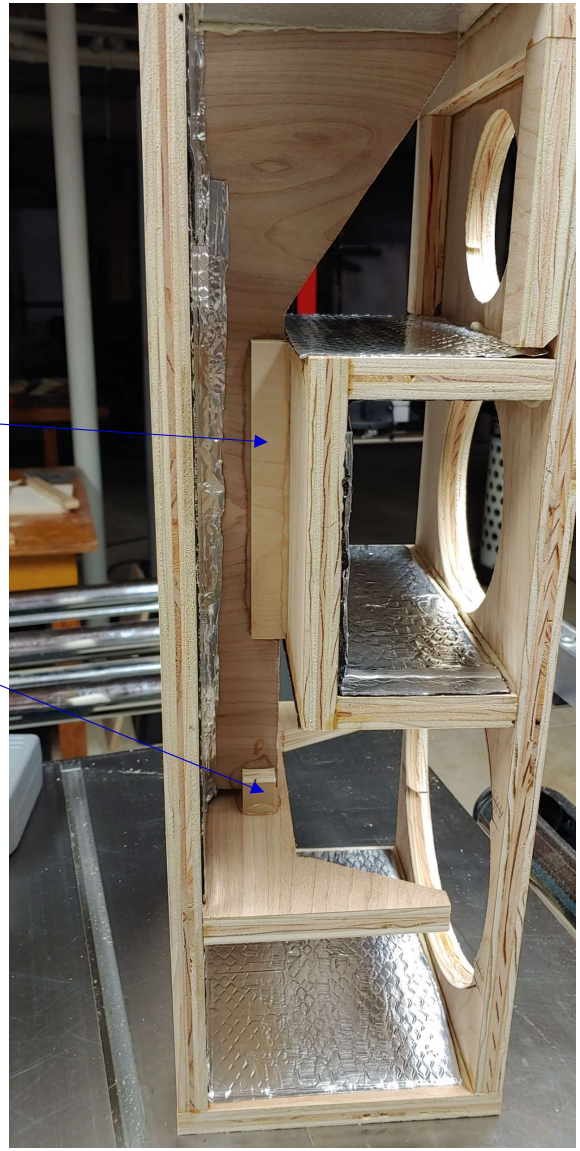
Corner gussets around the tweeter are needed because of the deep bevels to be cut later.

Midrange sub-enclosure functions as a partial bulkhead, reacting the midrange driver load into the sidewalls

80 mil butyl rubber+foil damping layer applied to all cabinet walls, and both interior and exterior of midrange sub-enclosure

In the interests of managing tolerance buildup, I left a small gap between the vertical brace and the midrange enclosure rear wall. This gap is spanned by a gusset block.

Similarly, there is a small gap between the horizontal woofer brace and the vertical brace, which is also spanned by a small gusset block.



Cabinet Assembly

- Attach the side panels
  - I applied the 80 mil butyl rubber damping before attachment
- Attach the outer baffle
- Using router, machine the driver holes and rebates
  - Drivers are fully recessed. Depth of recess should match the thickness of the driver flanges

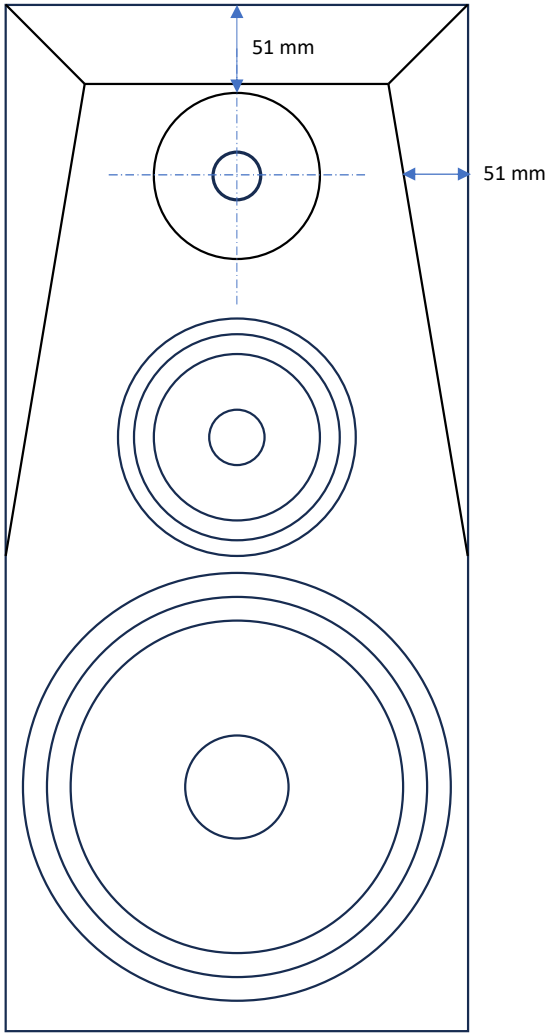
Bevels

Bevels

Bevels are designed to be 51 mm wide around tweeter.

Bevels are angled 35 degrees relative to the front baffle.

This configuration matches the prototype.



Tapered Bevels

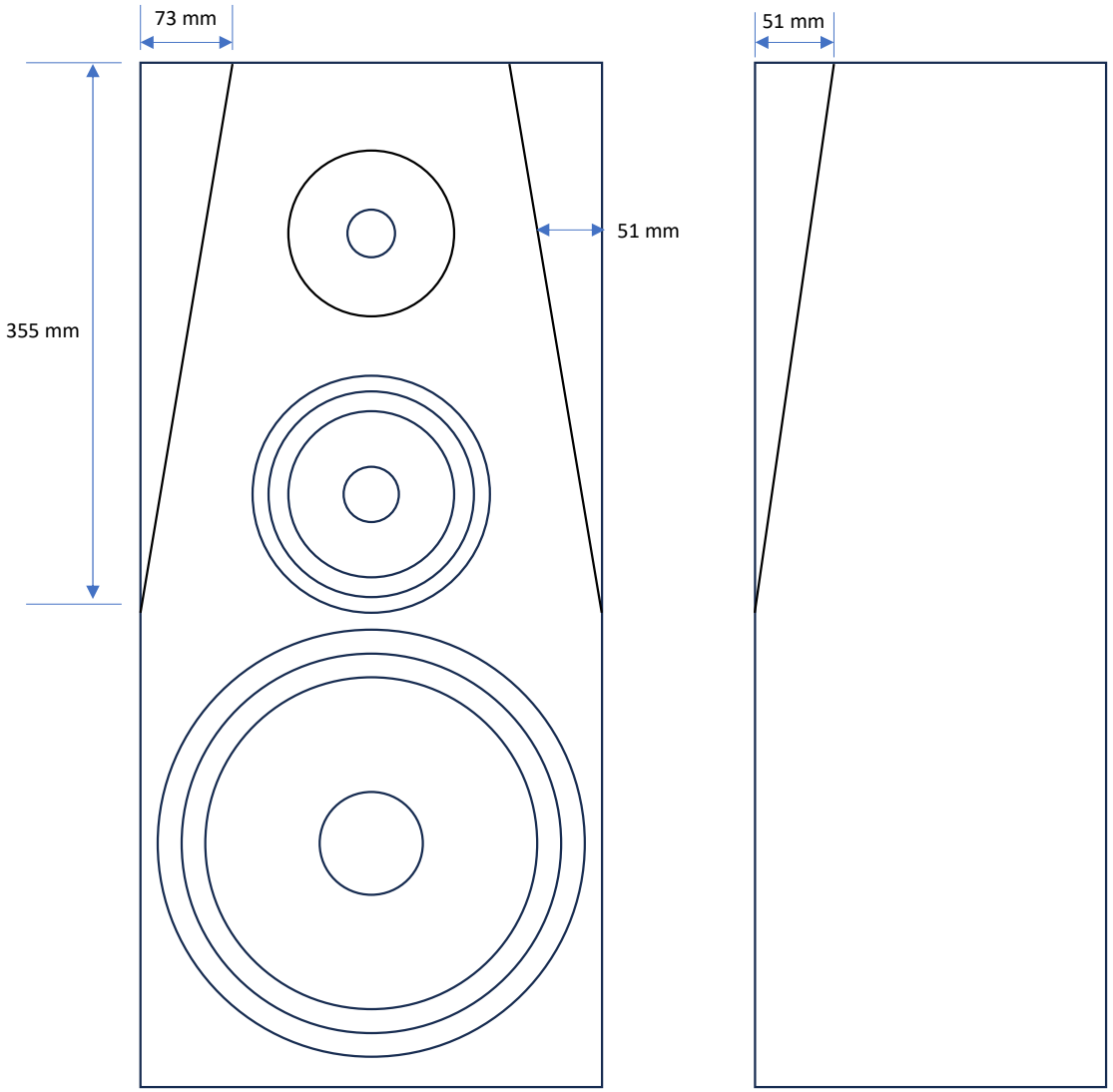
Shown before top bevel is cut

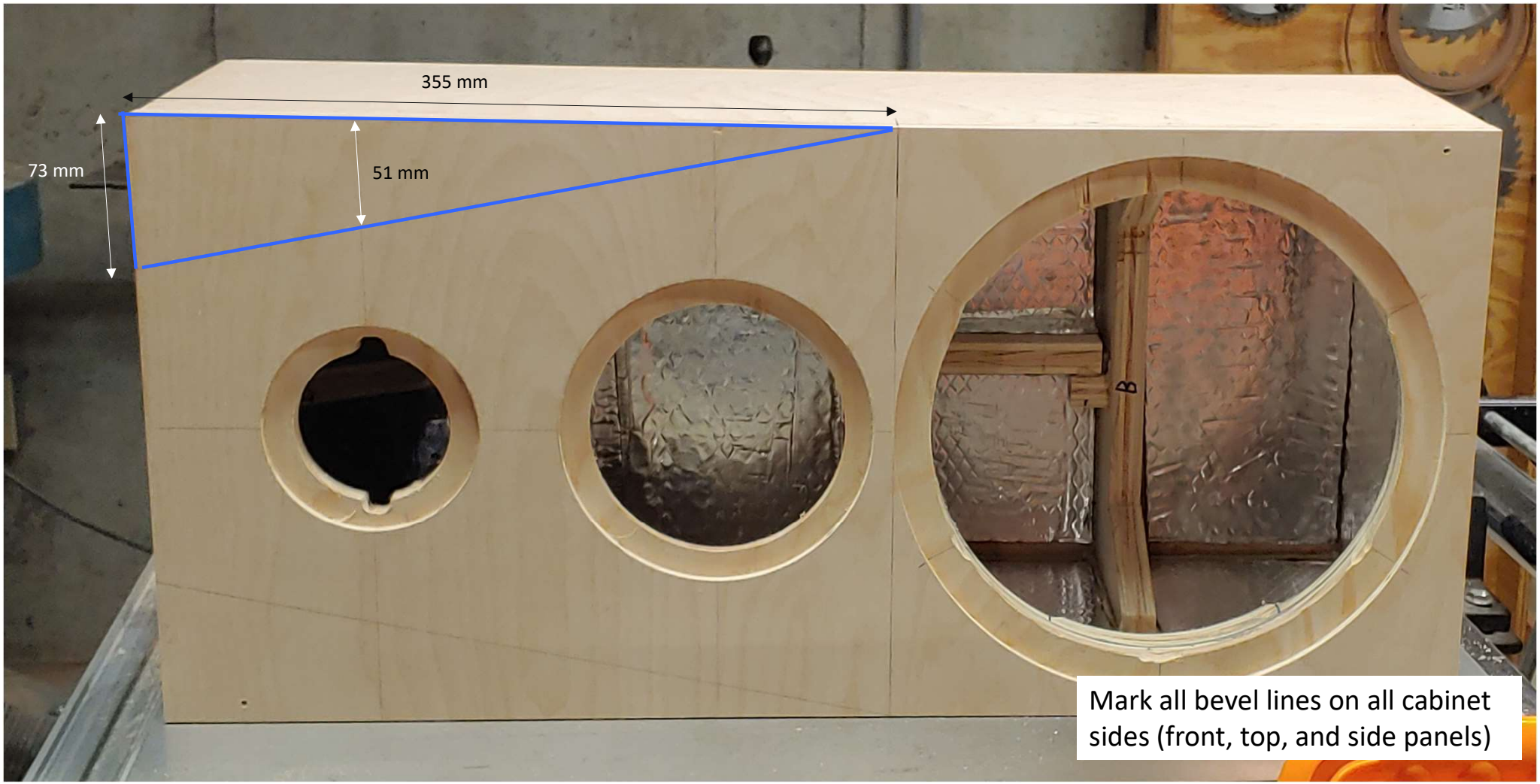
The tapered bevels along the sides are machined before the top bevel.

Tapered bevel starts at the top of the woofer and runs to the top edge of the cabinet.

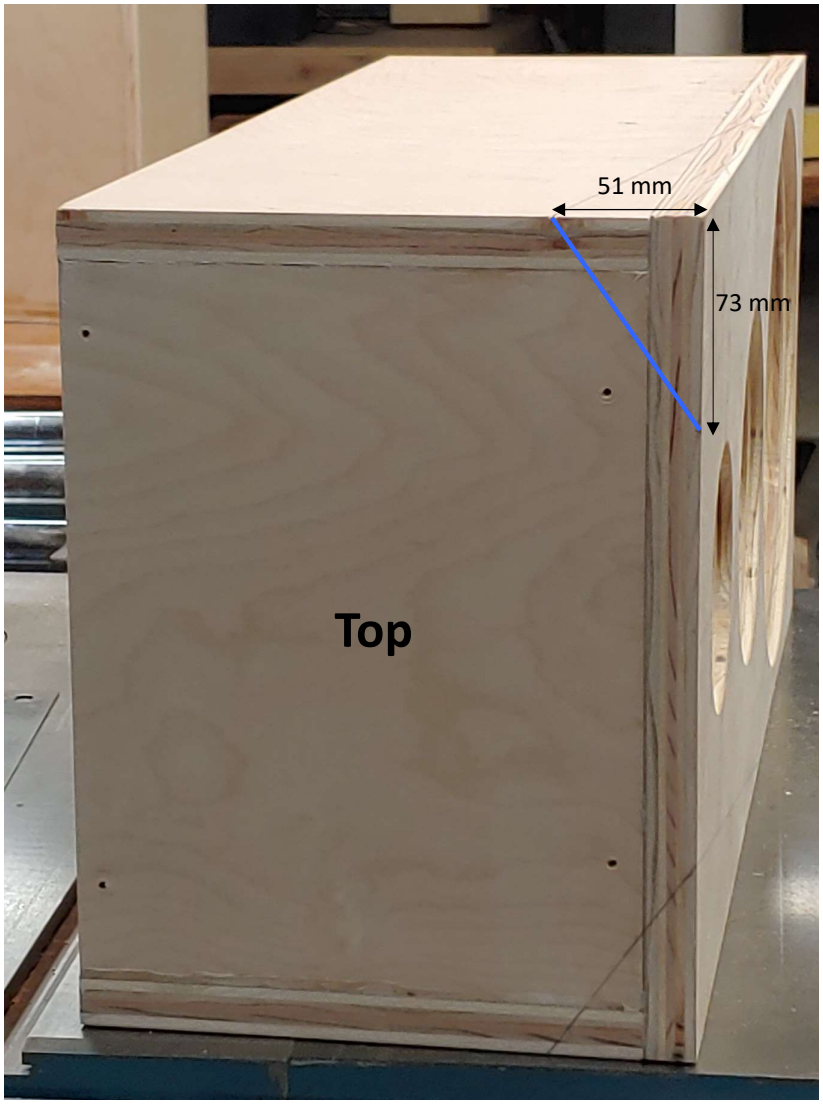
Bevel width at the tweeter centerline is 51 mm

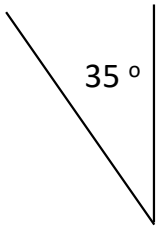
Bevel width at the top of the cabinet is 73 mm





Mark all bevel lines on all cabinet sides (front, top, and side panels)





35 degree bevel angle relative to the front baffle

Width of the bevel is 73 mm at the top of the cabinet.

Depth of the bevel is 51 mm

(73 mm) x Tan(35) = 51 mm

The angle along the side of the cabinet determines the angle of the jig

$Tan^{-1}(51/355) = 8^{o}$

Notes on Cutting Bevels

Setting up the saw

Before using the saw to cut large heavy workpieces (like an assembled cabinet), I apply wax to the table saw fence and table to minimize friction.

I set the saw blade to 35 degrees and raise it to its maximum height. I make a lot of practice pushes through the saw (blade fully retracted) to make sure the jig clears the fence, and there is no opportunity for anything to get caught up or pushed out of alignment. No part of the cabinet should touch the fence, only the jig touches the fence. I also carefully arrange my outfeed and infeed rollers to support the cabinet as it goes into, and comes out of, the saw.

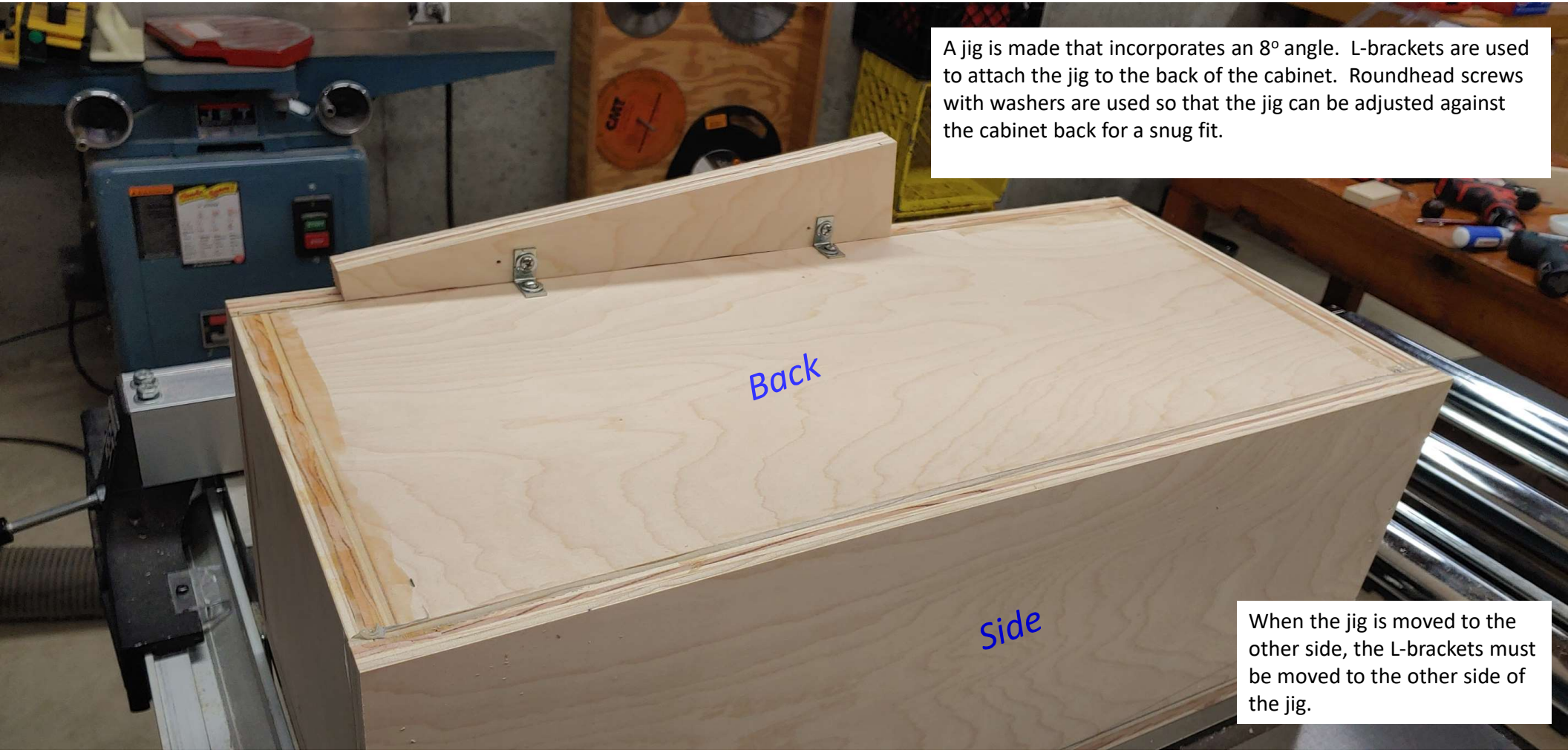
Cutting the tapered bevels

I attached the jig to the back of the speaker. The left hand bevel is cut by placing the left side of the cabinet against the table, baffle facing the blade. The cabinet is fed into the blade bottom first. This means the blade starts by cutting the thinnest section of wood, but finishes by cutting the thickest.

When cutting the right hand bevel, the jig must be attached to the opposite side of the cabinet, and the jig itself must be flipped over and the L brackets attached to the opposite side. The right side of the cabinet is against the table, and the cabinet is fed into the blade top first. This means the blade starts by cutting the thickest section, and finishes by cutting the thinnest section.

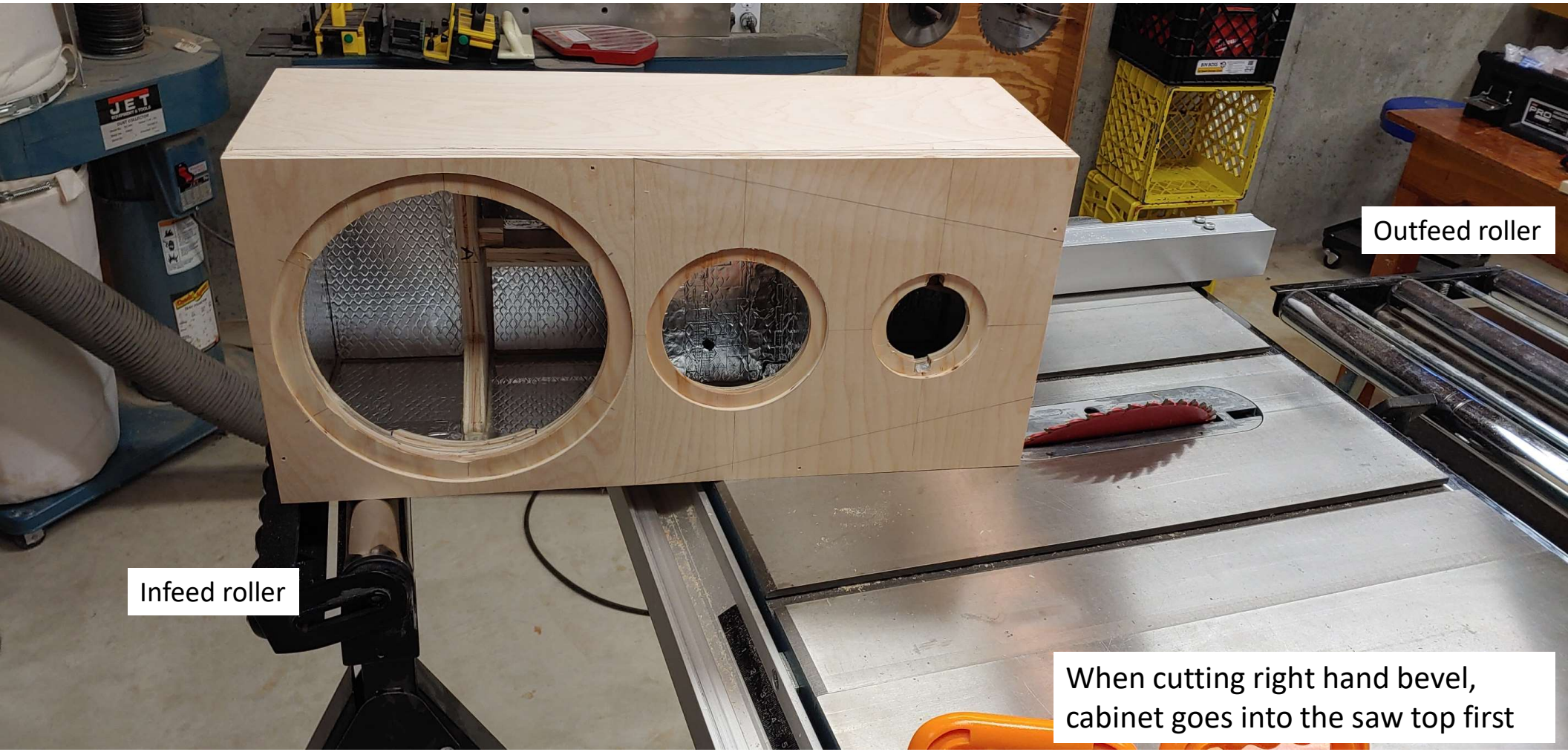
I do not attempt to cut the full bevel in a single pass. My saw is very “old school” and it has no CNC features or any sort of precision measurement system built in. I mark lines on the work piece, and then I cut to the line. In the case of a big complex cut such as this, I slowly “walk” myself up to the line by making a series of cuts. I start by cutting about ½ of the cut width, and then carefully examining the finished cut to be certain everything is lining up. If there is an alignment or setup problem, I usually will have plenty of remaining cabinet material to make adjustments and continue. I continue to progress with deeper cuts, about ¼ inch at a time (6 mm). The final cut should be less than the width of the blade, and this ensures the smoothest possible cut.

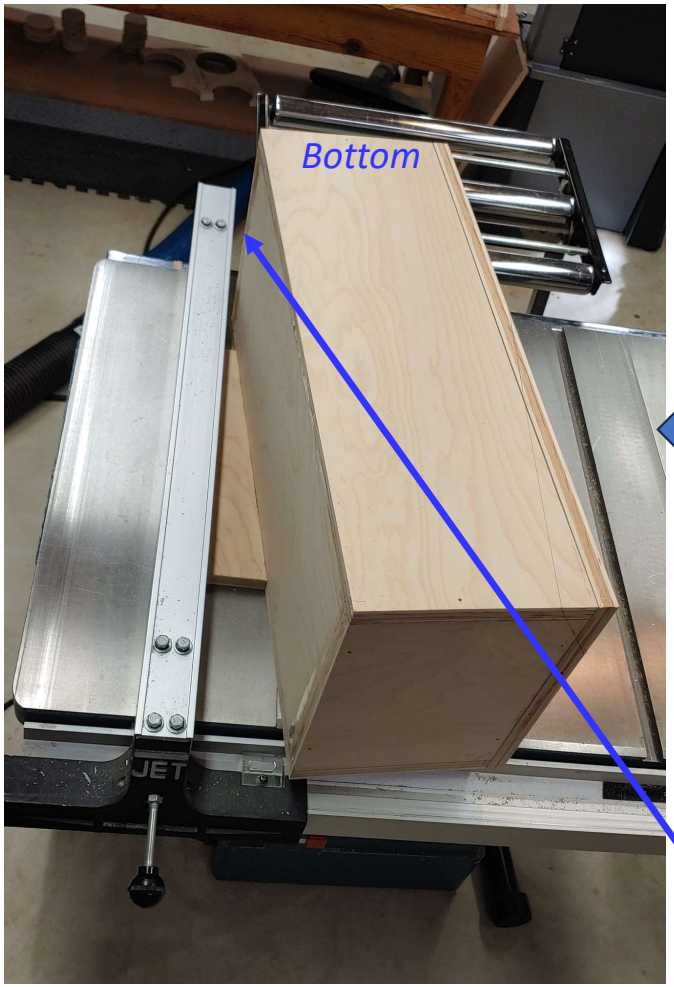
It is absolutely critical that the jig maintain contact with the fence during the entire operation. It takes some force to push the cabinet through the blade, and it is easy to accidently push things out of alignment. It is best to practice pushing the cabinet across the saw table before using the blade.



A jig is made that incorporates an 8° angle. L-brackets are used to attach the jig to the back of the cabinet. Roundhead screws with washers are used so that the jig can be adjusted against the cabinet back for a snug fit.

When the jig is moved to the other side, the L-brackets must be moved to the other side of the jig.

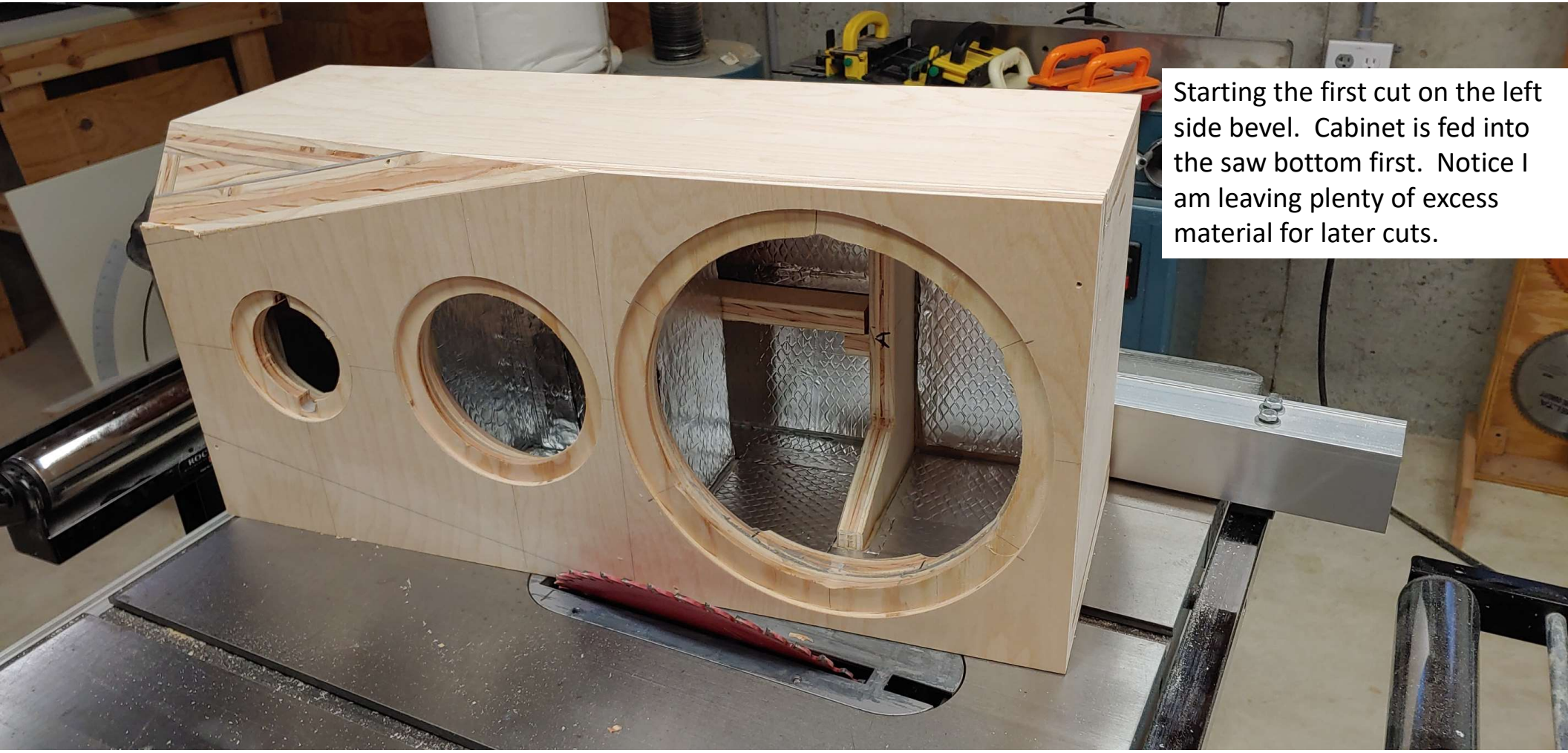

Outfeed roller
Infeed roller
When cutting right hand bevel,
cabinet goes into the saw top first



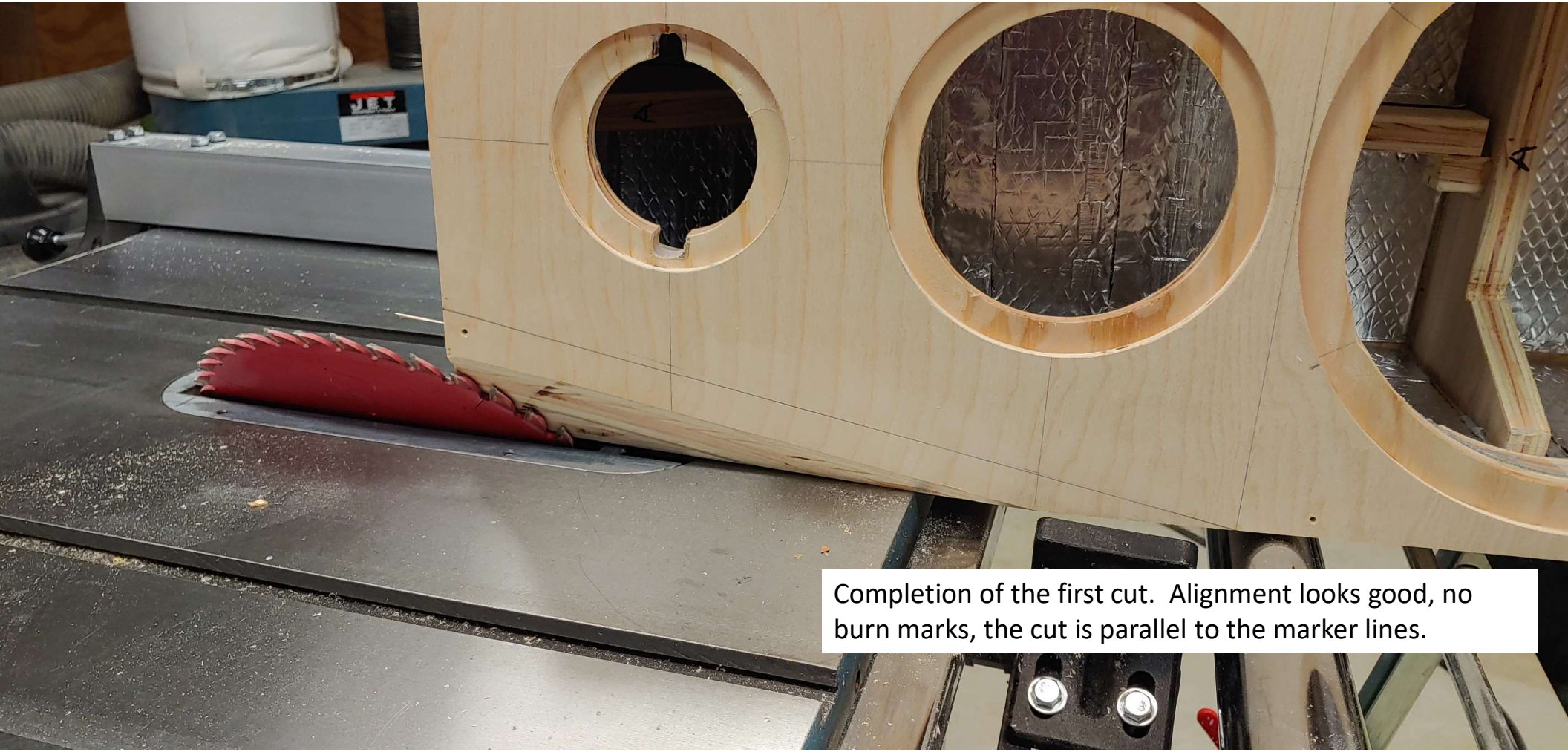
Right hand bevel: cabinet goes into the saw top first

Left hand bevel: cabinet goes into the saw bottom first.

Watch for clearance – make sure the cabinet clears the edge of the fence. The only thing which can touch the fence is the jig.



Starting the first cut on the left side bevel. Cabinet is fed into the saw bottom first. Notice I am leaving plenty of excess material for later cuts.



Completion of the first cut. Alignment looks good, no burn marks, the cut is parallel to the marker lines.

Notes on Cutting Bevels

Cutting the top bevel

The top bevel is easier than the tapered side bevels, although it looks more intimidating. The speaker is placed top down against the table surface, with the baffle facing the blade. No jig is used, and the back of the cabinet is against the fence, and the bevel cut is parallel to the baffle. Once again I recommend practicing the motion first, and then making a first cut that is only half depth. Then walking up to the final cut line.

Why cut the top bevel last? When cutting the right hand tapered bevel, the top of the speaker goes in first. If the top bevel has already been cut, it would be very difficult to see the mark lines and position the line up to the saw blade. So I do the bevels first.

My final resulting cuts are close to the mark line, but not exact. This process is very sensitive to the angle of the jig, and how closely it matches the design angle. However, it is not so important that the actual cuts match the intended design, only that all four cuts are the same, and in this case I was successful.

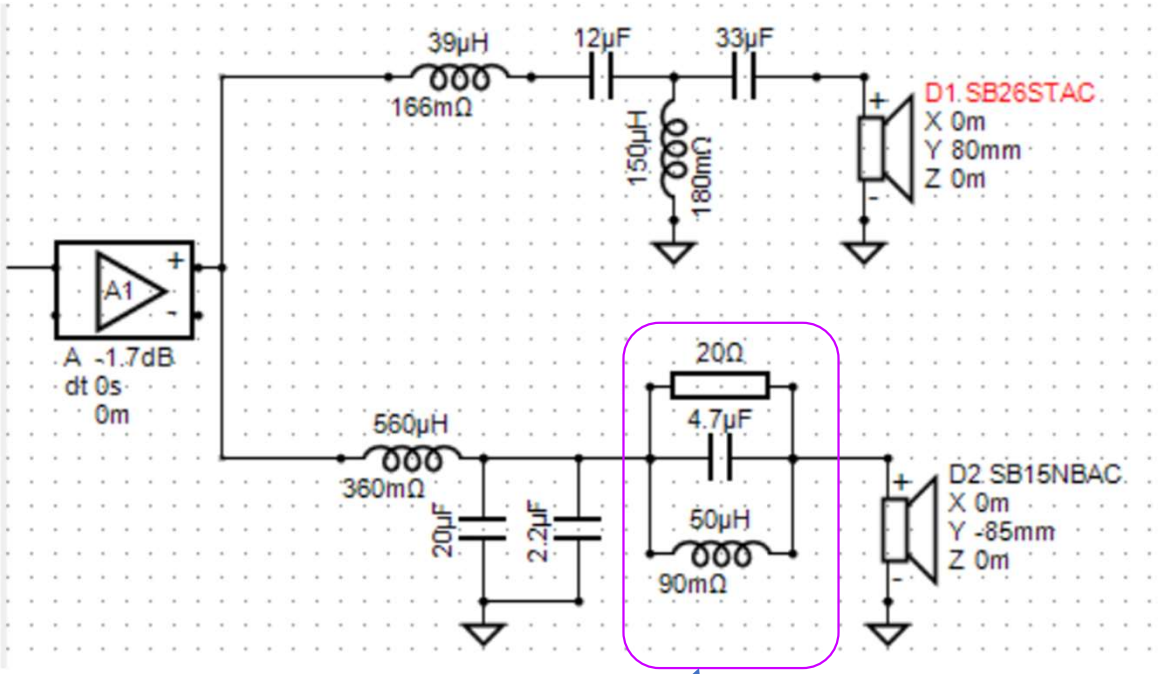
First cut of the top bevel

Cabinet is ready for paint, veneer, or other finish

I find it easier to rout the driver holes and recesses before I cut the bevels.

Passive Crossover

Passive Crossover



Midrange notch filter

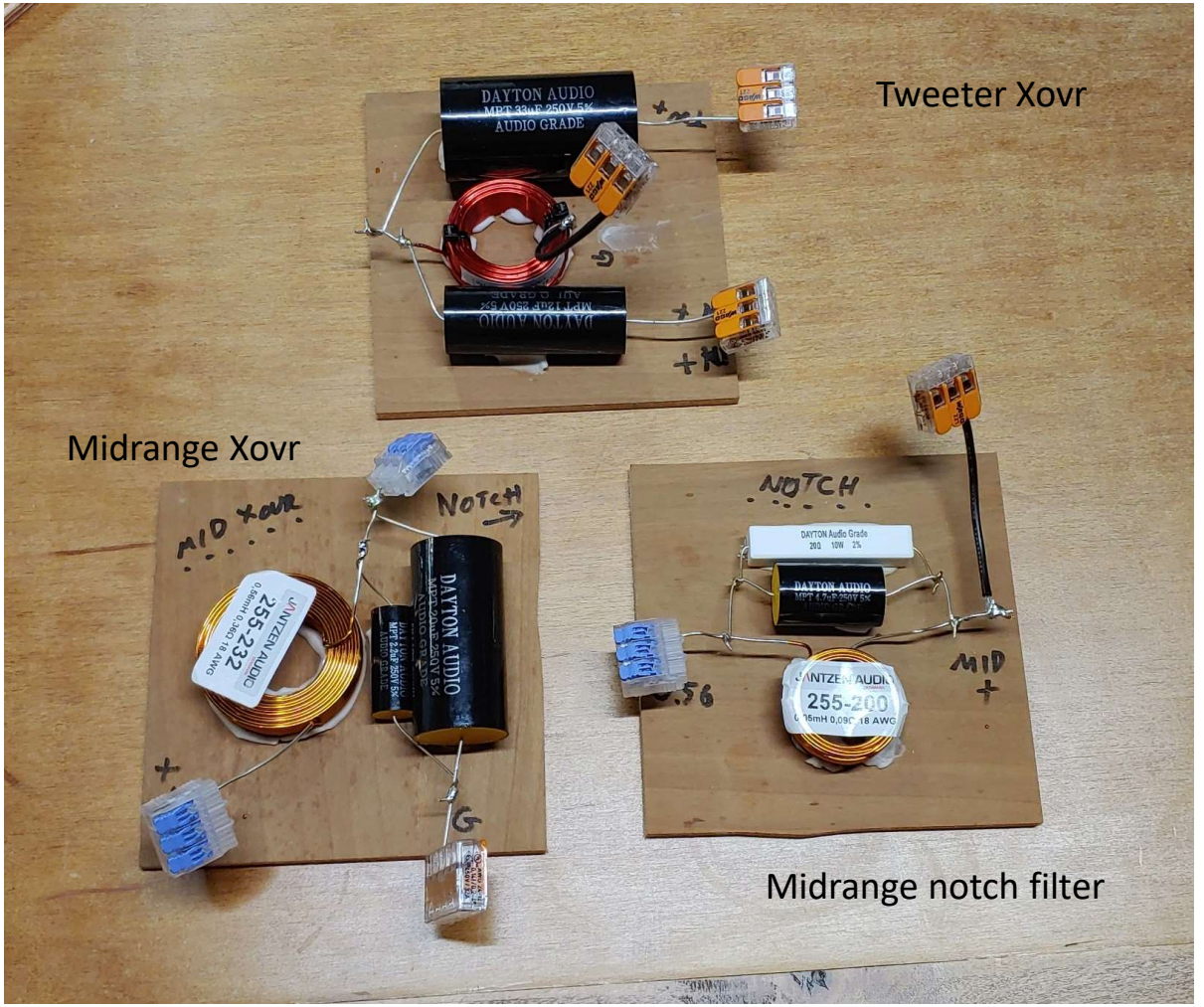
Inductors	L	DCR
L1	150 µH	0.18 Ω
L2	560 µH	0.36 Ω
L3	50 µH	0.09 Ω
Capacitors	**C**	**Type**
C1	12 µF	PP
C2	33 µF	PP
C3	20 µF	PP
C4	4.7 µF	PP
C5	2.2 µF	PP
Resistors	**R**	**Pmax**
R1	20 Ω	10 W

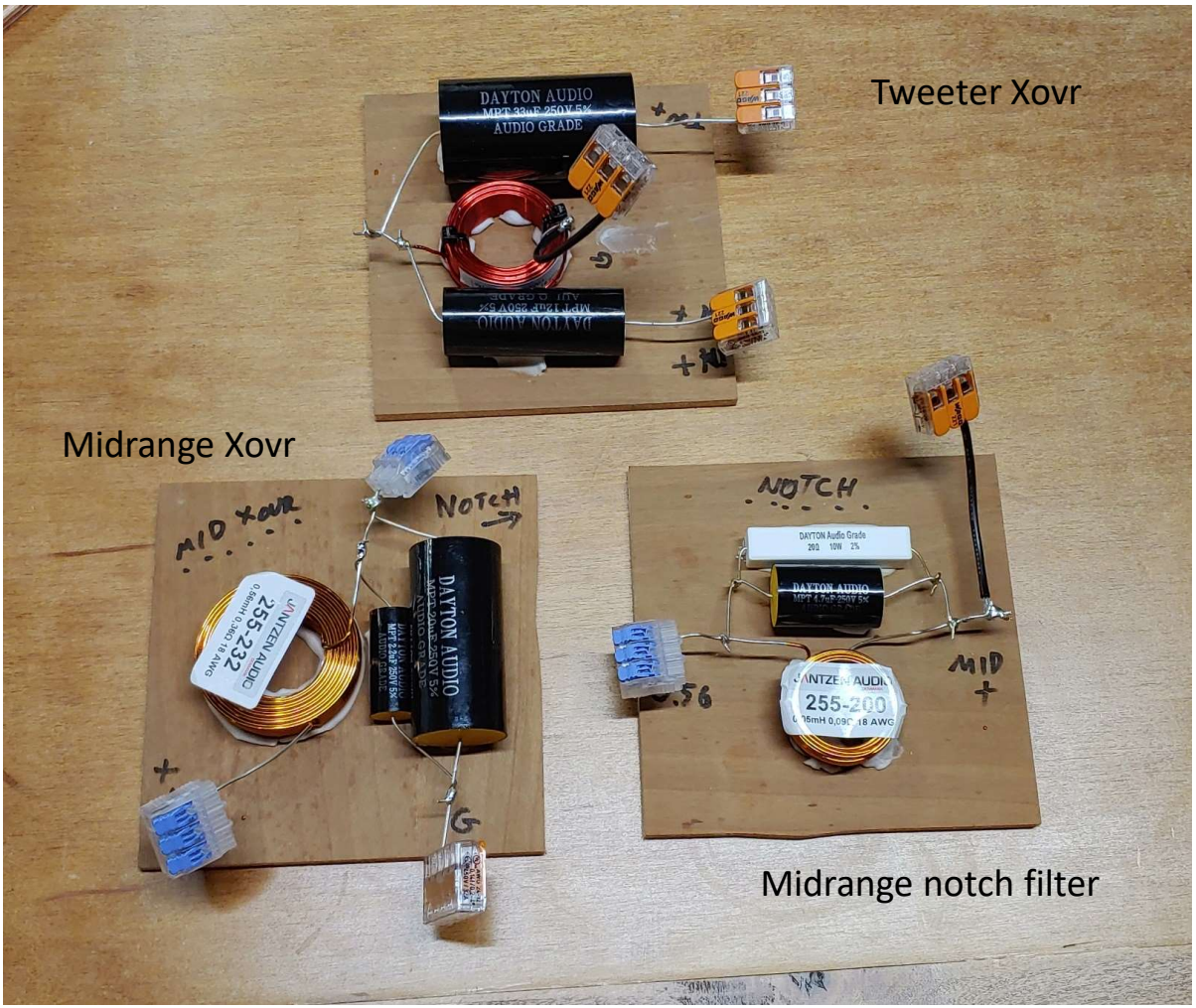
Passive crossover was assembled on ¼” plywood

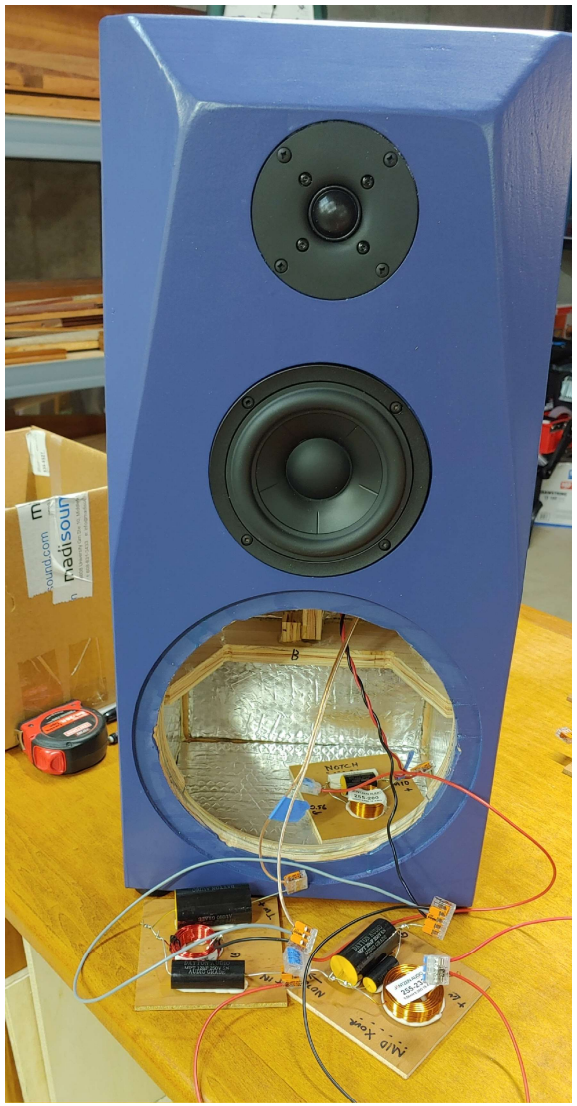
Components were attached with quick setting construction adhesive, and then soldered

The crossover was separated into three sections
1) Tweeter high pass
2) Midrange low pass
3) Midrange notch filter

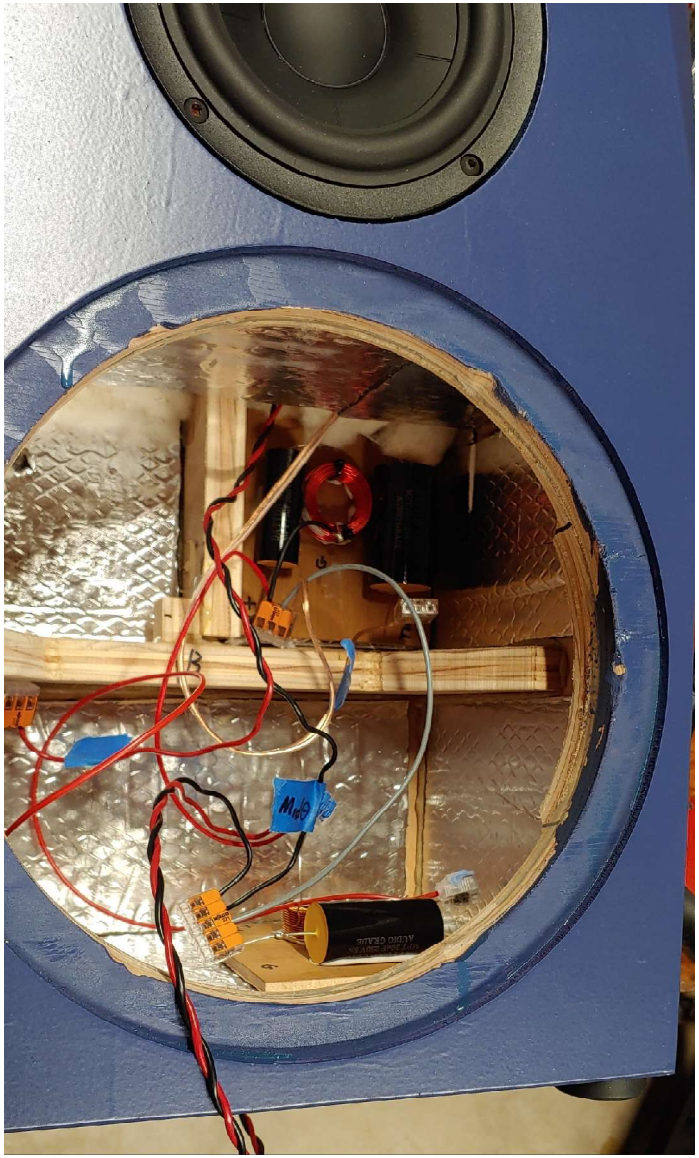
I used lever-lock wiring connectors to connect the various crossover sections.







Testing the mockup crossover

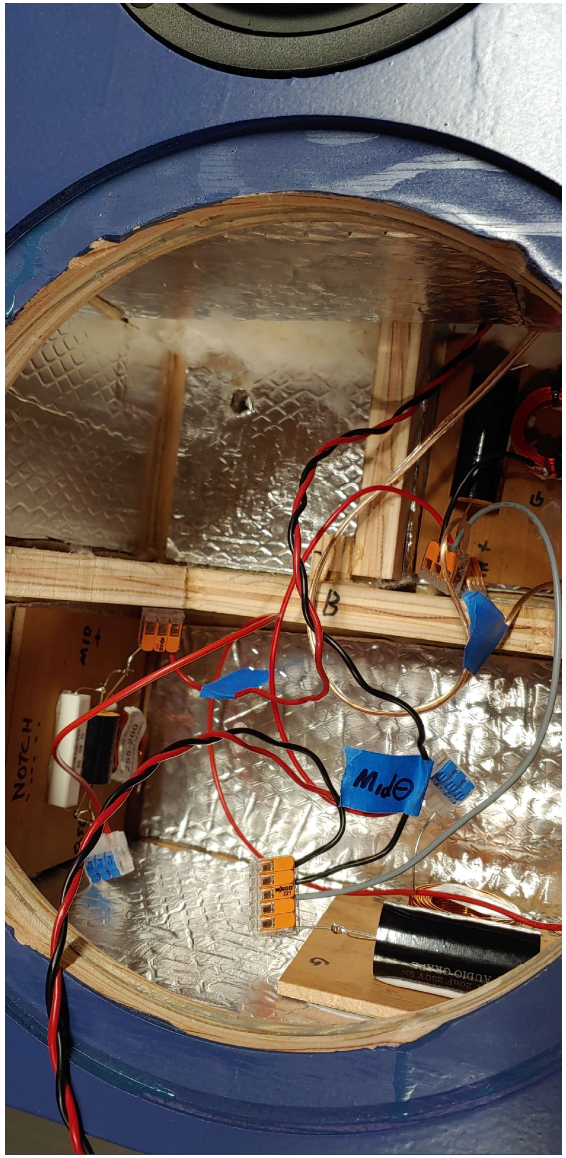


Crossover boards are installed on the bottom, side, and rear of the cabinet. This ensures that all three inductors are orthogonal to each other .

I used fast setting construction adhesive to attach the boards.

There are many ways to do this, and other builders may prefer a different way of assembling the passive crossover.

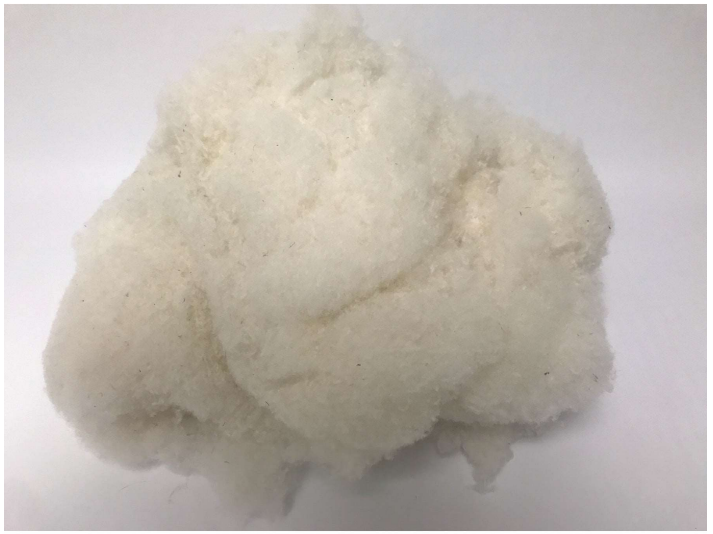
All drivers are wired with positive polarity
The midrange and tweeter are inverted using a feature in the MiniDSP.

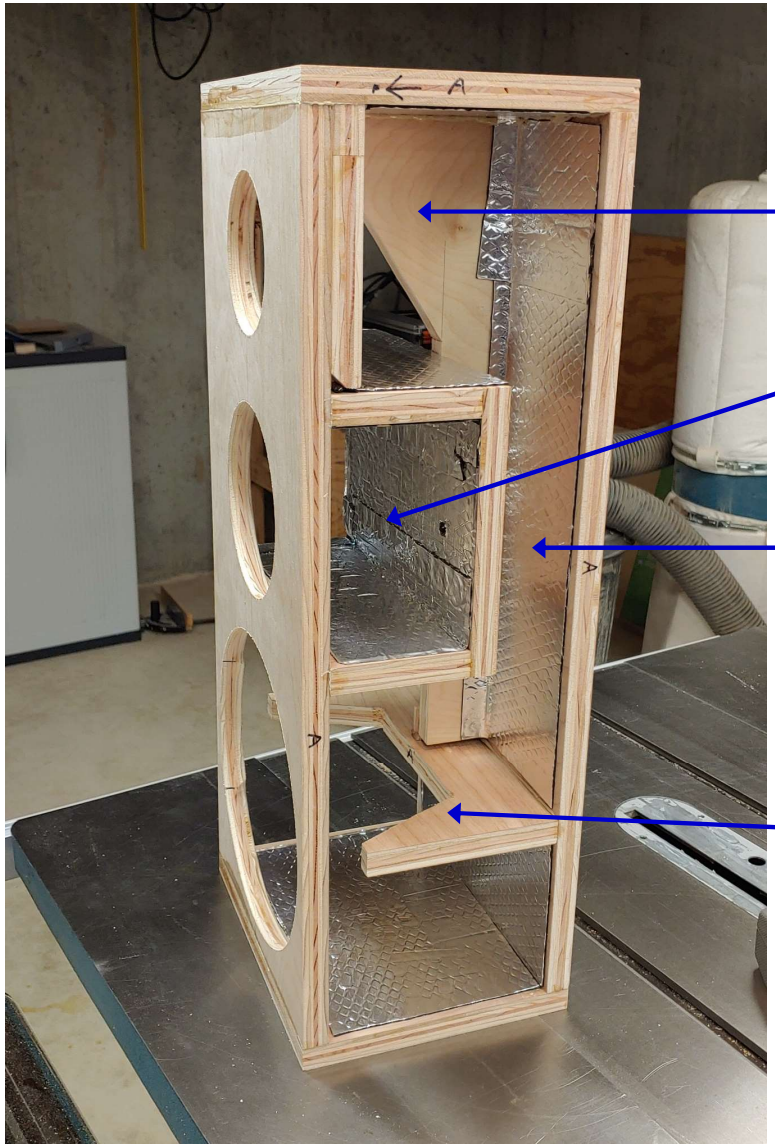


Cabinet Stuffing (Damping)

Cabinet Stuffing

- Stuffing provides acoustical damping
- I used natural sheep's wool stuffing
  - Fully teased out to a very loose state
- The midrange box is stuffed at 16 grams per liter (60 g)
- The bass volume is divided into 3 regions
  - Region 1 – Upper volume behind the tweeter
    - Heavy stuffing at 16 grams per liter (111 g)
  - Region 2 – Space behind midrange sub-enclosure
    - Heavy stuffing at 16 grams per liter (41 g)
  - Region 3 – Lower volume behind woofer
    - Light stuffing at 3.5 grams per liter (39 g)





Cabinet Stuffing

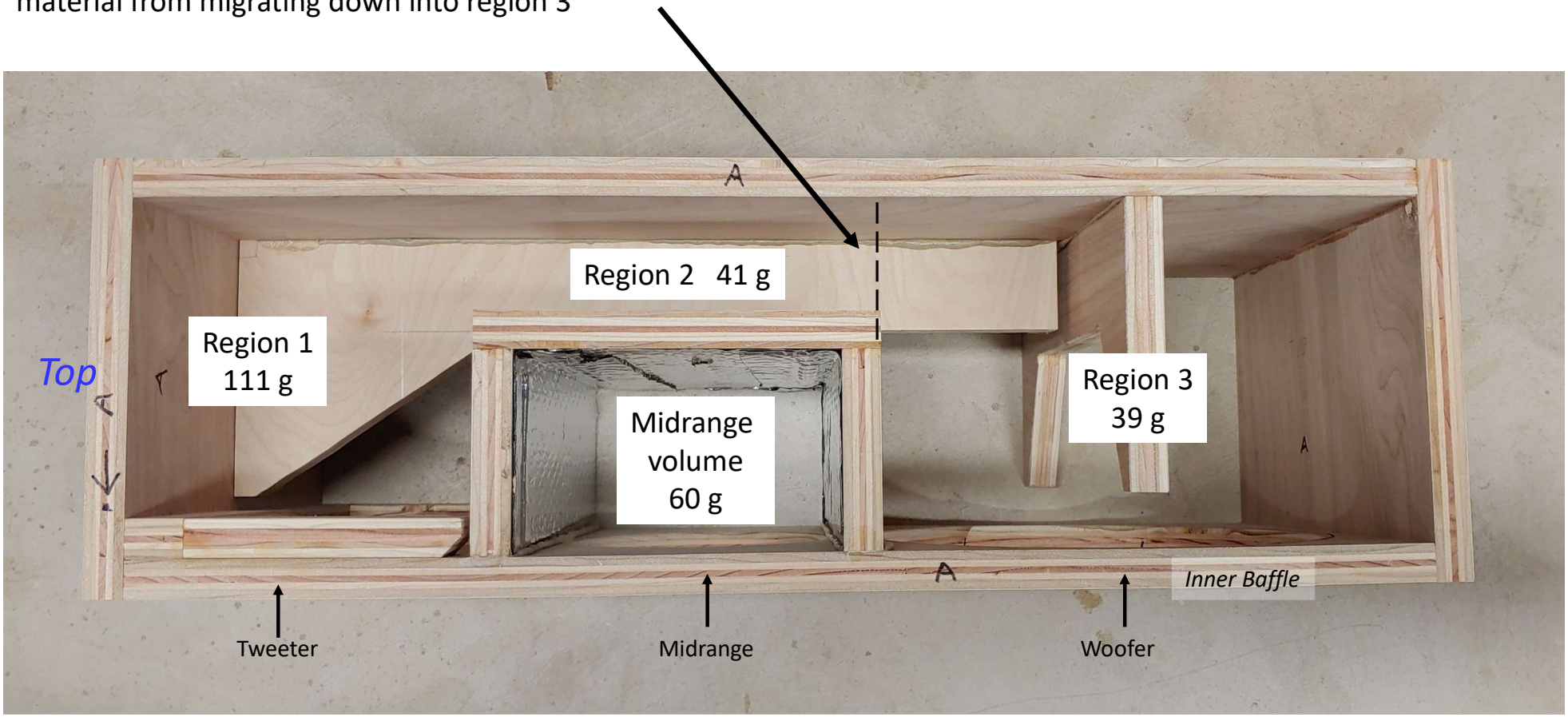
Region 1 behind tweeter: 111 grams

Midrange sub-enclosure: 60 grams

Region 2 behind midrange box: 41 grams

Region 3 behind woofer: 39 grams

It may be necessary to fix an acoustically transparent cloth barrier at the bottom of region 2 to prevent the damping material from migrating down into region 3



Other Damping Materials

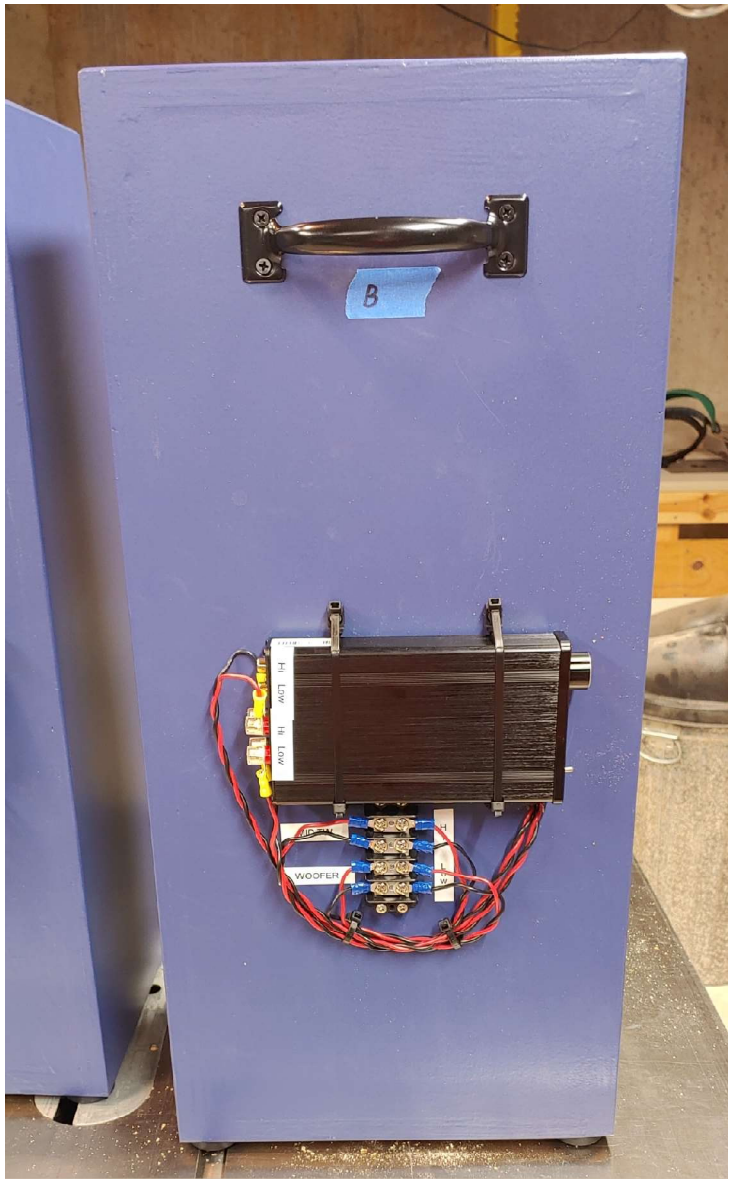
- Other materials can be used
  - Mineral wool, acoustistuff, shredded denim insulation, all do a good job
- The quantity of damping material will have to be determined empirically by the builder
- It is important that an internal resonance does not form between region 1 and region 3, with region 2 acting as a duct
- An impedance sweep of the woofer should be performed, along with a near field frequency response scan
- If the FR is not smooth, or if the impedance shows two peaks, then more stuffing is needed in region 1 and 2
- Wool tends to stay in place. Other materials might migrate. It may be necessary to fix a screen at the bottom of region 2 to keep the stuffing from falling down.

After the crossovers are attached, the stuffing is in place, and the wiring has been routed, the drivers can be installed.

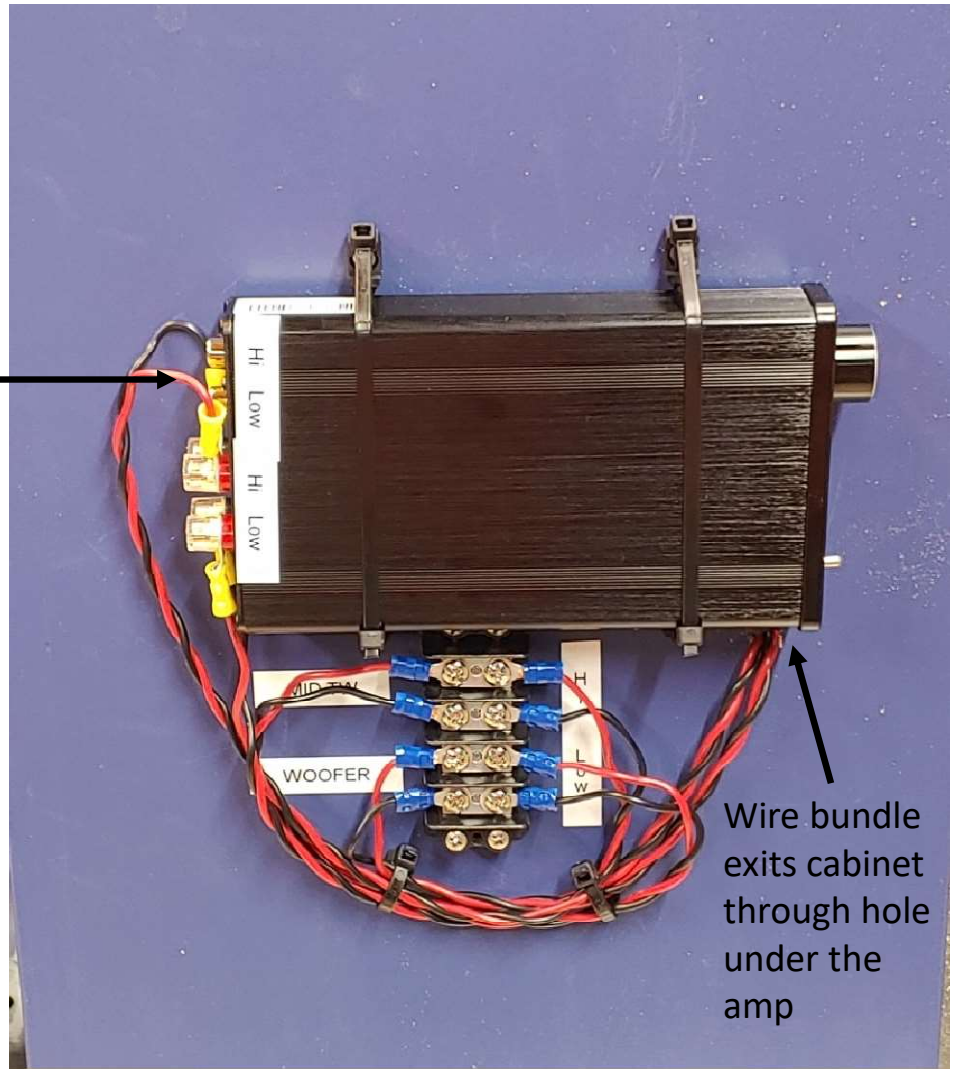
The wire bundle exits the cabinet through a hole in the rear. There are 4 wires: Woofer (+) (-), and midrange-tweeter crossover (+) (-). The hole is packed with foam.

The wiring is connected to a ring terminal block on the rear. The 2-channel amplifier is attached on the rear of the speaker.

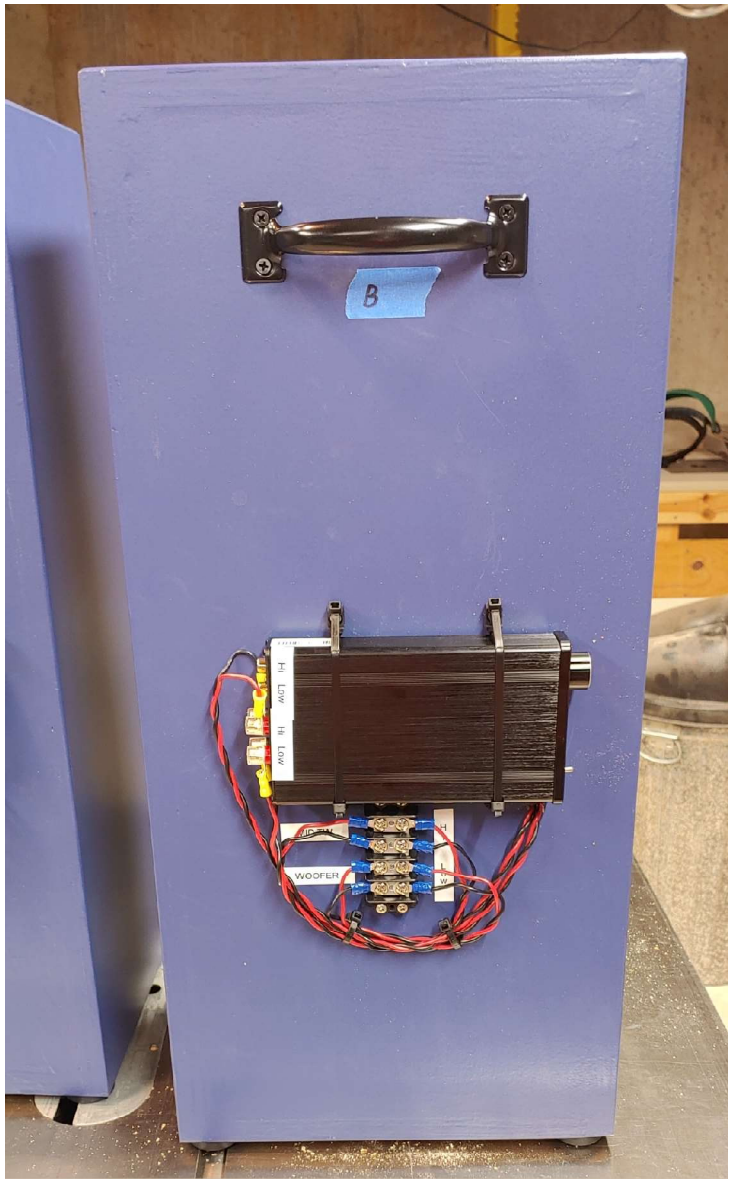
A handle is optional



RCA inputs from MiniDSP 2x4HD High and Low



Wire bundle exits cabinet through hole under the amp



Amplifier Discussion

I used a low cost 2 channel amplifier from Parts Express which uses the Class D TDA7498E chipset. It has approximately 120 W for woofer, 120 W for midrange + tweeter.

Like many inexpensive Class D amps, the frequency response above 10k is affected by the load impedance. This behavior has been accounted for in the DSP filter.

Any reasonable 2-channel amplifier could be used, as long as there is identical gain between the high and low channel.

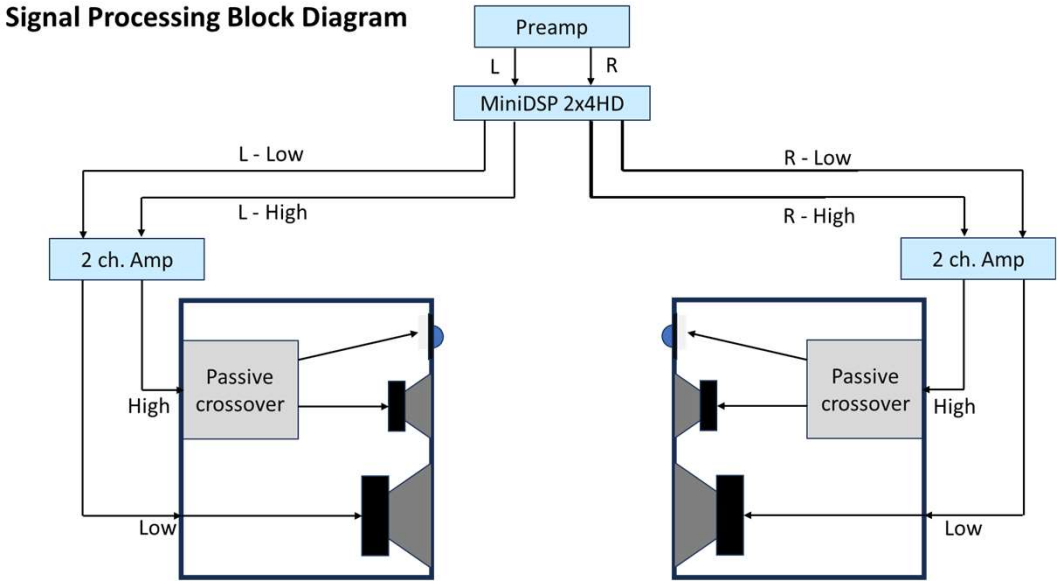
I recommend using a separate amp for the left and right speaker which ensures the gain between high and low sections is equal.

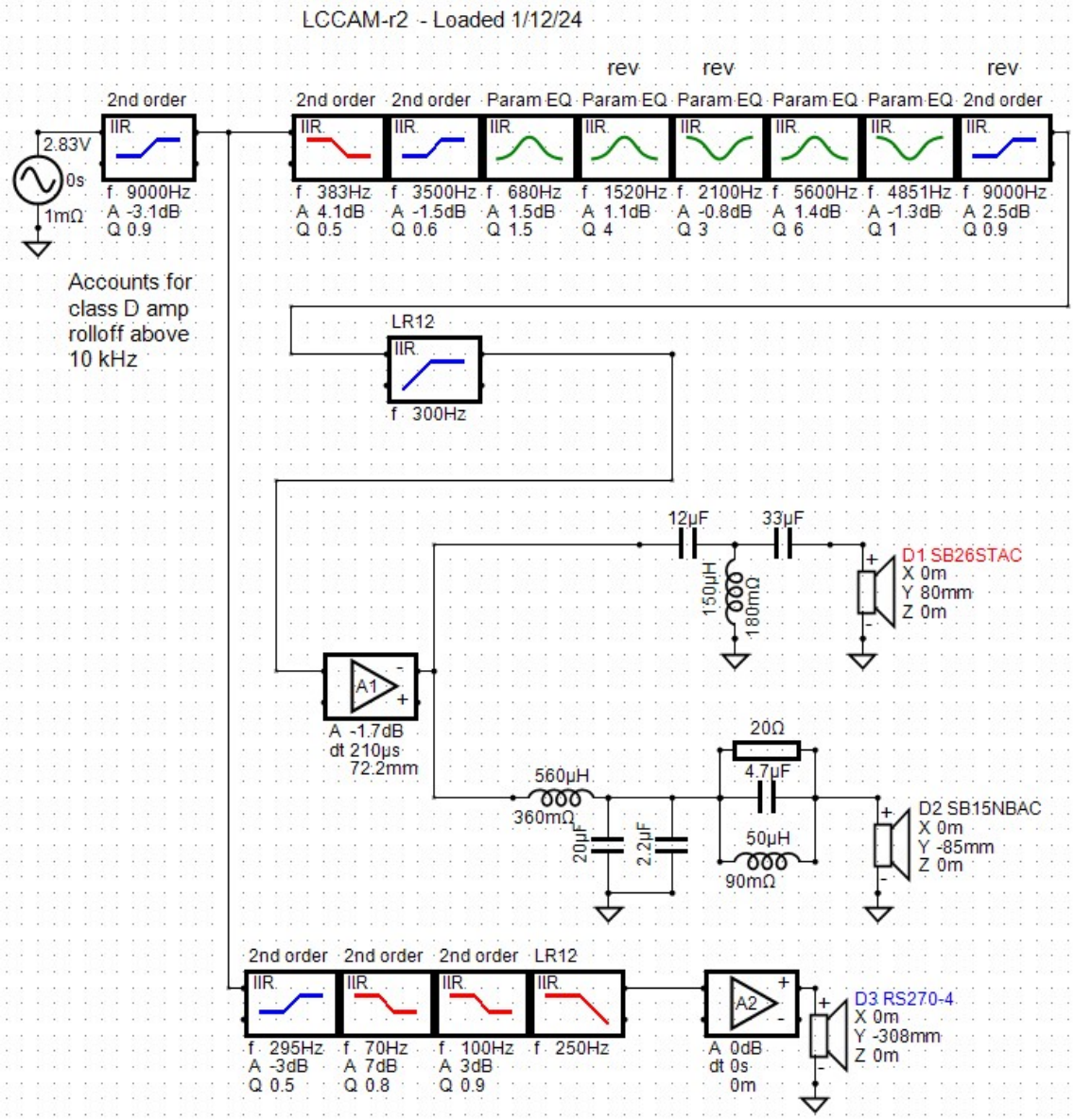
Alternatively, If one amp is used for the L/R high section, and another amp is used for the L/R low section, the user must ensure that the two amps have been carefully matched in gain.

DSP Filter

DSP Filter

- DSP filter is loaded into MiniDSP 2x4HD
- R/L low channel is for the woofer
- RL high channel is for the mid-tweeter





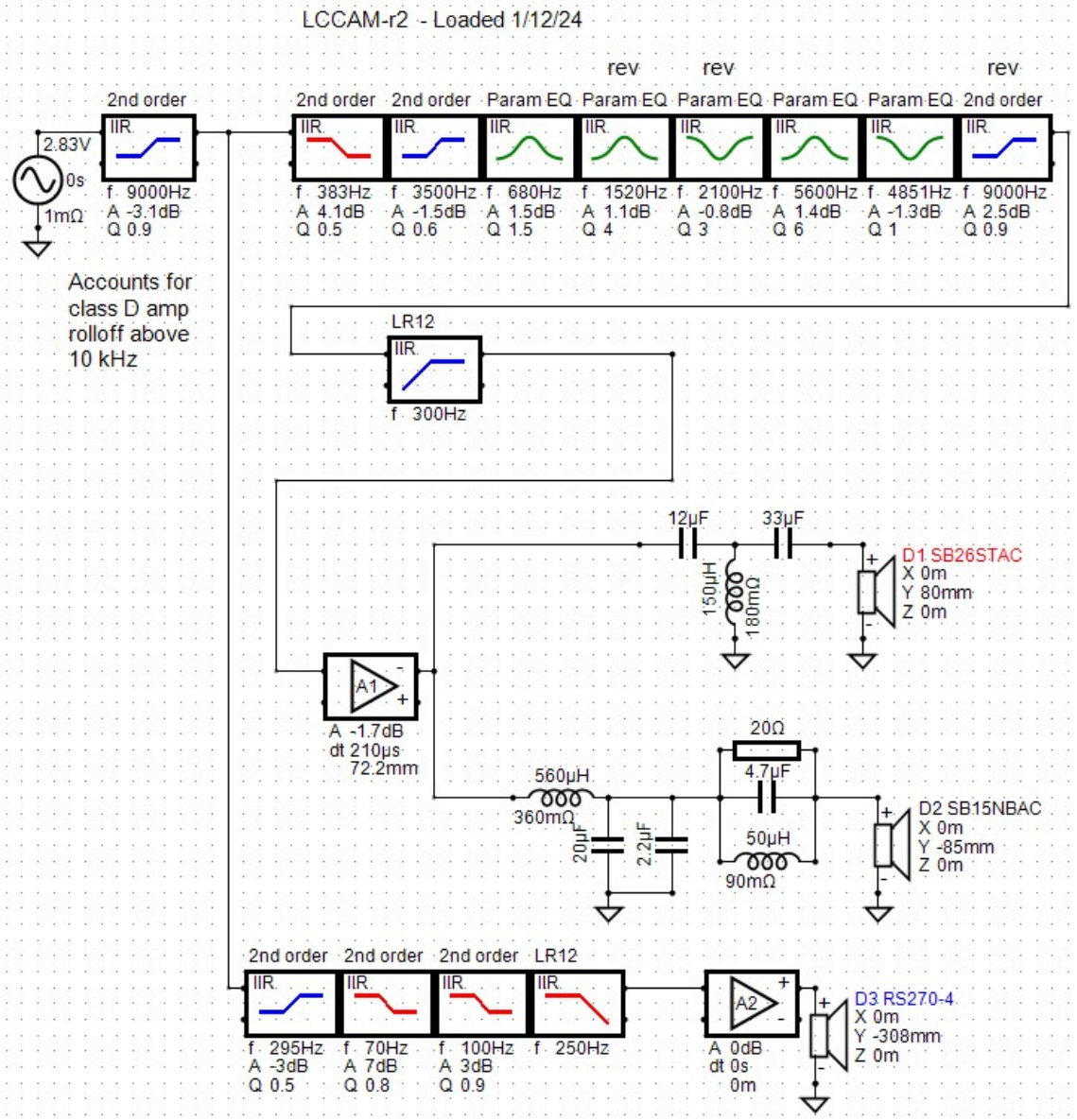
MiniDSP 2x4HD Settings

- Upper channel has a delay of 210 µs and a gain of -1.7 dB
- Upper channel has 2nd order LR high pass filter at 300 Hz
- Upper channel has polarity inverted

- Lower channel has no delay and a gain of 0 dB
- Lower channel has 2nd order LR low pass filter at 250 Hz

TEMPLATE MODE

1 Left	2 Right	1 Left Low	2 Left High	3 Right Low	4 Right High
RMS-Meter (dBFS)	RMS-Meter (dBFS)	1 LEFT	1 LEFT	1 LEFT	1 LEFT
-44.6	-23.9	0 dB	0 dB	0dB	0dB
		2 RIGHT	2 RIGHT	2 RIGHT	2 RIGHT
Gain (dB)	Gain (dB)	0 dB	0 dB	0 dB	0 dB
0	0	PEQ	PEQ	PEQ	PEQ
PEQ	PEQ	CROSSOVER	CROSSOVER	CROSSOVER	CROSSOVER
MUTE	MUTE	FIR	FIR	FIR	FIR
		Delay (ms)	Delay (ms)	Delay (ms)	Delay (ms)
		0	0.21	0	0.21
		Gain (dB)	Gain (dB)	Gain (dB)	Gain (dB)
		0	-1.7	0	-1.7
		INVERT	INVERTED	INVERT	INVERTED
		MUTE	MUTE	MUTE	MUTE
		COMPRESSOR	COMPRESSOR	COMPRESSOR	COMPRESSOR
		RMS-Meter (dBFS)	RMS-Meter (dBFS)	RMS-Meter (dBFS)	RMS-Meter (dBFS)
		-20.2	-46.6	-25.1	-41.6

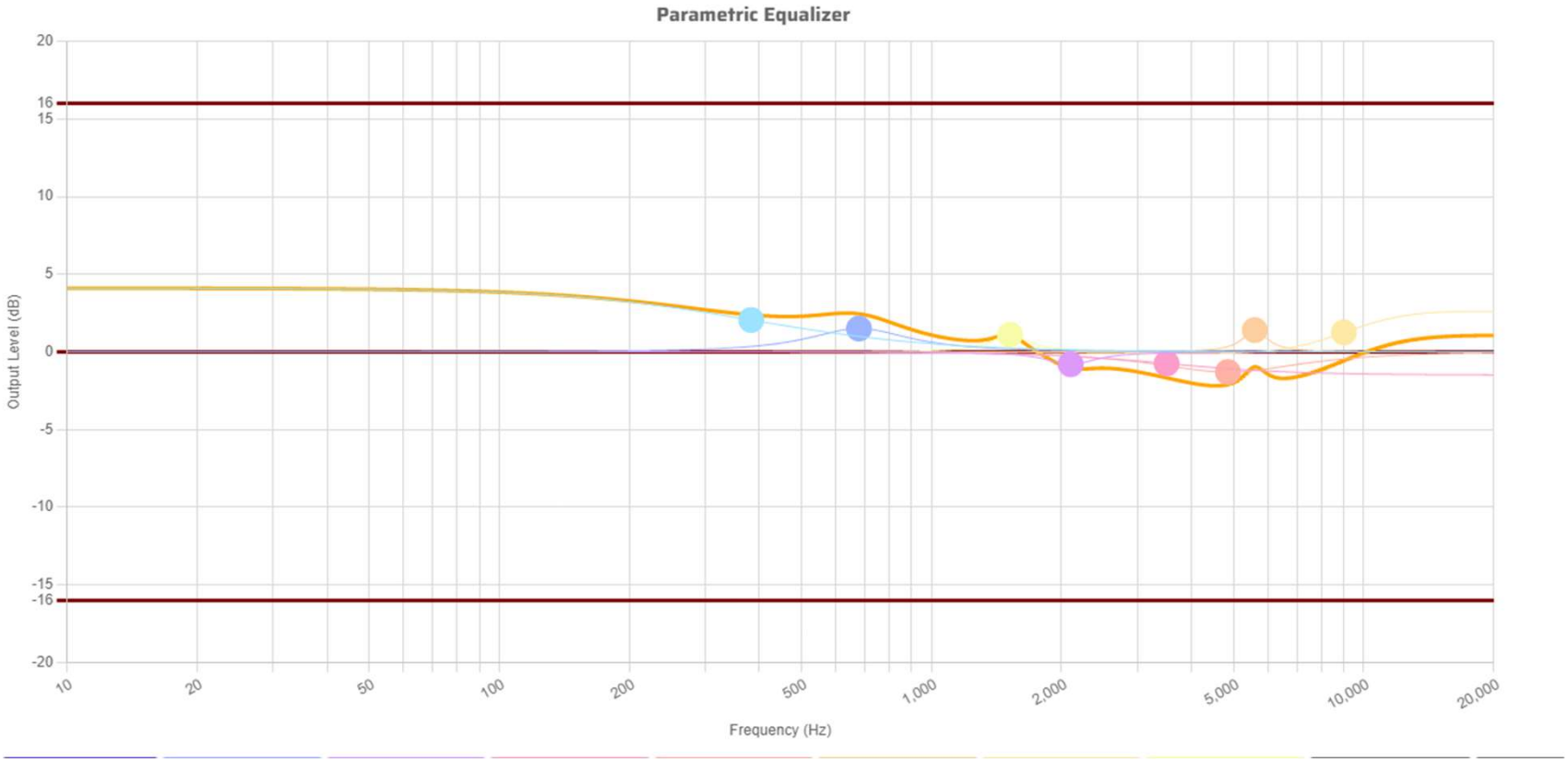


MiniDSP 2x4HD EQ

High Channel (mid-tweeter crossover)			
Filter Type	**Fc (Hz)**	**Gain (dB)**	**Q**
Low Shelf 2nd order	383	4.1	0.5
PEQ	680	1.5	1.5
PEQ	1520	1.1	4.0
PEQ	2100	-0.8	3.0
High Shelf 2nd order	3500	-1.5	0.6
PEQ	4851	-1.3	1.0
PEQ	5600	1.4	6.0
High Shelf 2nd order	9000	2.5	0.9
Low Channel (RS270-4 Woofer)			
Filter Type	**Fc (Hz)**	**Gain (dB)**	**Q**
Low Shelf 2nd order	70	7.0	0.8
Low Shelf 2nd order	100	3.0	0.9
High Shelf 2nd order	295	-3.0	0.5

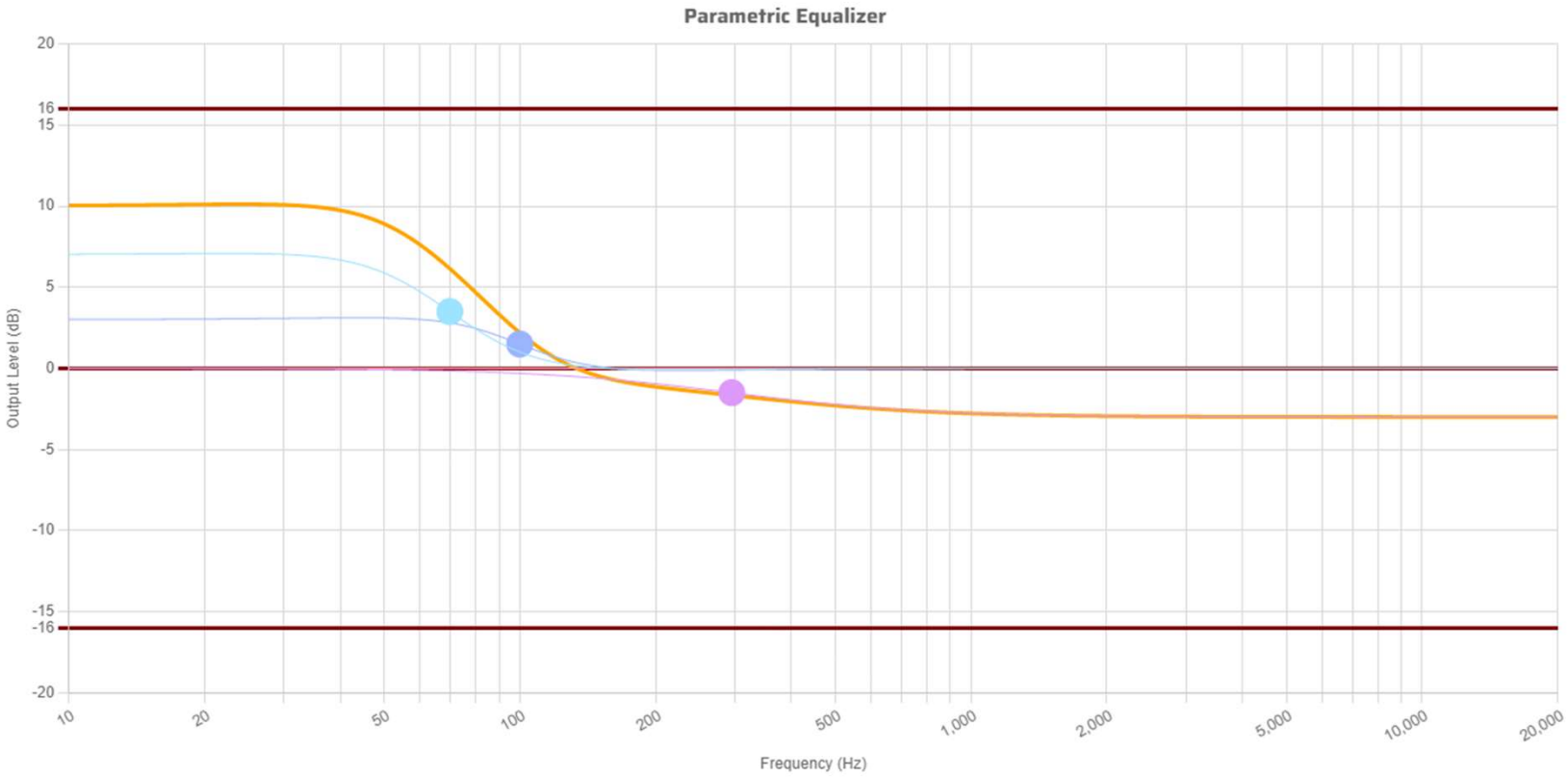
BACK PEQ Details (2 Left High)

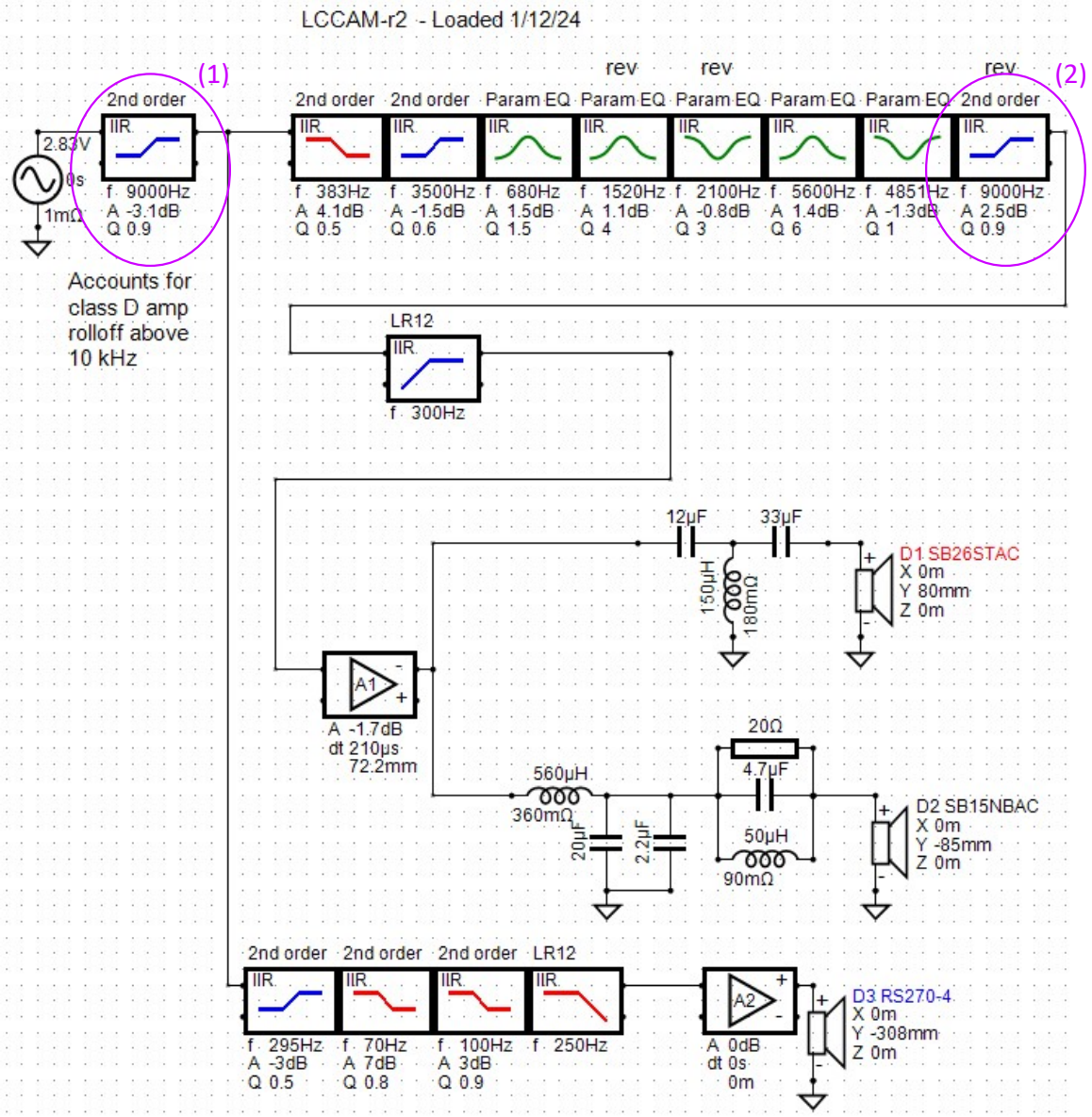
Menu



BACK PEQ Details (1 Left Low)

Menu





High Frequency Adjustment

The particular Class D amp that I used has a -3 dB rolloff in the high frequencies. This is caused by the tweeter+crossover impedance interaction with the amplifier's output low pass filter. Some Class D amps include the output low pass filter within the feedback loop, and thus avoid this issue.

I modelled this high frequency rolloff in VituixCad2 with a shelf filter at the amp (1). I needed a counteracting shelf filter (2) in the MiniDSP filter to bring the response back to normal.

Every Class D amplifier will behave slightly different. The end user must measure the high frequency response and make the appropriate adjustment in the MiniDSP.