Speaker Design Proposal

Home Theatre Speakers

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2012

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Design Goals

This system consists of a stereo pair that will mainly be used for television or film sound reproduction, but may occasionally be used for music reproduction as well. Enjoyment of the listening experience, rather than critical listening, is more valuable in this design. I usually listen at fairly low SPL levels, but I also want these speakers to be close to THX standards for sound reproduction. Ideally, these speakers would have low power requirements and the frequency response would cover almost all of the audible range, but certain sacrifices are acceptable to keep the design around $500 or less. Box size is flexible, but it must be big enough to be a floor standing speaker. Achieving good low frequency response is more important than high SPL, but both are desired if possible. Since box size is flexible, cost is the most limiting factor for this design.

Box Size Requirements

The size specifications for these speakers are relatively flexible since they will be placed on either side of a television that has open space around it. This home theatre setup will be fairly permanent so mobility is not a large factor. The preferable box size is smaller than 4' tall by 1.5' wide by 2.5' deep, but these are arbitrary measurements assuming that these will be floor-standing speakers flanking the television. The speakers will need to have the correct size and aiming to cover the listening area in a 12' by 16' by 8' room with an average listening height of 3.5 feet. A drawing and approximate values of the listening area are shown below. The walls of this room are relatively absorptive, so off axis response will not have a huge impact at the listening area; this means than that on axis response is paramount, and off axis response will not have much impact on driver choice.

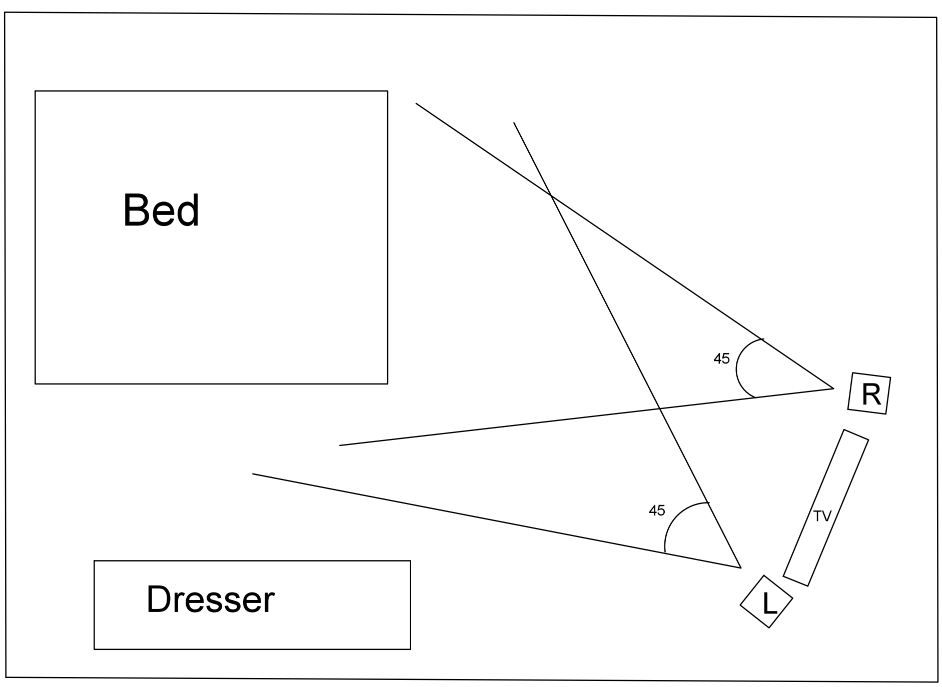

Figure 1: Approximate Listening Area

Ear Height Max	5’
Ear Height Min	3’ (sitting in a chair)
Ear Height Avg.	3.5’ (sitting on a 3’ high bed)
Ideal Ear Distance From Speakers	7’
Room dimensions	14’ wide by 20’ long by 8’ high

Table 1: Approximate Listening Room Dimensions and Positions

SPL

My listening levels are generally much lower than average, around 48 dBA if the noise floor is low enough. Considering that the noise floor in the intended space for these speakers is higher than the room I based my preferences on, the average listening level will probably be closer to 60 or 70 dBA. It is also important to consider that I will not be the only one listening to these speakers, so a more universal standard of SPL capabilities is beneficial. Each speaker in THX systems are calibrated to a reference level of 85 SPL with a C-weighted level meter, and have a maximum, undistorted, level of 105 SPL.[1] Having speakers that are capable of THX standards is ideal, but lower SPL output is acceptable if necessary. Taking my listening preferences into mind, maximum SPL as low as 85 dBA would be acceptable. With these two values, 85 dBC and 90 dBA, and taking crest factor into account these speakers would have to be able to produce a maximum of 105 dBC and 110 dBA, respectively.

Room Level	**Comfortably low listening level**	**Mixing Level**	**Rocking out to a really good song level**	**Beginning of discomfort**
40 dBA	48 dBA	60 dBA	73 dBA	90 dBA

Table 2: My SPL preferences based on levels taken in Walker 212[2]

1 Tomlinson Holman, Sound for Film and Television, (Focal Press, 1997), 208-209.
2 Alison Pittsley, experiment, (SPL Preferences, Michigan Technological University, Michigan January 20, 2012).

Power Requirements

Ideally, power requirements would remain low, with driver sensitivities 85 dB or above. Given that the listening area is about 2 meters away from each speaker, 1 watt of power would be enough to deliver the average listening SPL; higher sensitivities would easily allow smaller amplifiers to produce maximum SPLs over 100 dBA. Having high driver sensitivity is a very important since many home theater receivers do not provide more than 100 W per channel. Assuming a maximum of 100 W, 20 dBW is the most that could be gained by using more power so a driver with the sensitivity of 85 dB would have a maximum of 105 dB after considering the crest factor. To reach the maximum of 105 dBC for a THX system, the sensitivity of the drivers would have to be 105 dB or above; considering sensitivities above approximately 92 dB are less common and more expensive, a good balance of power capabilities and cost must be found for each driver.

___ Watts (W)	to deliver ___ SPL (dBA)	at ___ Meters (M)	dBW
1	79	2	0
2	82	2	3
4	85	2	6
8	88	2	9
16	91	2	12
32	94	2	15
64	97	2	18
128	100	2	21
256	103	2	24
512	106	2	27

Table 3: Example power requirement chart, driver sensitivity = 85 dB 1W/1m

___ Watts (W)	to deliver ___ SPL (dBA)	at ___ Meters (M)	dBW
1	84	2	0
2	87	2	3
4	90	2	6
8	93	2	9
16	96	2	12
32	99	2	15
64	102	2	18
128	105	2	21

Table 4: Example power requirement chart, driver sensitivity=90 dB 1W/1m [3]

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3 Christopher Plummer, lecture, (course on Transducer Theory, Michigan Technological University, Michigan January 11, 2012).

Frequency Response

Given that this system will be used mainly for television or films, some might think that the low frequency limit could be high because vocal frequencies wouldn't be affected until around 300 Hz, the vocal frequency range for humans being about 300 Hz to 3.5 kHz.[4] Though dialogue is usually considered, on the surface, to be the driving force in TV and films, there is so much more sound involved in communicating stories, much of it outside the vocal range. Knowing this, but not knowing how much low frequency usage is common in film mixing, I used THX standards for an idea of the required frequency response for films and TV. Speakers in THX systems are calibrated to the X-curve, which begins to roll off around 50 Hz and is about 4 dB down around 25 Hz.[5]

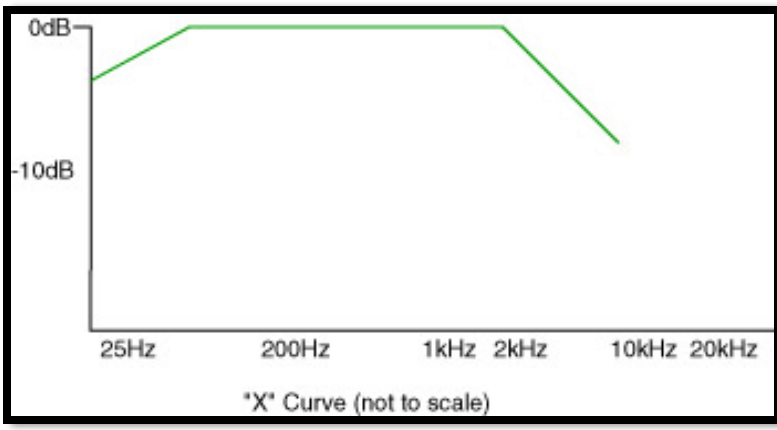

Figure 2: X Curve[5]

In addition to finding the THX standards, I also did an experiment to find my own low frequency extension preferences while listening to music. For this experiment I loaded four songs that represent the kind of music I like to listen to into Logic Pro and put a high pass filter on all of them. Playing each song and my preferred listening level, I swept the filter higher until I noticed significant change in the quality of the music. Doing this I found the frequencies where I thought that low frequency loss was acceptable, and the point at which I thought the loss was not acceptable (results of this experiment are shown on the next page). Using this information, and keeping the THX standards in mind, the highest low frequency limit that could be considered is around 75 Hz, with 43 Hz being the middle ground, and 20 Hz being ideal.

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4 Ken Ellis, "Sound and Light SALT Manual," Last modified 05 19, 2001, http://www.kodachrome/salt/sunderst.htm.

5 Brian Florian, "Learning from History: Cimema Sound and EQ Curves." Last modified 06, 2002. Accessed January 21, 2012. http://www.hometheatrehifi.com/volume_9_2/feature-article-curves-6-2002.html.

Song Title (Artist)	Maximum loss (Hz)	Acceptable loss (Hz)
Thunderstruck (AC/DC)	81	49
Circle the Drain (Katy Perry)	63	43
Juke Box Hero (Foreigner)	87	49
The Luckiest (Ben Folds)	142	112

Table 5: My low frequency extension preferences[6]

Woofers

To begin the woofer selection process I searched for woofers in my price range that had large frequency ranges and high sensitivities. With these parameters, I came up with the following list to compare.

Woofer	Cost	sen.	power (W)	Max SPL (dB)	Q_ts	F_s (Hz)	Box Volume V_b (ft^3)	f_3 (Hz)
Seas CA18RLY	$71.55	88	80	107	0.45	40	1.187713006	43.312
Aura NS6-255-8A	$11.50	91	50	108	0.55	55	0.838113058	53.9825
Seas CA12RCY	$66.40	86	60	103.5	0.31	57	0.084420221	106.7268
Peerless HDS Nomex	$76.67	89.7	NA		0.38	30	1.880061394	40.368
Peerless HDS 4" GF Cone	$38.33	85.9	30	100.4	0.58	89	0.175989137	79.032
Peerless HDS PPB 4" Midwoofer	$37.23	87	NA		0.54	77.6	0.183771032	71.974
Peerless HDS 5.25" GF Cone	$47.30	87	30	101.5	0.49	66	0.329939471	65.8878
Peerless HDS 5.25" Alu Cone	$53.67	86.1	30	100.6	0.65	72	0.524224879	60.4944
Peerless HDS PPB 5.25" Midwoofer	$43.42	88.3	NA		0.41	56.1	0.337695505	67.83051
Peerless SDS 5.25" Midwoofer	$19.14	87	NA		0.54	62.4	0.563564499	57.876
Seas L15RLY/P	$78.25	86	80	105	0.35	44	0.26612409	67.3772
W5-1685	$65.70	86	45	103	0.46	50	0.525404181	52.925
Dayton RS225-8	$57.42	86.2	80	105.2	0.36	27.6	1.461003082	40.38432

Table 6: Woofer Spec Spreadsheet

6 Alison Pittsley, experiment, (Low Frequency Extension Preferences, Michigan Technological University, Michigan January 20, 2012).

Using Win Speakers, I modeled the system frequency response of all these drivers assuming a SBB_4 alignment (box volume and f_3 shown in above table). From these models I easily chose five drivers to examine more closely. They were:

- Seas CA18RLY
- Aura NS6-255-8A
- Seas L15RLY/P
- TB W5-1685
- Dayton RS225-8

From this point I closely examined frequency response of the drivers and of the system. The qualities I took into account were, in order:

1. Lowest extending/flattest system response
2. Flattest driver response
3. Highest driver response (as least 3000Hz for crossover at 2000Hz)
4. High sensitivity (All drivers meet minimum sensitivity requirement)

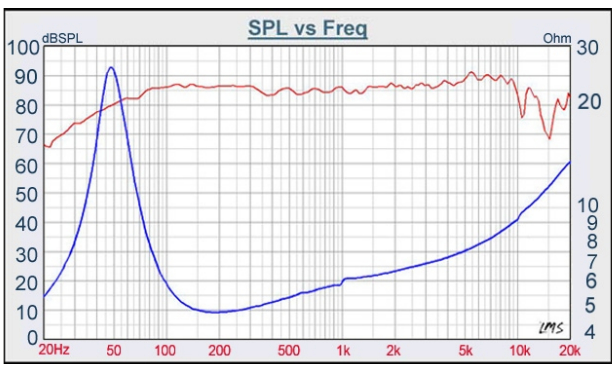

Figure 3: W5-1685 Frequency Response

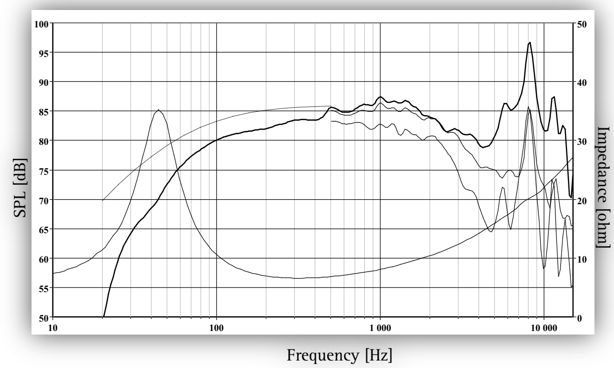

Figure 4: Seas L15RLY/P Frequency Response

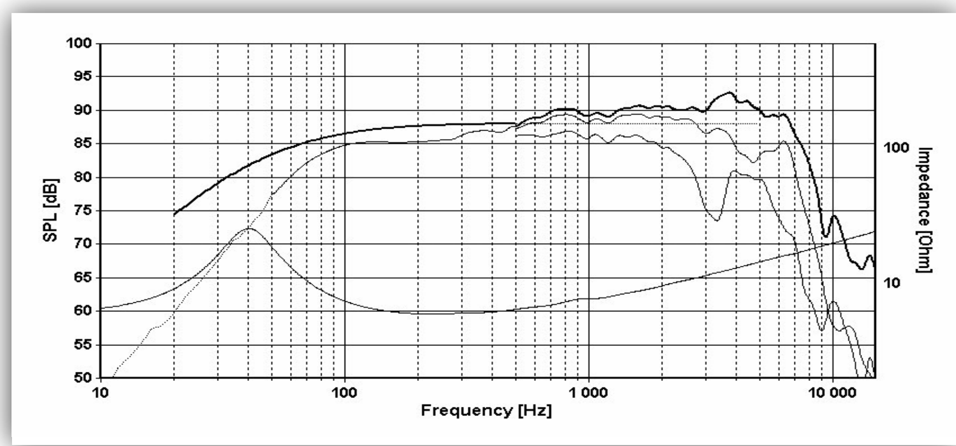

Figure 5: Seas CA18RLY Frequency Response

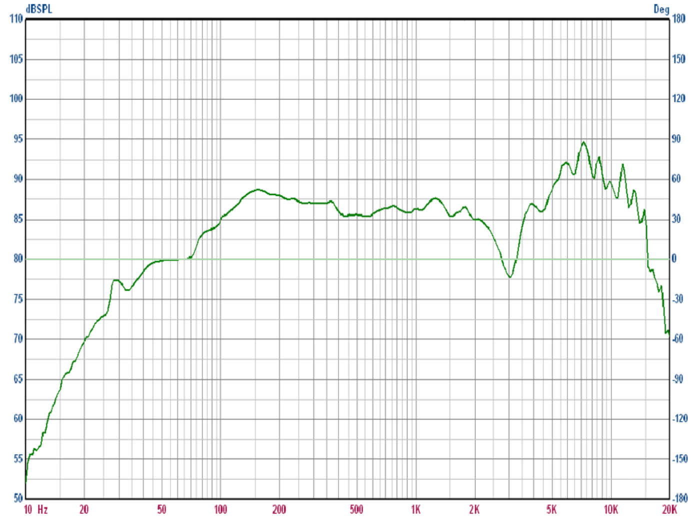

Figure 6: Dayton RS225-8 Frequency Response

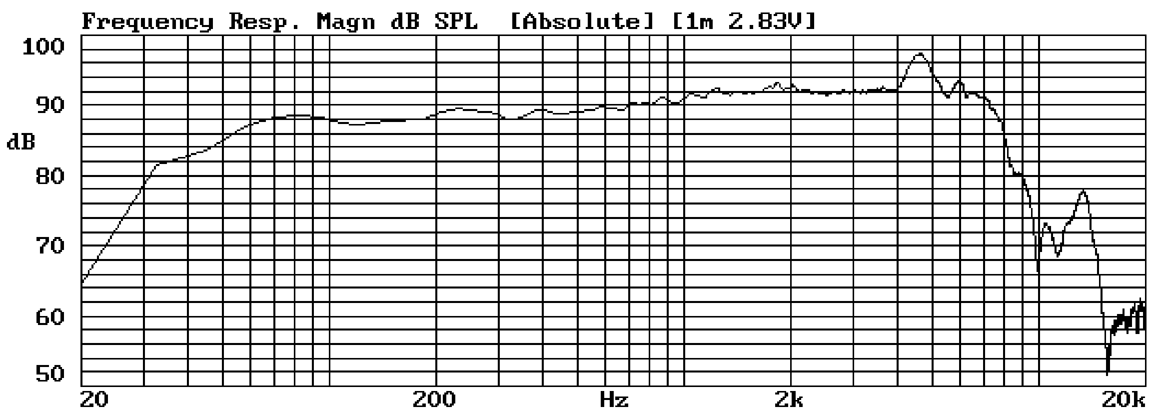

Figure 7: Aura NS6 Frequency Response

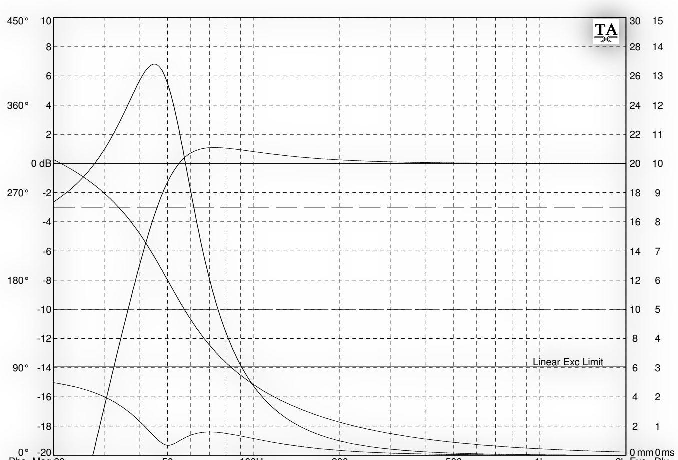

Figure 8: W5-1685 SBB_4 Response

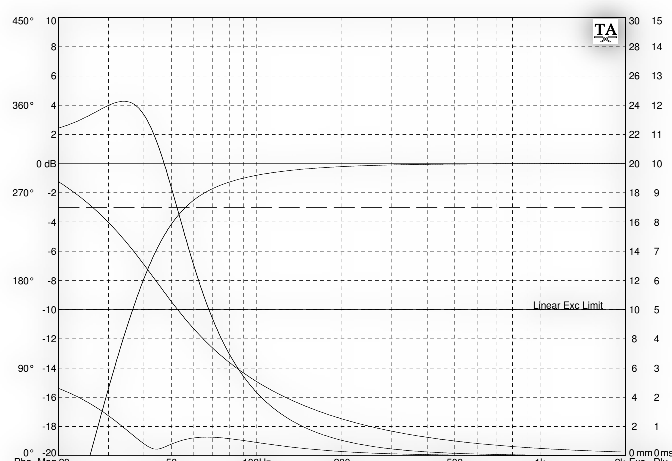

Figure 9: Seas L15RLY/P SBB_4 Response

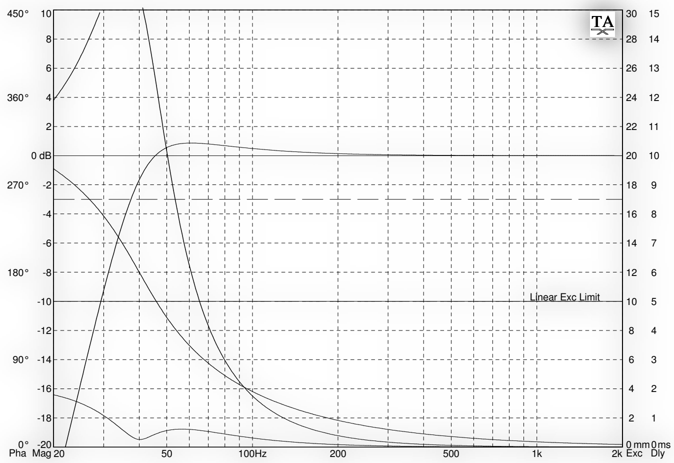

Figure 10: Seas CA18RLY SBB_4 Response

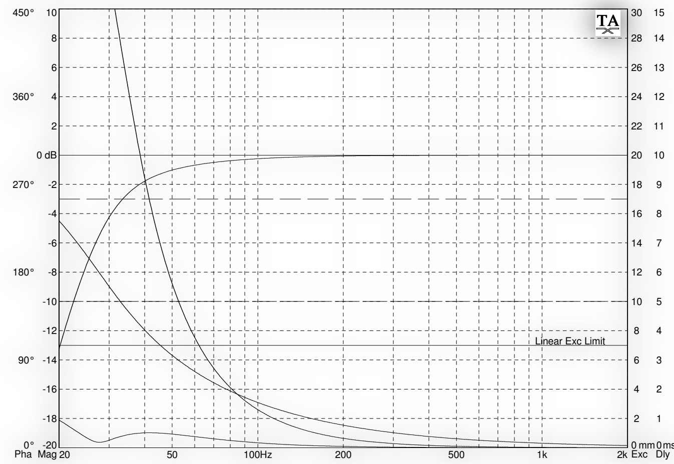

Figure 11: Dayton RS225-8 SBB_4 Response

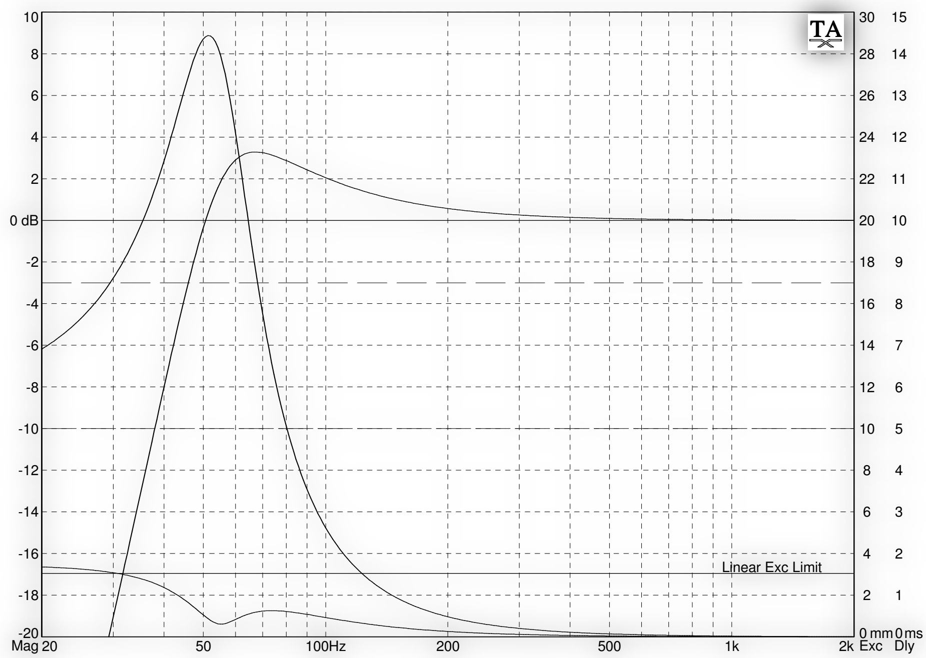

Figure 12: Aura NS6 SSB_4 Response

From these choices I cut the drivers that had an f_3 above 50Hz. The final two options were the Aura NS6-255-8A and the Seas CA18RLY; I chose the Aura because it had a higher sensitivity, a higher frequency extension, and the Seas low frequency response was not superior enough to outweigh the benefits of the Aura. When choosing drivers I left the prices out of my spreadsheet so they would not affect my decisions; once I finally looked up the prices, I realized that I had chosen a driver that was only $11.50 and thought I must have made a mistake. I did; I had entered 40Hz as the f_B when it was really 55Hz; this factor had been a huge part in my decision-making process. The correct system response, as seen above in Figure 12, is not nearly as attractive as the one that was incorrect.

With the correct system response, the Aura is not as attractive as the Seas in terms of low and flat frequency response, but all the qualities I liked about the Aura initially were still there, so deciding whether to keep the Aura, or use the Seas, was very difficult. Initially when comparing the final drivers, I used f_Bs for SSB_4 alignments because it is the best in terms of low tuning and transient response, with the SC_4 coming just below it in quality.[7] After I realized that I chose the Aura's based on the lower f_B of 40, I noticed that the Aura's f_B with the SC_4 alignment is 42Hz. Given that this alignment gave the type of f_B I needed to get a nice system response and keep the high sensitivity and high frequency extension, I decided to stick with the Aura's. Using the Aura's, I experimented with the number of drivers and box volume to see if I could come up with a better response. With this, I decided to use four woofers in each speaker, separating the drivers into two spaces, with two drivers in each space.

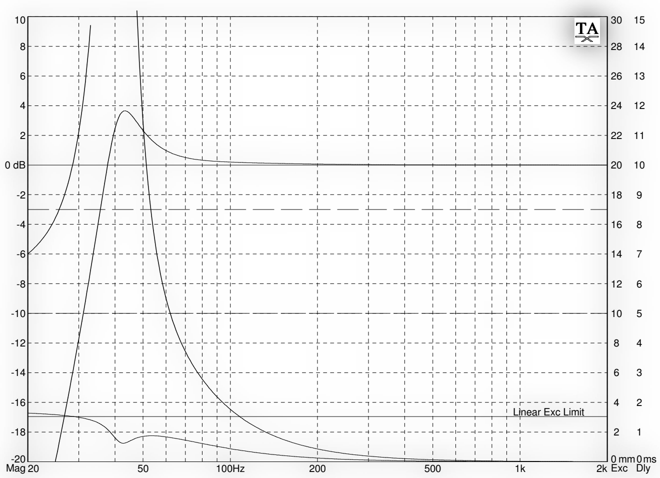

Figure 13: Aura NS6 SC_4 Response

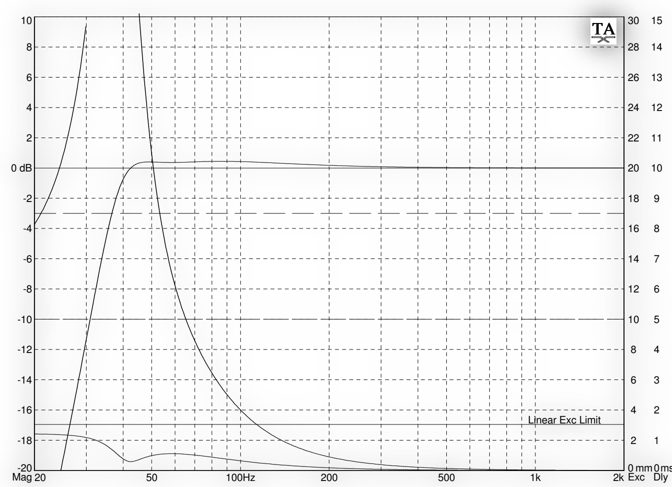

Figure 14: Aura NS6 Double Driver Response

7 Vance Dickanson, Loudspeaker Design Cookbook, (Peterborough, New Hampshire: Audio Amateur Press, 2006), 62.

Tweeters

To begin the tweeter selection process I searched for tweeters in my price range that extended lower than 2000Hz (assuming a crossover at 2000Hz) and with high sensitivities. With these parameters, I came up with the following list to compare.

Tweeter	Cost	F_s	sensitivity	power (W)	f_3 (Hz)	impedence (ohms)	Max SPL (dB)
Dayton DCS8F-8	$18.00	637.2	89	50		8	106
Seas H1189	$42.40	550	90	90		6	109
Seas H1212	$45.35	550	92	90		6	111
Vifa BC25TG15-04	$17.00	1130	87.8	50		4	104.8
Vifa BC25SC55-04	$19.80	1400	89.3	100		4	109.3
Vifa XT25SC90-04	$27.20	825	89.9	100		4	109.9
Vifa D27TG-06	$31.17	720	87.4	100		6	107.4
Vifa XT25TG30-04	$34.25	436		110		4	NA
Vifa XT19TD00-04	$38.75	763	87.7	120	900	4	108.7
Vifa XT25BG60-04	$40.10	589	91.5	100	900	4	111.5
Fostex FT48D	$96.25		93	50	1000	8	110
ScanSpeak D2608/9130	$81.40	700	91.3	80	1500	8	110.3
ScanSpeak D2606/9220	$51.90	850	91.4	100	1000	6	111.4
ScanSpeak D2606/9200	$36.65	1100	91.4	100	900	6	111.4
Fostex FT28D	$68.20		90	40	1500	8	106
Audax TW034X0	$72.05	800	93	70	700	8	88.5
Morel CAT 328-104	$90.80	650	90	200	1700	8	223
Morel MDT 32S	$80.40	650	90	200	1500	8	223
Dayton DCS8FS-8	$26.75	812.9	89	50		8	106
Dayton RS28A-4	$54.75	592.2	88	100		4	108

Table 7: Tweeter Spec Spreadsheet

Looking at the specs for these tweeters I cut the ones with the least flat responses and highest frequency extensions first, as well as any tweeter with a nominal impedance below 6 ohms, and ended up with the following to compare more closely:

- Fostex FT48D
- ScanSpeak D2608/9130
- Audax TW034X0

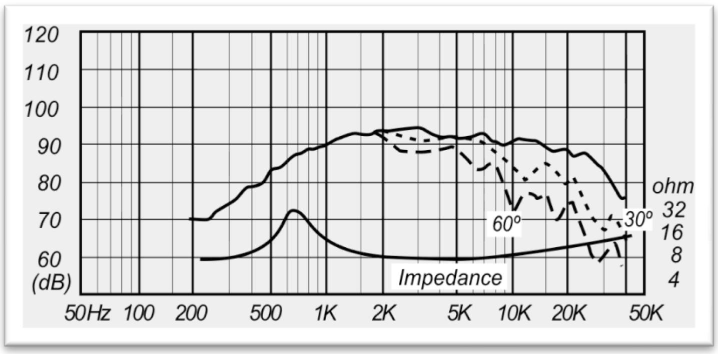

Figure 15: Fostex Frequency Response

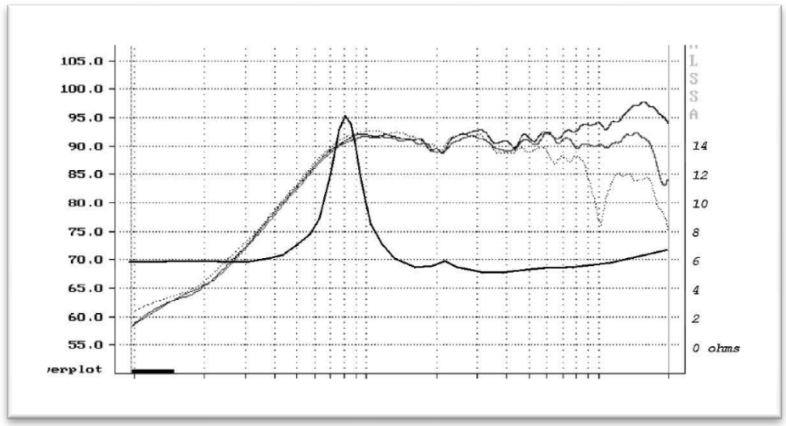

Figure 16: Audax Frequency Response

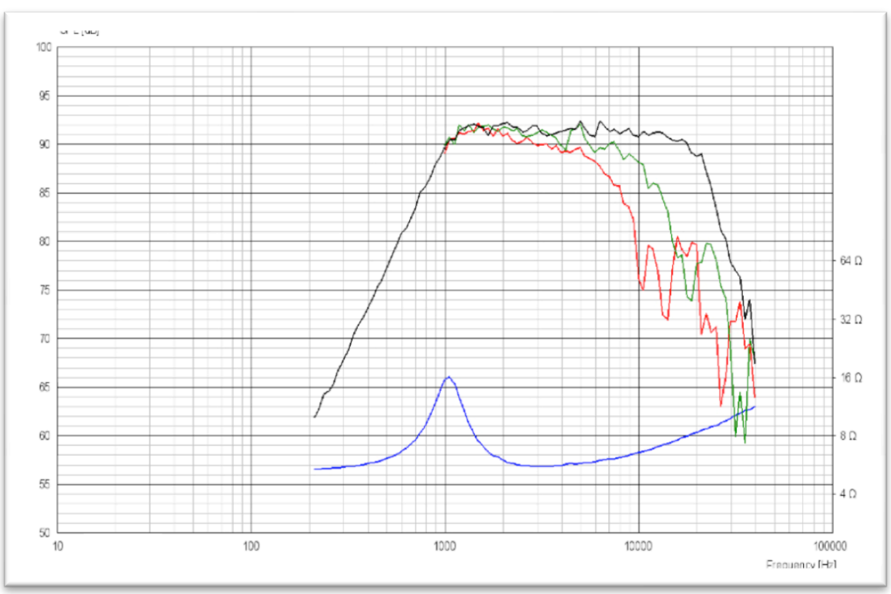

Figure 17: ScanSpeak Frequency Response

Of these tweeters, I chose the one that I thought had the best balance between:

1. Low frequency extension
2. Smooth low frequency roll off
3. Flat high frequency extension through 20kHz
4. Off axis response close to on axis response
5. High sensitivity (All drivers meet minimum sensitivity requirement)

With the idea of a first order crossover in mind, it was important to have low frequency extension with a smooth roll off. Two of the three of the final tweeters had really smooth roll offs so I had to take flatness of the high frequencies, off axis response, and sensitivity into higher account for my final selection. I I ended up choosing the ScanSpeak D2608/9130, even though the off axis response is very inconsistent at high frequencies, because it has flat response on axis and a high sensitivity; because the room these will be placed is non-reverberant the off axis response will not have a very big impact on the listening area.

Crossover

A first order crossover is the "only conventional crossover whose combined output reconstruct the input waveform."[8] This is the reason I put such high value on having a woofer and tweeter that extended above and below 2000 Hz, respectively. With the ScanSpeak D2608/9130 tweeter and the Aura NS6-255-8A woofer a first order crossover at 2000 Hz makes a smooth roll off of both the highs and lows, making for a smooth transition between the tweeter and the woofer. However, a second order crossover gives a much safer drop in dB at the tweeter resonant frequency and will probably allow the tweeter a longer life than a first order crossover.

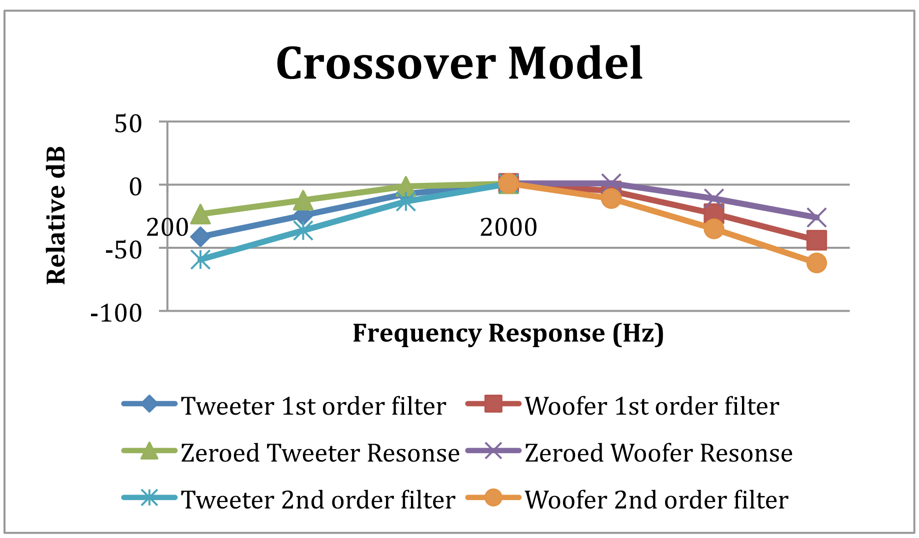

Figure 18: Crossover model of ScanSpeak D2608/9130 tweeter and Aura NS6-255-8A woofer

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8 Philip Newell, and Keith Holland, Loudspeakers for Music Recording and Reproduction, (Elsevier Ltd., 2007), 132.

For these reasons, I decided to go with a second order Linkwitz-Riley crossover, which sums to a flat magnitude.[9] As stated before, in the woofer section, these speakers will have four drivers split into two sections. This provides an opportunity to extend low frequency response by compensating for the baffle step loss with a .5 crossover on the low end. Two woofers will cover the low and mid frequencies, and the other two will only cover low frequencies. This makes the speakers more consistent on the vertical axis.[10] With the .5 crossover added on the low end, the final design will be a second order Linkwitz-Riley 2.5 way crossover.

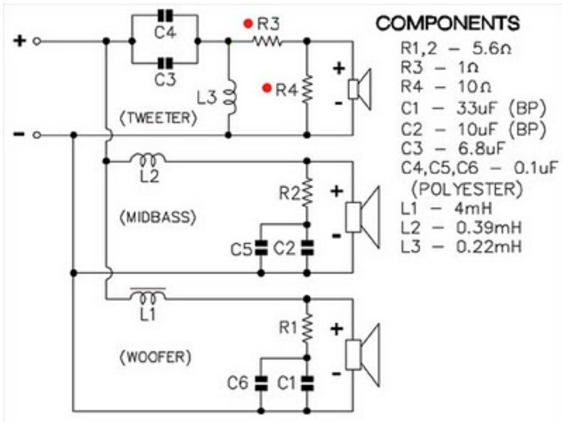

Figure 19: Example 2.5 Way Crossover[11]

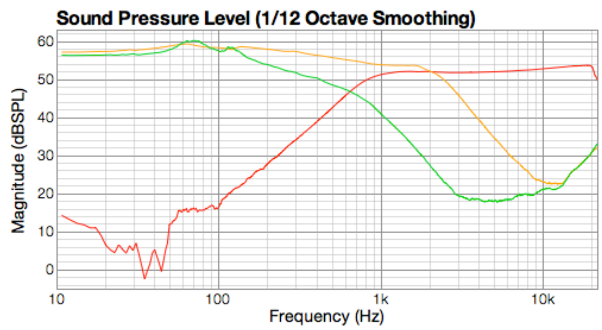

Figure 20: Example 2.5 Filter Response

Box Shape & Materials

The boxes are intended to be floor standing, approximately 3.5ft tall by 1.5ft deep by 1.5ft wide. I had originally planned on making rectangular speakers with rounded edges to reduce edge diffraction, but the effectiveness of this is rather limited.[12] With a rectangular design, the drivers were to be placed different distances from the edges of the speakers, which makes a big improvement in the diffraction loss.[13] I opted for the more complex diamond shape because I like the look, and because the 45-degree angles off the front baffle help to reduce diffraction loss a great deal more than rounded or chamfered edges. With the symmetrical look of the diamond shape, I chose to keep the drivers center on the baffle to keep the symmetrical look.

9 Vance Dickanson, Loudspeaker Design Cookbook, (Peterborough, New Hampshire: Audio Amateur Press, 2006), 162.
10 Christopher Plummer, lecture, (course on Transducer Theory, Michigan Technological University, Michigan Feburary, 15 2012).
11 Paul Spencer, Red Spade Audio Blog, "Etude TL crossover." Last modified 06 29, 2011. Accessed April 26, 2012. http://redspade-audio.blogspot.com/2011/06/etude-tl-crossover.html.
12 Linkwitz Lab, "Diffraction from baffle edges." Last modified 10/04/2011. Accessed January 29, 2012. http://www.linkwitzlab.com/diffraction.htm.
13 John L. Murphy, Introduction to Loudspeaker Design, (Andersonville, TN: True Audio, 1998), 71.

The box material needed to be stiff enough so that the speakers will not resonate with the drivers. To achieve stiffness of the box I decided to use two layers of wood. On the outside, ¾" birch plywood with the highest ply possible to increase rigidity, and on the inside, ¾" MDF which is heavy and will vibrate less in tandem with the driver.[14] The MDF will also be used a brace that separates the box into two sealed enclosures (besides the ports). Each box will have two tuning ports, one for each enclosure. These ports will be located on the back diagonal of the boxes so that the box noise will not be directed at the listening area, nor will it be reflected off the wall behind it.

Once the boxes are constructed, the unique shape and wood grain will create a nice aesthetic. I plan to keep this natural look by using natural wood stain, and possibly a clear glossy coat to a more finished look.

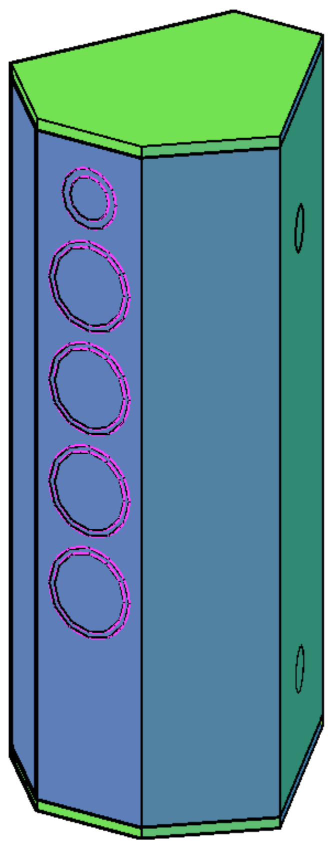

Figure 21: 3D Rendering of Speaker Design

[14] Philip Newell, and Keith Holland, Loudspeakers for Music Recording and Reproduction, (Elsevier Ltd., 2007), 87.

Cost

The budget for these speakers is around $500, with limited flexibility for better quality. My initial thought was that each driver could cost no more than $100, which was one of the limiting factors when finding drivers to compare. This would have left about $100, which would not have been enough to cover wood and crossover costs. The low cost of the woofers and tweeters leaves enough money for wood and crossover materials, in addition to less significant costs like shipping, glue, and stain.

	Quantity	Cost	Total
Woofer	8	$11.50	$92.00
Tweeter	2	$81.40	$162.80
Baltic Birch 4x8	2	$60.00	$120.00
MDF 4x8	2	$40.00	$80.00
Total:			$454.80

Table 8: Current Speaker Budget

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