Speaker Design Proposal
By: Dan Wilson
1. Introduction and Functional Goals:

A. Functional Description

I don’t want to drive very high SPL’s. On the other hand, there are times where I would want to pump some jams out at a higher level. I am designing these speakers for my father who is funding not only my education, but these speakers. My dad has a daily routine consisting of waking up early in the morning and going downstairs to read a book while listening to music in the living room. While listening to his classical morning broadcast, or early morning jazz he usually keeps it at a low level while everyone is sleeping.

By keeping these two requirements in mind, I took an SPL meter and recorded what I thought to be average as well as loud listening levels in the morning and at night. Both these levels have a large chance of changing due to our perception of sound changing through the day. On the quiet side in the morning at around 7am, a comfortable listening level was around 55-65 with 70 being a little on the loud side. At night the comfortable listening level went up 10 dB to sit around 65-75dB. I would like these speakers to not only be accurate at low listening levels, but also at levels around 80-85dB with a 14 dB crest factor enabling these speakers to have a 14dB range of headroom with its maximum output at 95-99dB.

My parents like to move the furniture around a lot, so I would like my speakers to be small enough to move around with ease. These speakers are intended to be put on the top of a desk and not to be placed inside of a bookshelf because of the way I want to

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mount my tweeters. My tweeters are going to be placed on a smaller baffle and placed on top of the enclosure for my woofer. This will make them easily movable/changeable and will battle against any delay caused by a change of distance between the voice coils. A large reason why these would not be good to put inside of a bookshelf is because the bookshelf would act as an enclosure to the tweeter on its own and will add coloration to the overall sound of the tweeter. Also, these speakers will have a vent in them to help lower the bass response. Since the lowest note on a bass guitar is about 41Hz, I would like to go just a little lower with no real need to go as low as 20Hz. The vent will be placed on the top of the speaker behind the tweeter baffle.

I want these speakers to be easily portable. I do not want this to limit the potential of my speaker, but at the same time there are really good drivers out there that aren’t that big. There are naturally some trade offs to be taken into consideration in terms of size like how smaller enclosure sizes force smaller woofer sizes, further taking away from the potential of low frequency response which a bigger woofer could probably produce. Some of the woofers I have looked at recommend sizes of enclosures for them, and after modeling them in Winspeakrz, it appears that these dimensions will be perfectly suitable for my design by supplying the sound with enough room to develop that full bodied bass while the ribbon handles the crystal clear highs. I will however add a port to the box to further extend the low frequency range.

2. Drivers

A. General Considerations

I am lucky because my budget is a little larger because my dad’s funding these and unfortunately quality comes with a price. I would like to keep my driver selection
under $600 and the rest of the materials I will need I would like to keep under $400 to give me an overall budget of $1,000. When looking at woofers, it’s nice to not have to worry about the cost as much as the frequency response. I looked at woofers that were within $100 of each other and compared their frequency responses to their prices. I initially wanted to make a three way system that did well portraying the whole audible range with great accuracy, but have decided against it for reasons of budget.

B. Woofer

These speakers will be used only for musical listening and not for video or mixing purposes. They will need to have a frequency response from a reasonably low end around 30 or 40 Hz with the intension of adding a port to further lower their limit. The problem with two-way systems is their incapability of portraying a broader frequency response than a 3 way could. To battle this, I will choose a driver that has a reasonably high frequency response so that it will crossover perfectly with my tweeters.

The woofers that are in consideration are summarized below. I arrived at this list by simply taking important figures from each of the woofers spec sheets and filling them in below. These figures are important because they each show to some extent what the

<table>
<thead>
<tr>
<th>Driver</th>
<th>Price</th>
<th>Diameter</th>
<th>Fs</th>
<th>Sensitivity</th>
<th>Qts</th>
<th>V(as)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hi-Vi D8.8</td>
<td>$95.30</td>
<td>9&quot;</td>
<td>32 Hz</td>
<td>(2.83v/1m)(dB) : 86</td>
<td>.40</td>
<td>37.8 L</td>
</tr>
<tr>
<td>SEAS Prestige CA22RNX</td>
<td>$87.75</td>
<td>8”</td>
<td>31 Hz</td>
<td>89.5 dB</td>
<td>.41</td>
<td>97 L</td>
</tr>
<tr>
<td>Eton 7-200/A8 Symphony</td>
<td>$180.15</td>
<td>7”</td>
<td>32 Hz</td>
<td>1W/1m 89 dB</td>
<td>.31</td>
<td>Vas</td>
</tr>
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<td></td>
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<td>25.37 L</td>
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speakers are capable of. These numbers are also all used when imputing information into Winspeakerz. By looking at these numbers next to each other I can see close similarities and subtle differences. The Eton midrange woofer would allow for my boxes to be much smaller, hence more portable. They also have almost the same sensitivity and $f_3$. They are however much more expensive than I planned for. The Hi-Vi also would allow for more portability while maintaining about the same responses. After modeling all of these drivers in Winspeakrz, I found that the Seas CA22RNX would be most ideal for keeping a flatter low end response. (Winspeakzer graph included in section A of Technical Goals)

Eton 7-200/A8

CA22RNX (Below)

C. Tweeters
With the specific choices of music that will be played through these speakers being classical and jazz, I want a tweeter that can portray crystal clarity in the high range up to 20Hz. Ribbon tweeters are excellent in doing this, and because of this I mostly looked at ribbons. To at least give them a chance, I chose one dome tweeter to sample. The tweeter comparisons can be can be seen below. I chose the ribbons purely on how well they can perform in high frequencies.

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<tbody>
<tr>
<td>Hi-Vi RT8II Isodynamic tweeter.</td>
<td>$86.60</td>
<td>1.7k to 27kHz.</td>
<td>93 dB</td>
<td>&gt;2,000 Hz</td>
</tr>
<tr>
<td>Audax TW025A20</td>
<td>$103.25</td>
<td>2-5 kHz</td>
<td>93 dB</td>
<td>&gt;2,000Hz</td>
</tr>
<tr>
<td>Fountek NeoCd3.0</td>
<td>$89</td>
<td>1,400-40,000Hz</td>
<td>95 dB</td>
<td>2,500Hz / 2nd-Order</td>
</tr>
</tbody>
</table>

The reason I chose two ribbons and one dome is easy. I was almost positive on choosing a ribbon tweeter, but I did not want to make my choice without at least
weighing the advantages and disadvantages of dome tweeters. I know that dome tweeters are usually cheaper and stronger/less fragile than ribbons. I also learned through the B&W video we watched in class that very rigid bodies like the diamond tweeter used in their speakers are generally clearer. This is why I chose a dome tweeter made of aluminum. Although ribbon tweeters generally have a better/flatter response than dome tweeters, they do not have the versatility of being able to rotate. I thought of the horizontal and vertical orientation of my speakers and knew that if I chose ribbons I would not be able to stand them up as well as lay them on their sides. By placing a ribbon tweeter sideways, it changes the directivity of the unit and would give greater directivity either up and down or side to side, not both. This is another part of the design where one would weigh the pros and cons. I’ve chosen the ribbon tweeter and decided to keep the orientation always the same with the tweeter in its normal vertical layout.

Technical Goals

A. Confirmation of SPL capability.

Looking at the woofers I’ve chosen, it can be seen that they all are right around the sensitivity of 86-89dB. A driver’s power handling is how loud something can play before being distorted and is divided into, thermal (how hard it can drive before melting), and mechanical (how far the cone can physically move). I chose the Seas woofer which has a 1W/1M sensitivity of 89.5 dB which means by listening to these speakers at 1 meter away using 1 watt of power they can reach 89.5dB. Unfortunately my dad won’t be 1 meter away, but 4 meters away changing things a bit. These woofers also have a thermal

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2 B&W Movie
power handling of 80W, but the receiver I plan to use is 60W. By looking at the Winspeakrz plot I can see that 60W is perfectly acceptable for these woofers without damaging anything.

By using the inverse square law, I know that every doubling of distance produces a 6dB loss of sound. Every doubling of power boosts the sound by 3dB. Taking this into account and applying simple math, it can be seen that this woofer can produce 83dB at 4 meters with one Watt. If we double the Wattage, and then double it again we’re back at 89 dB which is still lower than my 99dB level. Luckily I plan on using more than 4 Watts for my speaker and aim to use more like 60 Watts.

By looking at the Winspeakerz plot, the excursion line shows me that the woofer I chose can play up to 108 dB by only using 60W of power. The max power it can use is 80W, so this woofer is not only capable of playing well above my 99dB limit, but it also is capable of doing so without using full power. The tweeter has a recommended crossover frequency of 2.5kHz. By applying a little nugget of knowledge gained when meeting with
Christopher I can be assured that “as long as the crossover is above the recommended crossover frequency, the tweeter will be able to play loud enough.”

B. Driver Evaluation

Evaluating these speakers in Winspeakrz has led me to choose the ones with the best low end frequency response. The Hi-Vi D8.8 has the lowest frequency response of 30Hz and an f3 of 35 Hz, but there was a boost at around 200Hz which would not have been ideal. The mid-range (Eton 7-200) driver had a slightly better response in terms of the bump at 200Hz, but also would not have been ideal. Also I based my choices on the recommended box sizes. The Hi-Vi D8.8 has the smallest recommended box size making it even more suitable for my size requirement. By looking at a woofer frequency response, it can’t really do it justice because response charts having nothing to do really with the woofer lower than about 200Hz. This is where Winspeakerz comes in handy by helping simulate what that specific driver will do in a modeled box of specific dimensions. Looking at the graph I can see that the CA22RNX woofers do not add that bump at the 200Hz range like the other two woofers, but rather contains a smooth roll off beneath that level.

The tweeters don’t really have recommended box sizes, so when looking at these I focused on the frequency response as well as their sensitivity and power handling. It can be seen that the NeoCD3.0 ribbon tweeter has the broadest frequency response as well as the best power handling. The specs suggest that by using an advanced composite material ribbon diaphragm, it will provide higher power handling and guarantees a high degree of signal fidelity and broad frequency response. It also goes on to state that it is effective

__^{3}\ __^{3} \hspace{1pt} \text{Christopher Plummer, “SPL Levels: Interview with Christopher Plummer,” interview by Dan Wilson, room 212. April 20, 2009.}
from 1,200Hz upwards due to the large diaphragm area and low self-resonance. To top it off, this tweeter has low distortion factor, good power-handling capabilities, high linear impedance and amplitude.

The D8.8 woofer has a Mineral filled polypropylene cone with 4" diameter voice coil. Such materials have very high strength/weight ratios (paper being even higher than metals) and tend to be relatively immune from flexing during large excursions. This allows the driver to react quickly during transitions in music and minimizes acoustical output distortion.\(^4\) The Seas Woofer is a paper cone allowing it to have a higher strength than the other two drivers. D8.8 is initially the woofer I decided on because of its broad frequency response, but plugging its information into Winspeakerz has led me to believe that there is a better choice. (Seas plot below, Hi-Vi and Eton included separately at end of report)

I want to keep the size under 2 cubic feet, and by plugging 1.5 cubic feet into Winspeakerz and applying that size to my woofers it has shown that the Seas woofer would be better suited for lower frequency response.

C. Crossover Decision

Newell offers information about the differences between active and passive crossovers, stating that “for high quality loudspeaker applications, the universal consensus is usually in favor of active.”\(^5\) He also goes on to state the advantages and disadvantages between the two. Even though the Universe seems to enjoy active crossovers more than passive, I need these speakers to be easily portable and don’t want to wheel a bunch of things along with the speakers every time they get moved. With part of my design demands being the simplicity of its set up/tear down, I will make a passive crossover that will be beneficial to the ribbon tweeter by not ruining the tweeter when turning on the amp. This makes it easy to just connect the speakers directly from the receiver. This has a disadvantage because “passive crossovers rely entirely on the long term stability of each component part for their overall stability, which is not easy to achieve…”\(^6\) In effort to make long lasting crossovers, I will choose components that have a good reputation for life expectancy. With the wide frequency response demanded by my design, it makes it more difficult to find the right drivers that will crossover well with each other. Fortunately the woofer I chose (Seas CA22RNX 8") has peaks above 1k that will work to my advantage. “The ‘textbook’ drivers will have a woofer with extension at least one octave above the crossover frequency and a tweeter with at least one octave

\(^5\) Philip Newell, Loudspeakers: For music recording and reproduction (Burlington MA, Elsevier Ltd.) p.142
\(^6\) Philip Newell, Loudspeakers: For music recording and reproduction (Burlington MA, Elsevier Ltd.) p.142
Since my tweeter of choice (NeoCD3.0 ribbon tweeter) has such a broad frequency response it makes it much easier to crossover at many different frequencies. With the woofer’s response going up 6db at 2.5k, this adds significantly to the capability of its range. Since the tweeter is better suited to play these frequencies, I will choose to start rolling the woofer off at 1.5k with a first order electrical roll off. This causes the woofer to roll off faster and levels out the peak at 2.5k.

By looking at the frequency response of the woofer we can see that by adding a first order electrical roll off at 1.5k, it corrects the woofer’s rising response from 1.5-2.5k by dropping it 6dB. Starting at 2.5k, the driver’s roll off is a natural third order which, added to the first order gives me a 4th order crossover. The tweeter will have to start working at 2.5k to supplement what the woofer cannot manage. My tweeter has a natural resonance frequency of 400Hz, and generally you want to crossover higher than an octave above this. At 2.5k the tweeter does not have a roll off; therefore I would need to add a 4th order electrical crossover to smoothly integrate my woofer and tweeter.

I initially wanted to build a three way, but in effort to keep things simple, I decided on a two way. Newell mentions how fewer crossover points tend, in general, to lead to better axial responses. This can help keep the directivity stable through the horizontal axis.

When choosing which crossover to purchase I resorted to Dickason’s text. “The flat magnitude response, high attenuation rate, and low sensitivity to offset error makes

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7 Wayne Jaeschke, “Choosing the crossover frequency,” http://www.speakerbuilder.net/web_files/Articles/xover%20article/xpointmain.htm
8 Jaeschke, “Choosing the crossover frequency,” http://www.speakerbuilder.net/web_files/Articles/xover%20article/xpointmain.htm
9 Philip Newell, Loudspeakers: For music recording and reproduction (Burlington MA, Elsevier Ltd.) p.142
[Linkwitz-Riley] one of the best tweeter filters.” I used a passive crossover design calculator online to help decide what components I need to buy for the crossover.

\[
C_1 = 4.82285714286E-06 \text{ farads} \quad C_2 = 9.64571428571E-06 \text{ farads} \quad C_3 = 1.2665E-05 \text{ farads} \quad C_4 = 2.815E-06 \text{ farads} \quad L_1 = 0.00028 \text{ henries}
\]

**D. Cabinet**

The cabinet needs to be small enough to fit my demands, but also needs to be acoustically sound and needs to be pretty. The general shape is to be rectangular because I want my speakers to be squarish while not giving each side the same dimensions and trying to stick to the “golden ratio” as much as possible. Murphy talks about how the worst box you can make is cubic/square because the sound bounces around the same dimension causing undesirable sounds. They will be about 1.5 cubic feet and be 1.5” thick. By using a combination of MDF and ¾” Oak on the outside, I will design these cabinets to dampen the sound waves and try to reduce any sounds waves resonating through the sides of the cabinets. Christopher mentioned how Oak might change/shift due to humidity and the changing of seasons. I asked Kalen Larsen about this and he

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10 Vance Dickason, Loudspeaker Design Cookbook (Petersborough NH, Old Colony Sound Lab) p. 164
11 John L. Murphy, Introduction to Loudspeaker Design (Andersonville TN, True Audio 1998) p. 65
12 John L. Murphy, Introduction to Loudspeaker Design (Andersonville TN, True Audio 1998) p. 67
mentioned that Oak would change due to humidity, but it won’t do much to the speakers.\textsuperscript{13} The front baffle will be made of MDF while the inside walls be lined with fiberglass to absorb some of the sound and “make the size of your box seem bigger”\textsuperscript{14} The outside of the box will have $\frac{3}{4}$” of Oak wood to make it pretty. By adding more wood to the speaker it will make it heavier, but hopefully will aid in the absorption of sound.

One thing to keep in mind when designing speakers is the baffle step. The baffle step is “the transition from half space loading to full space loading”\textsuperscript{15} and results in a 6dB loss of bass. To calculate the baffle step, I used the equation $4560/\text{width in inches of baffle}$.\textsuperscript{16} This leaves me with a baffle step of $4560/12"=380\text{hZ}$. This means at that frequency my speakers will suffer a 6dB loss. My speakers are designed with the intention of them always being placed very closely to a wall which will in turn boost the low frequency response.\textsuperscript{17} Because I have not physically made the speakers yet, I do not know how this will effect them in detail yet.

**Conclusion**

These speakers will be pretty straight forward in the construction stage. With the drivers I’ve chosen and the pricing of them, it should not be too expensive for me to make these speakers now that I’ve decided on a two-way. They will be acoustically accurate while being visibly appealing as well. The woofers are going to cost me ($88\times2$)


\textsuperscript{14} Christopher Plummer, “Internal construction: Interview with Christopher Plummer,” interview by Dan Wilson, *room 212*. Feb. 12, 2009.

\textsuperscript{15} John L. Murphy, Introduction to Loudspeaker Design (Andersonville TN, True Audio 1998) p. 67


\textsuperscript{17} Philip Newell, Loudspeakers: For music recording and reproduction (Burlington MA, Elsevier Ltd.)p.203
$176, and the tweeters will cost ($89x2) $188. The drivers alone are going to cost $362, and there will be more money put into the crossover and the wood. I don’t think I will be spending the $600 I initially allotted for myself.
Bibliography


   B&W Speakers. Bowers & Wilkins.


